

Metacognition in Irish Senior Cycle and
Preservice Teacher Chemistry Education:
An action research inquiry at a time of
curriculum reform, *and the death of a
positivist*

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Thesis submitted for the award of
Doctor of Philosophy

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2025

Declaration Page

I hereby certify that this material, which I now submit for assessment on the programme of study leading to the award of *Doctor of Philosophy* (PhD) is entirely my own work, and that I have exercised reasonable care to ensure that the work is original, and does not to the best of my knowledge breach any law of copyright, and has not been taken from the work of others save and to the extent that such work has been cited and acknowledged within the text of my work.

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Date: 26.06.2025

Dedication

For Patsy, my father, my teacher, my friend.

Digging

*Between my finger and my thumb
The squat pen rests; snug as a gun.*

*Under my window, a clean rasping sound
When the spade sinks into gravelly ground:
My father, digging. I look down*

*Till his straining rump among the flowerbeds
Bends low, comes up twenty years away
Stooping in rhythm through potato drills
Where he was digging.*

*The coarse boot nestled on the lug, the shaft
Against the inside knee was levered firmly.
He rooted out tall tops, buried the bright edge deep
To scatter new potatoes that we picked,
Loving their cool hardness in our hands.*

*By God, the old man could handle a spade.
Just like his old man.*

*My grandfather cut more turf in a day
Than any other man on Toner's bog.
Once I carried him milk in a bottle
Corked sloppily with paper. He straightened up
To drink it, then fell to right away
Nicking and slicing neatly, heaving sods
Over his shoulder, going down and down
For the good turf. Digging.*

*The cold smell of potato mould, the squelch and slap
Of soggy peat, the curt cuts of an edge
Through living roots awaken in my head.
But I've no spade to follow men like them.*

*Between my finger and my thumb
The squat pen rests.
I'll dig with it.*

Digging, by Seamus Heaney, from *Death of a Naturalist* (Heaney, 1966)

Acknowledgements

I would first like to acknowledge the guidance, support, and time my supervisors provided throughout the five AR cycles and the writing of this thesis. I owe a great deal of gratitude to Assoc. Prof. Odilla Finlayson and Assoc. Prof. James Lovatt.

I would like to thank the students and PSTs who participated in this research, as well as all the students I have taught, who have, in many ways, fuelled my curiosity about metacognition in chemistry.

I would like to thank my colleagues in the CASTeL group at DCU, the School of Education at Trinity College, the School of Chemistry at UCD, and Gill Education for all their support. In particular, I would like to thank Professor Emeritus David Coughlan at Trinity College and Professor James O'Sullivan at UCD for their support and advice.

Thanks to my friends, and in particular the Brookfield scholars, for their support and most importantly their sense of humour and kinship over many years. Friends are like stars, you might not always see them, but you know they are always there.

Thanks to my family, we are shaped by our experiences, and I believe none is more important than the experience we have with our family.

Most significantly, thank you to my love, my rock, my comfort, Emily. Since I started this research, we have gotten married, welcomed Donnchadh into the world, bought our home, and shared that home for two special years with Patsy. Through it all we have always made time for love, humour, and time for thinking, an exercise we both hold dear in an evolving human world that seems to value it less. I look forward to having more time free for these with you, which I have learned are the most important aspects of life.

List of publications and presentations

- Trimble, J., Lovatt, J., & Finlayson, O.E., 2019. Questioning strategies to promote and assess, cognition metacognition and conceptual understanding in chemistry: an analysis. In Levrini, O. & Tasquier, G. (Eds.), *Electronic Proceedings of the ESERA 2019 Conference. The beauty and pleasure of understanding: engaging with contemporary challenges through science education, Part 1* (co-ed. Anna De Ambrosis & Odilla Finlayson), (pp.147 - 153). Bologna: Alma Mater Studiorum – University of Bologna. ISBN 978-88-945874-0-1/978-88-945874-0-1
- Trimble, J., Finlayson, O.E. and Lovatt, J., 2020a. Classroom Discourse to Promote Metacognition and Conceptual Understanding in Chemistry: An Analysis. In *ICERI2020 Proceedings* (pp. 8755-8764). IATED.
- Trimble, J., Finlayson O.E., Lovatt, J., 2020b. Teaching and Learning Strategies Which Promote Metacognition and Conceptual Understanding in Chemistry [Oral Presentation], 15 European Conference on Research in Chemical Education, Excellence and Innovation in Chemistry Teaching and Learning, Weizmann Institute of Science, Rehovot, Israel.
- Trimble, J., Finlayson, O.E. and Lovatt, J., 2021a. Pre-service chemistry teacher education; incorporating metacognitive pedagogical strategies. In *ICERI2021 Proceedings* (pp. 1141-1147). IATED.
- Trimble, J. Finlayson, O.E. and Lovatt, J., 2022. Central concepts within the Leaving Certificate Chemistry Curriculum [Oral Presentation]. *Science and Maths Education Conference 2022*, Dublin City University, Dublin, Ireland, 25-26 June.
- Trimble J., Finlayson O.E., Lovatt J., 2022. Teaching Strategies to Promote Metacognitive Regulation in Second Level Chemistry Education. In G.S. Carvalho, A.S. Afonso & Z. Anastácio (Eds.), *Fostering scientific citizenship in an uncertain world (Proceedings of ESERA 2021)*, Part 2 Strand 2 (co-ed. Florence Le Hebel & Vanessa Kind), pp.137-146. Braga: CIEC, University of Minho. ISBN 978-972-8952-82-2.

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List of abbreviations and explanations

BGN, BTD, DEH, DGD, DHE, DJC, FRK, FJT, KQN, LKN, UKN.	Senior cycle student participant
DES	Department of education and skills
Junior cycle	Lower second level education, first three years of second level education in Ireland
MAI	Metacognitive Awareness Inventory
MAIT	Metacognitive Awareness Inventory for Teachers
MARSI	Metacognitive Awareness of Reading Strategies Inventory
MCK	Metacognitive conditional knowledge
MDK	Metacognitive declarative knowledge
ME	Metacognitive evaluation
Metacognitive strategies	Teaching and learning strategies which incorporate metacognition
MSLQ	Motivated Strategies for Learning Questionnaire
MM	Metacognitive monitoring
MOLES-S	Metacognitive Orientation Learning Environment Scale-Science
MP	Metacognitive planning
MP	
MPK	Metacognitive procedural knowledge
NCCA	National Council for Curriculum and Assessment.
OECD	Organisation for Economic Co-operation and Development
PR	Practitioner/researcher
PST	Preservice chemistry teacher
RQ	Research question
RC	Regulatory checklist
S 1-12	Preservice teacher participant in the methodology module
PS 1-8	Preservice teacher participant in the pilot methodology module
SEM	Strategic evaluation matrix
SEMLI-S	Self-Efficacy, Metacognition Learning Inventory- Science
Senior Cycle	Upper second level education, final three years of second level education in Ireland
Student	Upper second level student
TMI	Teacher Metacognition Inventory

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Abstract

James Trimble

Metacognition in Irish Senior Cycle and Preservice Teacher Chemistry Education: An action research inquiry at a time of curriculum reform, *and the death of a positivist*

This action research (AR) investigates the affordances and limitations of metacognitive teaching and learning strategies in senior cycle chemistry and preservice chemistry teacher (PST) education in the Irish context. My motivation for this research stemmed from: (i) the importance of metacognition in chemistry due to its abstract nature, and (ii) the research took place during a period of significant reform in Irish second-level education, which emphasises key competencies across Junior and Senior Cycle subject specifications, including metacognition.

The AR methodology allowed insights across five cycles. In the senior cycle study (AR Cycles 1–3), I explored the incorporation of metacognitive teaching and learning strategies in chemistry lessons. Insights from this study informed the design and implementation of a PST methodology module (AR Cycles 4–5). I analysed both qualitative and quantitative data as part of triangulation. I acknowledge the limitations of my inquiry, the challenges of identifying metacognition and conducting AR, and I discuss the rigor and trustworthiness of the findings.

Through planning, acting, observing, and reflecting on theory and practice across the AR cycles, I propose contributions to actionable knowledge, including a model for integrating metacognition into the teaching and learning of abstract chemical concepts. I identify the value of student/PST generation of representations as a domain-specific approach for incorporating metacognition in chemistry, facilitated through associated descriptions. Contributions to practice and policy emphasise integrating metacognitive strategies into second-level chemistry and PST education, including ensuring PSTs experience, plan, and practice these strategies to appreciate their value within a domain-specific context. Contributions to theory include three cornerstones of a ‘metacognitive lens’ for teaching and learning strategies of abstract chemical concepts. These cornerstones address metacognition through awareness of the (i) voice (ii) evolution and (iii) consolidation of cognitive processes. Contributions to research include the detail of my epistemological and ontological journey, particularly the evolution of my perspective on knowledge from positivism to interpretivism, as a natural scientist conducting research in a social science context.

Chapter 1 Introduction

This action research (AR) follows my story of how I aimed to incorporate metacognition as part of senior cycle chemistry lessons and preservice chemistry teacher (PST) education in the Irish context, a context which has seen substantial curricular reform in recent years (see Section 1.2).

A central premise of this research is my agreement with studies arguing that domain-specific incorporation of metacognition promotes a deeper, more robust conceptual understanding in chemistry (e.g. Rickey & Stacey, 2000; Tsai, 2001; Georghiades, 2004; Lavi et al., 2019; Abarro et al., 2021). Since Flavell coined the term ‘metacognition’ or knowledge about cognitive phenomena in the 1970’s and introduced it as ‘a new area of cognitive-development inquiry’, its place in education literature has gained prominence. While many academic studies highlight the value of metacognition in science education, reports of efforts to integrate metacognition into ordinary classrooms remain rare (Georghiades, 2004; Lavi et al., 2019), particularly in the Irish context.

This AR involved five cycles, a senior cycle study (AR Cycles 1-3) and a PST study (AR Cycle 4 & 5). The senior cycle study documented my experience incorporating strategies which promote metacognition in senior cycle chemistry lessons. This study included pilot studies with two different Transition Year (TY) classes (AR Cycles 1 & 2) and a fifth-year class (AR Cycle 3). This research then explores how I incorporated the insights from the second-level study into the design and implementation of a PST methodology module, where I was the teacher-educator (AR Cycles 4 & 5). The PST study offers a particularly valuable perspective, as previous research has argued that, while few researchers question the importance of metacognition, this recognition is not consistently reflected in the practices of teachers or teacher educators (Sulaiman et al., 2021; Mohammad et al., 2020; Zohar & Barzilai, 2013; Meloth & Deering, 1999; Hartman, 2001; Seraphin et al., 2012; Thomas, 2012).

AR is the appropriate methodology for this research because it can be both robust for scholars and useful for practitioners and has the implementation of change at its core (Coghlan, 2011). In the current research choices are made, and AR is characteristically full of choices (e.g. literature reviewed, data collection techniques, data samples, data analysis strategies), and I am aware the primary rule in approaching quality in research is to be aware of the choices that are made and their consequences (Reason, 2006). The

choices I made in this research are discussed at relevant points in this thesis. The model of AR followed was one where each AR cycle involved a spiral of three repeating phases (Figure 1.1) (Kemmis & McTaggart, 2000);

- (i) *Planning* (e.g. review of literature, planning how strategies would be implemented, incorporation of learnings from previous cycles and literature)
- (ii) *Action and Observation* (e.g. implementation and observation of metacognitive strategies in lessons and workshops).
- (iii) *Reflection* (e.g. my reflection on lessons and workshops, review of audiovisual recordings, descriptive analysis, PST interviews).

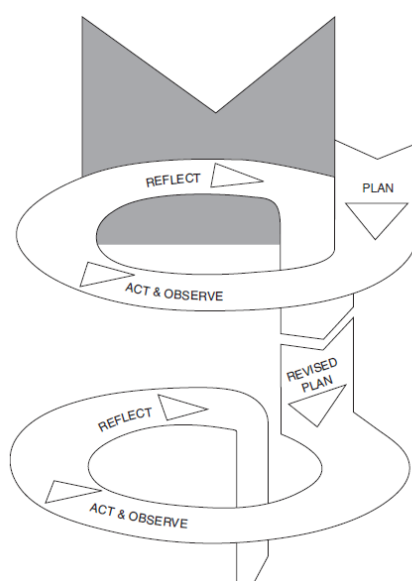


Figure 1.1 The action research spiral and phases

1.1 My background and philosophy of chemical education

My experience teaching chemistry prior to this research led me to recognise my students and my own cognitive processes (e.g. thinking, visualising, understanding, learning) as the central foundation for any pedagogical approach. It was these beliefs that motivated me to conduct research on strategies that encourage students to be more aware of their cognitive processes in chemistry, in other words, to incorporate metacognition into chemistry teaching. While it can be argued that the established Leaving Certificate chemistry curriculum and associated examination (NCCA, 1998) promote rote learning (Smyth & Banks, 2012; Baird et al., 2016), my own understanding and teaching of chemistry led me to believe that relying on a rote learning approach actually made the subject more challenging for senior cycle students, while also being less engaging for

both students and teachers. Central to this is my belief that I saw little value in repeatedly revisiting definitions to memorise them, which I view as a series of cul-de-sacs in the exploration of knowledge in chemistry. My views were inevitably shaped by my early experiences studying chemistry, where my approach was guided by the principle that, to truly learn about a chemical phenomenon, I needed not only to understand it but also to reflect on how I understood it. I came to realise that this required both time and awareness of my cognitive processes.

Given my positivist natural science background, this research challenged my assumptions and my own metacognition in terms of (i) my understanding of cognition and metacognition (ii) the implementation of metacognitive teaching and learning strategies (metacognitive strategies) (iii) theorising based on my experiences during the research, and (iv) my world view in terms of research and knowledge. In this sense, this research presents an intervention of my own interpretation and development of metacognition across senior cycle and PST education as a practising teacher, teacher educator and researcher.

I hold a Bachelor of Science in Chemistry Education (BSc. Ed) and I have 16 years of chemistry teaching experience in second level education, and five years' experience teaching a specialist chemistry methodology module to PSTs. Prior to the beginning of this research, I furthered my theoretical knowledge of chemistry through a Master of Chemistry (M.Sc.) which was conducted mostly from a positivist stance, while I furthered my theoretical knowledge of education through a Master of Education (M.Ed.) which was conducted predominantly from an interpretivist stance. Through these postgraduate studies I developed my research skills and the importance of being aware of my own biases as part of carrying out data collection, interpreting data and in reaching findings. Before beginning this AR, I was a co-author of mathematics textbooks and teacher resource books, which further developed my awareness of reducing cognitive overload by connecting topics and phenomenon through underlying concepts, which was a central focus of the textbook series (Trimble et al., 2021b; Trimble et al., 2021c; Trimble et al., 2021d; Trimble et al., 2021e).

The interpretation of any research findings inevitably reveals underlying philosophies, supporting and extending the idea that all knowledge is knowledge from a particular point of view (Mounce, 2002). For example, as discussed, I began this research with the belief

that promoting awareness of one's cognitive processes is central to understanding chemical phenomena. My philosophical beliefs as a researcher are grounded in the pragmatic paradigm (See Section 3.2). I see the relevance of this research as education reforms both nationally and internationally towards a more metacognitive education for students in senior cycle education (NCCA, 2022; OECD, 2005, 2018). My epistemological and ontological stances are discussed in Chapter 3.

1.2 Context of this research and curriculum reform in Ireland

National curricula with recommended teaching and learning strategies undergo reforms periodically, both in Ireland and internationally. However, I see the underlying purpose of education which threads such reforms as being the development and awareness of cognitive processes.

Internationally, the Educational Policies Commission (EPC, 1961) in the United States of America when addressing itself to the task of identifying the central purpose of education, states: “*The purpose which runs through and strengthens all other educational purposes - the common thread of education – is the development of the ability to think*” (p. 12). The OECD (2005) identified the key competency of *Reflectiveness* - which includes cognition and metacognition – as an overarching goal of education systems. The OECD Learning Framework 2030 indicates that as part of the education, students should develop cognitive and metacognitive skills (OECD, 2018). Components of metacognition become increasingly important as children enter secondary school, where reasoning, regulation and reflection become more integral to the curriculum (OECD, 2018). As part of the rationale for a focus on metacognition in the *conceptual learning framework* (OECD, 2018), the argument is that while Artificial intelligence (AI) is making inroads into many domains, it is unlikely to replace workers whose jobs involve the creation of new ideas (OECD, 2018).

Providing context for this research, in Ireland, second level education has two cycles, Junior and Senior. Junior Cycle covers the first three years of second level education, typically from the ages of 12 to 15 years. Prior to their progression to Senior Cycle, students complete the Junior Cycle examination. Science is an optional subject to study at Junior Cycle. At the end of their Junior Cycle studies, students enter the senior cycle and can take an optional one-year programme, known as Transition Year (TY). The Leaving Certificate programme is the final two-years of second level education in Ireland,

at the end of which students sit the Leaving Certificate examination. Students typically select seven subjects to study as part of their Leaving Certificate. Students can select from five Science subjects for their Leaving Certificate studies– Agricultural Science, Biology, Chemistry, Physics, and Physics with Chemistry (a combined subject). The results of a student's Leaving Certificate examination mark the completion of their senior cycle education and are used for determining a student's progression to third level courses.

Recent reforms of second level education in Ireland have increased the focus on student cognition and metacognition. *The Framework for Junior Cycle* (DES, 2015) outlined the major educational changes for Junior Cycle level in Ireland, which explicitly included the key skills of *Managing myself* and *Managing Information and Thinking* as part of generic skills embedded in subject syllabuses across the curriculum. The specification for Junior Cycle science emphasises certain key skills such as *Being able to reflect on my own learning, Knowing myself, Thinking creatively and critically* (DES, 2015).

More recently, the advisory report on the reform of senior cycle education includes “*providing opportunities for new and deep learning and for critical, creative and innovative thinking*”, and “*developing students’ greater independence in, and understanding of, how they learn*” as part of the guiding principles for a redeveloped senior cycle in Ireland (NCCA, 2022, p. 24). The Senior Cycle Key Skills Framework (NCCA 2023a) draft document on the development of ‘key competencies (the knowledge, skills, values and dispositions for students) in senior cycle’ includes ‘cognitive and metacognitive skills’ through *physical education; community work, voluntary work or work experience; civic education or education for sustainable development; creativity, the arts and culture, intercultural education* (NCCA, 2023a). While the report suggests the development of these skills in experiences outside of the classroom, I believe an interesting question exists; how metacognition can be embedded within subject domains in the Irish context.

The story of my experience, told through this AR on incorporating metacognition into chemistry education, is particularly relevant in Ireland during this period of second level curriculum reform at both the Junior and Senior Cycle levels. The Senior Cycle framework builds upon the foundational skills established in the Junior Cycle and incorporates a competency framework (NCCA, 2023a). In particular, the attention at senior cycle is directed towards progressing from Junior Cycle, involving a deliberate

shift to rebalance the distribution of knowledge where the aims include the prioritisation of student agency (NCCA, 2023a, 2023b). A central part of this is the development of student epistemic knowledge including knowing what knowledge is; knowing what one knows and can do; and how that learning came about (NCCA, 2023a), i.e. metacognition.

As part of the rollout of nine new subjects in Senior Cycle, a new revised syllabus for Chemistry will be rolled out for students beginning senior cycle (fifth-year students) in 2025 and this will incorporate externally assessed components that are not a traditional written examination. The draft chemistry specification outlines how a Leaving Certificate key competency of '*Thinking and problem solving*' can be developed in Leaving Certificate Chemistry through students developing the ability to visualise and innovate their own internal models of chemical processes (NCCA, 2023b). In relation to the Leaving Certificate key competency of '*Managing learning and self*' the draft Chemistry Specification indicates that students become more self-aware and use this awareness to develop personal goals. Leaving Certificate Chemistry is intended to be learner-centred and encourage student agency and decision-making, particularly in their investigative work and developing models. The draft Chemistry syllabus also describes '*model*' as an action verb where it is a student's ability to generate a mathematical representation (e.g., number, graph, equation, geometric figure) or physical replica for real world or mathematical objects, properties, actions, or relationships (NCCA, 2023b).

Second level preservice teacher education in Ireland dates from 1912 and has traditionally been located within universities (Harford, 2010). There have been numerous changes and new initiatives in teacher education since the establishment of the Teaching Council (national professional standards body) in 2006 (O' Donoghue, et al., 2017; Prendergast, et al., 2021). For example, the 2011 *Review of the structure of initial teacher education provision in Ireland* (Sahlberg, et al., 2012), recommended introducing a masters level qualification to replace the diploma for consecutive teacher education. Currently two models for second level teacher education exist in Ireland, namely consecutive and concurrent models. The consecutive model comprises a programme of professional training in pedagogy and teaching (resulting in a Professional Master of Education, PME) usually taken after having first completed a primary degree in a discipline. While the concurrent model is one in which academic subjects are studied alongside educational and professional studies, in a four-year or five-year joint academic–subject and education degree (Harford, 2010). For context, the preservice teacher participants in this research

were in the fourth and final year of a concurrent degree in chemistry and mathematics education which, when complete, qualified them to teach chemistry and mathematics to senior cycle level in Ireland.

1.3 Focus of the current research and research questions

The broad aim of this AR is to discuss my journey, experiences, and learnings as a teacher, teacher educator, and researcher as I work to incorporate metacognition into senior cycle and PST education within the Irish second-level educational context during a period of reform. The research also follows my journey as a researcher with a positivist natural sciences background, to carrying out social science research on metacognition in chemistry education.

This AR study was guided by two overall research questions, each corresponding to two different studies:

1. Senior Cycle Chemistry study (AR Cycles 1–3):
What are the affordances and limitations of integrating metacognitive strategies in Senior Cycle chemistry lessons in the Irish context?
2. Preservice Chemistry Teacher (PST) Education study (AR Cycles 4–5):
What is the impact of explicitly integrating metacognitive strategies on preservice chemistry teachers' (PSTs') awareness and lesson planning in chemistry teaching in the Irish context?

It should be noted that there has been significant research in the area of scientific modelling and experimental work in second level chemistry and PST education (e.g. Cheung, 2008. Donnelly et al, 2014; Dunne et al., 2013). While I recognise the importance of these as part of overall teaching strategies, they are not a primary focus of this thesis. Laboratory or experimental work are not isolated in this research as a metacognitive strategy, as its use in addressing metacognitive regulation across the science domains has been well documented in the literature (Kipnis & Hofstein, 2008; Kalemkus et al., 2021; Lee, et al., 2021). Models are used in a variety of ways in scientific practice; they can, for example, function as proto-theories, pedagogical devices, or as tools for generating and testing hypotheses (Wimsatt, 1987; Bokulich, 2011). In addition, scientific modelling can refer to physical modelling and internal mental modelling (NCCA 2023; Bokulich, 2011). This thesis is focused on the student's metacognitive awareness of their cognitive processes in relation to chemical phenomena, and to provide

clarity the terms ‘modelling’ or ‘model’ were not used to describe the cognitive process of visualising or used as an action verb (NCCA, 2023b).

1.4 Thesis structure

The AR cycles included significant and broad analysis of relevant literature on metacognition and investigating the incorporation of teaching and learning strategies reported as supporting the development of metacognition. A summary of this analysis is presented in Chapter 2 and embedded in other chapters where particularly relevant. For example, metacognition and its relationship with cognition as presented in literature is discussed in Chapter 2. This includes both domain specific and domain general aspects of metacognition in education and chemical education. As part of Chapter 2 metacognitive literature relating to the teaching and learning of science is reviewed, as it relates to both the learner and the teacher. Literature on representations and visualisations are also discussed due to their particular evolving relevance during the AR Cycles.

The methodological aspects of the research are presented in Chapters 3, 4, and 5. Chapter 3 discusses the research approach, paradigm, and the AR methodology, including criteria to judge AR. Chapter 4 covers the data collection techniques, participant details, and ethical considerations. Chapter 5 focuses on data analysis, including discussions of reliability and trustworthiness.

Chapter 6 through Chapter 10 discuss the design and implementation of the five AR cycles. Through the spiral AR approach, my understanding of metacognition in chemistry, metacognitive practices in chemistry teaching, and my development as a researcher are discussed across these chapters.

Chapter 6 discusses the TY Pilot studies (AR cycles 1 and 2), including the aims and context of the studies, reflections on the TY pilot studies, and a summary of findings. As my understanding of metacognition in chemistry developed through reflective practice and theoretical study, the conceptual framework is introduced in Section 6.6 after the discussion of the TY pilot studies. It is important to note that the conceptual framework was continually reviewed over the five AR cycles; however, to provide context for the reader, it is presented in Chapter 6.

Chapter 7 discusses the fifth-year study, specifically detailing how I incorporated metacognitive strategies into senior cycle lessons over the course of an academic year. This is illustrated with examples from the senior cycle study, along with a discussion of

the metacognitively oriented environment in these lessons and the instruments used to analyse student metacognition. My learnings from the senior cycle study (AR cycles 1–3), addressed through the relevant research questions (see Table 3.1), are presented at the end of Chapter 7.

Chapter 8 discusses the design, implementation, and findings of the first iteration of the PST methodology module (AR Cycle 4), including a summary of key learnings in preparation for AR Cycle 5.

Chapter 9 describes the design of the second iteration of the PST methodology module (AR Cycle 5), while Chapter 10 discusses the PSTs' experiences in the module, focusing on their own metacognition in chemistry and their approaches to planning for teaching. The findings from the PST study (AR Cycles 4 & 5) are presented through a discussion of the relevant research questions specifically related to the PST methodology module, AR Cycles 4 and 5 (see Table 3.1).

Chapter 11 discusses the overall findings from the research across the five AR cycles, including contributions to practice, theory, and research, as well as limitations and suggestions for future work.

Chapter 2 Metacognition in education

My critical analysis of existing literature on metacognitive approaches in chemistry served as a precursor to AR Cycle 1 and continued concurrently through each AR Cycle, particularly during the *Planning and Reflection* phases. This chapter presents a summary synthesis of my review of existing knowledge related to the theoretical concepts addressed in this research. This chapter initially presents the concepts and components of cognition and metacognition. The later sections of the chapter discuss metacognition in teaching and learning with a particular focus on science and chemistry education. Chemistry is an abstract subject requiring visualisation and understanding of the submicroscopic level, hence representations (interpreted in this thesis as external, observable by others) of visualisations (interpreted in this thesis as internal, unobservable by others) are discussed in this chapter. Metacognition in the context of teacher education is also discussed as this is addressed through my own experience as the teacher in AR cycles 1-3 while providing background knowledge for the work with the PSTs in AR cycles 4 and 5.

2.1 Cognition

“*Cogito, ergo sum*,” the French philosopher Rene Descartes (1637) famously declared, “*I think, therefore I am*”. To think is to learn, and thinking is a cognitive process.

My initial analysis of the literature focused on how cognition is described before developing into the analysis of literature on metacognition, this presented challenges as I found neither cognition nor metacognition are described consistently. One of the earliest definitions of cognition was presented by Ulric Neisser in 1967 who noted that cognition is “*those processes by which the sensory input is transformed, reduced, elaborated, stored, recovered, and used*” (Neisser, 1967, p.4). The term ‘cognition’ has been used to refer to cognitive or mental processes, including attention, language, visualisation, problem solving, learning, memory, perception, understanding and thinking (Lachman, et al., 2015; Allen, 2017; Bayne et al., 2019). Summary descriptions of examples of cognitive processes from literature are given in Table 2.1. Within this table I note that ‘thinking’ is an essential part of every other cognitive process where thinking is normally directed toward achieving some certain goal or situation. For example, Holyoak and Morrison (2005) defined thinking as the systematic transformation of mental descriptions of knowledge to characterise actual or possible states of the world, often in the service of goals.

Table 2.1 Examples of cognitive processes

Cognitive process	Description
Thinking	Thinking is an essential part of every cognitive process. It allows people to engage in decision-making, problem-solving, and higher reasoning (Rowlands, 1999; Lachman et al., 2015)
Problem solving	Problem solving is a cognitive process of the brain that searches for a solution for a given problem or finds a path to reach a given goal (Wang & Chiew, 2010).
Decision making	Decision making is a process that chooses a preferred option or a course of actions from among a set of alternatives on the basis of given criteria or strategies (Wang, et al., 2004; Wilson & Keil, 2001).
Visualisation	Visualisation is a cognitive process involving visual (mental) imagery, visual memory, visual processing, visual relationships, visual attention and visual imagination (Kosslyn, 1994).
Attention	Attention is a cognitive process that allows people to focus on a specific stimulus in the environment while filtering out irrelevant information (Allen, 2017; Rueda et al., 2023).
Language	Language and language development are cognitive processes that involve the ability to understand and express thoughts through spoken and written words. This allows us to communicate with others and plays an important role in thought (Rowlands, 1999; Neisser, 1967).
Learning	Learning requires cognitive processes involved in taking in new things, synthesising information, and integrating it with knowledge (De Houwer et al., 2013).
Memory	Memory is an important cognitive process that allows people to encode, store, and retrieve information. It is an important component in the learning process and allows people to retain knowledge about the world and their personal histories (Rowlands, 1999; Neisser, 1967; Norris, 2017).
Perception	Perception is a cognitive process that allows people to take in information through their senses, then utilise this information to respond and interact with the world (Bayne et al., 2019).
Understanding	Understanding is an ongoing cognitive activity of acquiring, integrating and expressing knowledge according to the task or situation at hand (Blaha et al., 2022).

I see an understanding of working memory and its limitations as important when discussing cognitive processes in the context of this AR, for example metacognition includes having an appreciation for the boundaries of our working memory, and monitoring strategies to compensate for these limitations. The term working memory refers to a brain system that provides temporary storage and manipulation of the information necessary for complex cognitive processes such as learning and understanding (Baddeley, 1992). According to Baddeley and Hitch (1974), working memory temporarily stores and manipulates input when performing cognitive processes,

which involves the simultaneous storage and processing of information. In his 1956 paper, George A. Miller proposed that the human brain has a limited capacity for processing information; however, one can use 'chunks,' where information is grouped (Miller, 1956). For example, in chemistry, an underlying concept can link and facilitate understanding across multiple topics.

2.1.1 Cognition and chemistry

Particular to my own interest in this work was the awareness of cognitive processes in chemistry, and this involved exploring how to capture what cognition in chemistry means as a teacher and a learner. Understanding the ideas and practices on which chemical cognition is based is critical for those who rely on their chemical understanding to make important decisions (Sevain & Talanquer, 2014). Vincent-Ruz (2020) describes chemical cognition or 'thinking' as the development and application of chemical knowledge and practices with the main intent of analysing, synthesising and transformation (chemical changes) of matter. In chemical education, chemical cognition can be used to capture the knowledge, reasoning and practices that characterise learning in chemistry (Talanquer & Pollard, 2010).

Chemistry, by its very nature, is highly conceptual (Sirhan, 2007). Chemistry is based on many abstract concepts, for example electrons existing in orbitals or these orbitals overlapping to form chemical bonds all occurring at the submicroscopic level. Chemistry curricula commonly incorporate abstract concepts which are central to further learning in chemistry (Taber, 2002, Alam, 2020). Abstract concepts in chemistry are important because further chemistry concepts or theories cannot be easily understood if these underpinning concepts are not sufficiently grasped by the student (Zoller, 1990; Nakhleh & Mitchell, 1993; Ayas & Demirbaş, 1997; Coll & Treagust, 2001; Freire, et al., 2019). Due to the abstract nature of chemistry, students require a high-level skill set e.g., skills associated with their deeper understanding of how concepts can be described (Zoller, 1990; Taber, 2002; Lansangan, et al., 2007). Linked to the abstract concepts in chemistry is the submicroscopic level at which chemical reactions occur. Previous literature has identified that difficulties in learning chemistry are credited mainly to its abstract, unobservable, particulate basis and to the need for agile transfer across the various levels (macroscopic, submicroscopic, and symbolic) of chemistry understanding (Johnstone, 2000; Gabel, et al., 1992; Coll & Treagust, 2003). These levels are discussed in more detail in Section 2.5.

My belief in the value of metacognition in chemistry is founded on what I see as the difficulties that arise in the rote learning of a subject that is primarily based on application of abstract submicroscopic concepts. While much knowledge can be acquired by rote learning and this is often being reflected by efficient recall in examination questions, real understanding demands the bringing together of conceptual understandings in a meaningful way (Sirhan, 2007). Many researchers have reported problems areas in chemistry education where the focus is on rote learning. For example, students show some evidence of learning and understanding in examination papers, however researchers find evidence of misconceptions, and of certain areas of basic chemistry which are still not understood even in undergraduate level chemistry education (Vladušić, et al., 2016; Goodney, 2006; Johnstone, 2006; Hinton & Nakhleh, 1999; Bodner, 2003; Johnstone, 1974).

Due to the difficulties in learning chemistry linked to the abstract nature of the subject, I believe it is important to examine how to promote student and teacher responsiveness in terms of understanding chemistry through awareness and regulation of their cognitive processes (metacognition).

2.2 Cognition and metacognition

The term metacognition is credited to the work of developmental psychologist John Flavell in the 1970s, who described metacognition as “*one’s knowledge concerning one’s own cognitive processes, or anything related to them*” (Flavell 1976, p. 232). The prefix ‘meta’ derives from the Greek for ‘beyond’ or ‘with’ to indicate a concept that abstracts from another concept, often (but not always) with a self-referential flavour (Fleming, et al., 2012). The importance of metacognition can be traced back to Socrates’ questioning methods where the teacher poses thought-provoking questions and students actively engage by asking questions of their own cognitive processes (e.g. what is influencing the way you are thinking or understanding?), and to Dewey’s twentieth-century proposition that we learn more from reflecting on our experiences than from the actual experiences themselves (Dewey, 1933).

The concepts of cognition and metacognition are different although they are related to each other (Akturk, et al., 2011). For example, one important characteristic of the human mind is its ability to reflect critically on cognitive processes, not only as thoughts are taking shape, but also after a thought has given rise to action. This ability to think about

cognitive processes is termed metacognition (Flavell 1976). While cognition involves the cognitive processes such as learning or understanding something, metacognition involves being aware of and knowing how one learns or understands something. Cognition can be defined as the range of cognitive or mental processes people engage in (see Table 2.1). It not only supports the generation of new knowledge but also helps individuals apply their existing knowledge in everyday life. As such, cognitive processes allow normal functioning of individuals, while metacognition takes it a level higher, making a person more aware of and hence in control of his/her cognitive processes.

Cognition and metacognition serve complementary functions (Boekaerts, 1997; Nelson & Narens, 1994; Nückles, et al., 2009; Akturk, & Sahin, 2011). Veenman et al., (2006) emphasise the importance of the relationships between metacognition and cognition while arguing the border between them is fuzzy. Metacognitive and cognitive activities are cyclical processes, making it difficult to disentangle them in the assessment of metacognition. For example, we have a perception of a chemical phenomenon (cognition), we experience a new way to think about a similar phenomenon, our awareness of this new way of thinking (metacognition) may result in us returning to original chemical phenomenon and changing how we think about it and how we think about similar phenomenon going forward. In this way, cognitive strategies enable one to make progress to build knowledge, whereas metacognitive strategies enable one to monitor and improve one's progress to evaluate understanding and apply knowledge to new situations. Thus, metacognition is important to cognitive effectiveness (Gourgey, 1998).

Cognitive processes include problem solving and critical thinking strategies whereas metacognitive processing refers to awareness and control of problem solving and critical thinking (Schraw et al., 2006). Cognition acts to resolve problems and bring cognitive activity to a desirable outcome, while metacognitive function is the awareness and regulation of an individual's cognitive effort in executing a task (Vos, 2001). Similarly, cognitive processes assist a person in accomplishing a particular cognitive goal (e.g., understanding a chemical equation), while metacognition refers to control or regulatory processes which individuals use to ensure that the particular cognitive goal has been met (e.g. awareness and monitoring of knowledge and strategies one uses to understand a chemical reaction e.g. visualising the collision of molecules) (Livingston, 2003; Rubin,

2005; Garner, 1987). Hence, cognition facilitates task achievement, and metacognition helps to be aware, monitor, and regulate task achievement (McCormick, 2003).

An individual who has developed their metacognition has the ability to reflect upon, comment about, and report a variety of mental states e.g., in chemistry, state of confusion related to a chemical phenomenon, state of calculating a solution to a problem, state of visualising an abstract chemical concept, state of cognitive overload (overwhelmed with the amount of information to process). General assumptions for assessing metacognition are that metacognition is either an aptitude or an event (Winne & Perry, 2000). When metacognition is viewed as an aptitude, individuals are assumed to possess tactics of metacognition as a relatively enduring trait or to employ relatively stable approaches when solving different tasks (Muis et al., 2007). When metacognition is viewed as an event, the utilisation of metacognitive tactics is assumed to vary across different tasks/events, and individuals are assumed to adjust their learning behaviour dynamically to adapt to different context or task/event demands (Pieschl et al., 2012). Metacognition can sometimes be observed in a persons' verbalised self-instructions, but when it is not explicitly heard or seen during task performance, it needs to be inferred from evidence of certain cognitive processes (Veenman et al., 2006). A representation I synthesised, based on my initial reflections on existing literature, illustrates the dynamic interplay between cognition and metacognition, is shown in Figure 2.1. (e.g., De Bruin & Van Gog, 2012; Nelson & Narens, 1994; Schraw, 2001; Roelle et al., 2017).

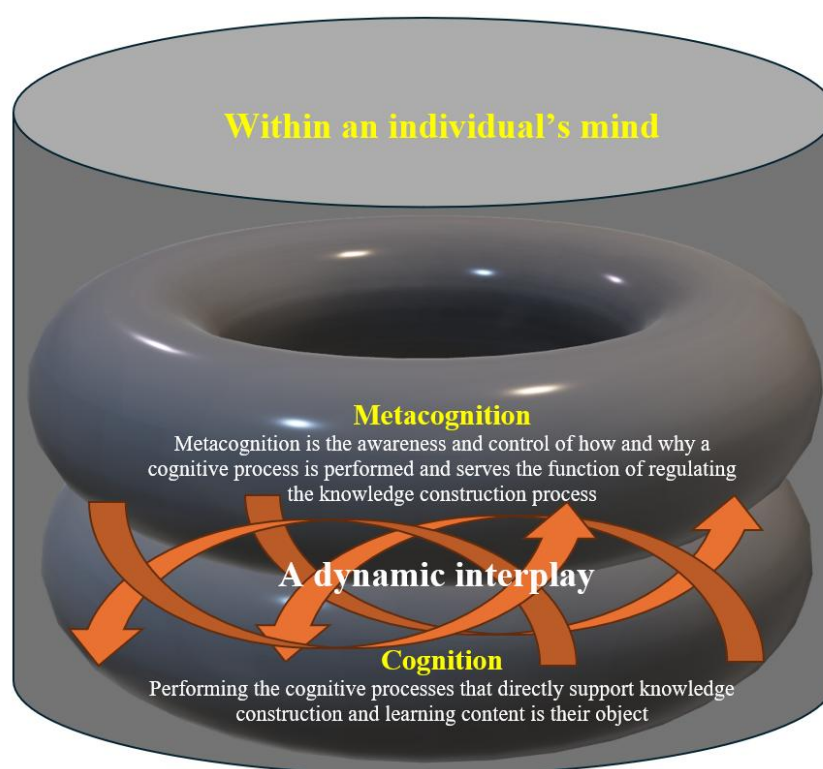


Figure 2.1 The interplay between cognition and metacognition

2.3 The subcomponents of metacognition

Flavell (1979) described metacognition as having the subcomponents of (a) metacognitive knowledge, (b) metacognitive experiences, (c) goals (or tasks), and (d) actions (or strategies). These are outlined in Table 2.2.

Table 2.2 Subcomponents used by Flavell (1979) to describe metacognition

Term	Explanation
Metacognitive knowledge	with the subcategories of person, task and strategy encompassing one's understanding of people or oneself as cognitive creatures, including ability to judge the cognitive demands of a particular task e.g., knowing one is better at arithmetic than spelling
Metacognitive experiences	these are cognitively conscious experiences that one is aware of e.g., a sudden sense one does not understand what another just said
Goals (or tasks)	the object of a cognitive challenge, e.g., completing a mathematical calculation
Actions (or strategies)	thinking in relation to how one achieves a cognitive goal and knowledge of what strategies to use for what purposes e.g., how one thinks about how to carry out a mathematical calculation.

Flavell's inclusion of metacognitive experiences as being aware of momentary puzzlement or a prolonged sense of understanding of the cognitive challenges faced when

learning is interesting, as metacognitive experiences are not often included as a distinct component of metacognition in later works (e.g., Schraw & Moshman, 1995; Young & Fry, 2008). This is possibly due to the difficulty in measuring or studying metacognitive experiences, as they are by their very nature often subjective and momentary. Within Flavell's description of metacognition, it is difficult to distinguish between the various components of metacognition he described, for example knowledge of goals (or task) overlaps with actions (or strategy), as part of understanding a strategy is to understand the goal.

Metacognition has also been interpreted through the lens of learning. For example, Gourgey (2001) interprets metacognition as an awareness of how one learns; awareness of when one does and does not understand; knowledge of how to use available information to achieve a goal; ability to judge the cognitive demands of a particular task; knowledge of what strategies to use for what purposes; and assessment of one's progress both during and after performance. Baliram and Ellis (2019) also use the term learning when describing metacognition, where they argue that metacognition raises an individual's consciousness of how s/he thinks and learns, and in agreement with this interpretation, Ford and Yore (2012) and Lavi et al. (2019) suggested that metacognition involves thinking about your learning as you are learning to improve your learning.

The interchangeable use of the terms 'learning' and 'thinking' related to metacognition is understandable as these are both cognitive processes, and Mayer (1992) argues thinking is at the heart of learning in that thinking makes higher-order learning and problem solving possible.

As can be seen, there are many different definitions of metacognition and its components in the literature, and the field still awaits future theoretical work that would provide a thorough theoretical analysis and integration of the extensive literature in this area to attain a unified definition of this construct (Veenman, et al., 2006; Rhodes, 2019). Though no universally accepted definition of metacognition can be found in the literature, themes which fall under distinct subcomponents appear in Flavell's original work and permeate through the literature: metacognitive awareness/knowledge, metacognitive regulation.

Following the analysis of the literature on metacognition, my synthesis of existing literature on the subcomponents of metacognition is shown in Figure 2.2. The metacognitive regulation has uniformly been described in the literature as containing the subcomponents of planning (MP), monitoring (MM) and evaluation (ME) (Flavell et al., 2002; Schraw et al., 2006; Schraw & Moshman; 1995; Veenman, 2012; Cross & Paris, 1988; Paris & Winograd, 1990; Schraw et al., 2006; Whitebread et al., 2009; Wang, 2015). Two sets of triplet subcomponents of metacognitive awareness/knowledge are discussed in the next section, along with the other subcomponents shown in Figure 2.2. My interpretation of metacognition and its subcomponents, as relevant to this work, is presented within the conceptual framework in Chapter 6, Section 6.6.

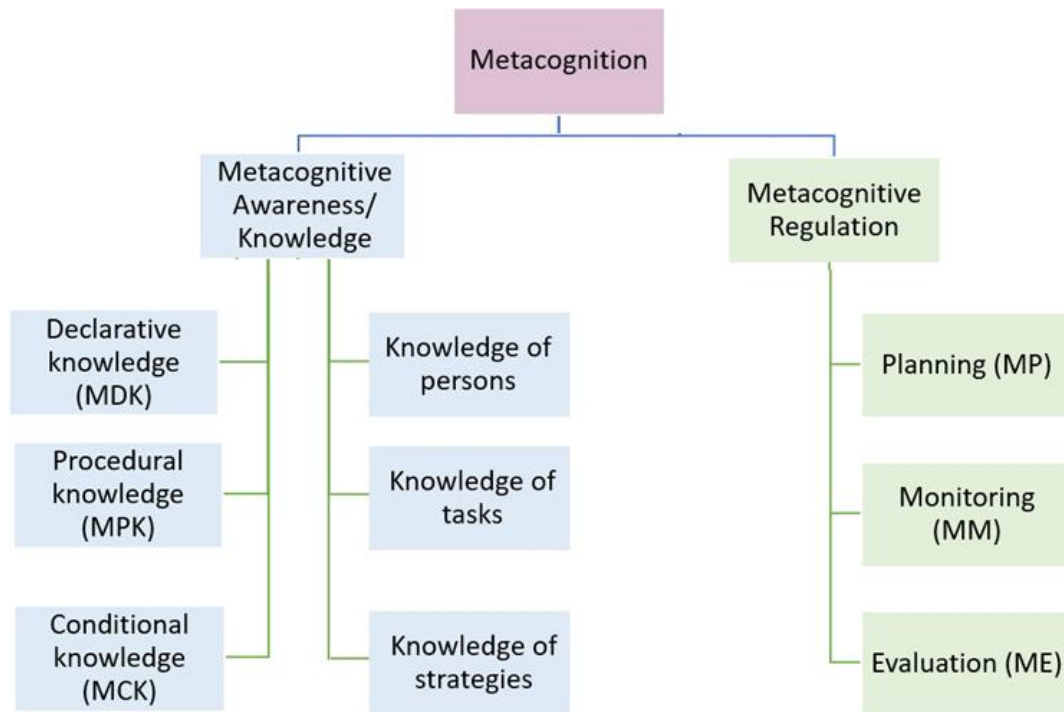


Figure 2.2 Overview of components of *metacognition*, from literature analysis

2.3.1 Metacognitive awareness/knowledge

The terms metacognitive knowledge and metacognitive awareness are used interchangeably to refer to the same component of metacognition. However, there is considerable debate about the scope and meaning of metacognitive awareness/knowledge and the nature and interrelations among the various subcomponents of metacognitive awareness/knowledge that have proliferated in the literature (Alexander, et al., 1991). Metacognitive awareness/knowledge can be further divided into two separate triplets of

subcomponents as shown in Figure 2.2. While two separate classifications of the subcomponents of metacognition awareness/knowledge exist, both of these triplets of subcomponents result in describing awareness of thought processes. For example, the word ‘learning’ is used by Flavell (1979) in particular instances, while ‘cognition’ ‘thinking’ and ‘knowing’ are also used by Flavell (1979) and others e.g., Schraw et al., (2006). In this example, learning requires thinking, therefore it is reasonable to argue that if one is aware and able to control one’s own learning, then one is aware and able to control one’s thinking. Flavell, (1979) describes metacognitive knowledge as referring to knowledge, beliefs, ideas, and theories about people as ‘cognitive creatures’ and about their diverse interactions with cognitive tasks and strategies. He proposed that metacognitive knowledge included knowledge of person, task, and strategy that can influence cognition. A number of other examples exist where metacognitive knowledge/awareness has been divided into the subcomponents of knowledge of tasks, persons and strategies; descriptions and examples of these subcomponents are shown in Table 2.3 (Flavell, 1979; Flavell et al., 2002; Pintrich, 2002; Ellis, et al., 2014; Whitebread & Cárdenas, 2012).

Table 2.3 Metacognitive awareness/knowledge - knowledge of tasks, knowledge of persons, knowledge of strategies

Sub-component	Description	Examples
Knowledge of persons	(i) self-knowledge of the variables that influence the individual's cognitive activity (ii) knowledge of the cognition of others and (iii) knowledge of the shared features (universals) of people's cognition	Knowledge (i) that you can learn most things better by listening than by reading (ii) that one of your friends is more mathematically minded than another (iii) that there are various degrees and kinds of understanding for people (attending, remembering, communicating, problem solving, etc.).
Knowledge of tasks	Understanding how the nature of task conditions, demands and goals affects cognitive activity	If one confronts a novel problem that is ill-defined, then general problem-solving techniques may be very useful. In contrast, if one confronts a chemistry problem regarding the ideal gas law, more specific procedural knowledge, not general knowledge, will be much more useful and adaptive for this task. When one consciously understands a lesson objective, activity, or procedure.
Knowledge of strategies	Knowledge about thinking, learning and problem-solving strategies that students might use in order to achieve goals. This entails knowledge about what thinking strategies can accomplish and about when, why, and how to use these strategies	Evaluating the validity of different logical statements, making appropriate inferences from different sources, and drawing on appropriate samples to make inferences. Repetition of words or formulas to be remembered. Various mnemonics for memory tasks, summarising, paraphrasing, and selecting main ideas from texts. Outlining, concept mapping, and note taking, where one makes connections between and among content elements.

(compiled from Flavell, 1979; Flavell et al., 2002; Pintrich, 2002; Ellis, et al., 2014; Whitebread & Cárdenas, 2012).

Several studies suggest a different categorisation of metacognitive awareness/knowledge (Figure 2.2 where the subcomponents are described as metacognitive declarative knowledge (MDK), metacognitive procedural knowledge (MPK), and Metacognitive conditional knowledge (MCK) (e.g., Schraw, et al., 2006; Ford & Yore 2012; Young & Fry, 2008; Cooper & Sandi-Urena, 2009; Brown, 1987). For example, Alexander, et al. (1991) describe metacognitive awareness to include one's MDK, MPK and MPK about cognition and cognitive strategies. Summative descriptions of these subcomponents with examples are given in Table 2.4.

The categorisation of metacognition awareness/knowledge as MDK, MPK and MCK appears to have more distinct subcomponents, without the high degree of overlapping which was possible with the classification of the subcomponents as knowledge of tasks and knowledge of strategies which occurs in the previously discussed categorisation. MDK refers to a more diverse awareness than how declarative knowledge is used in other areas of literature, e.g., declarative knowledge often refers only to facts and information about a phenomenon (Miller & Hudson, 2007). MDK describes the awareness of one's own knowledge of facts but importantly it also includes one's awareness of one's cognitive processes and cognitive processes in general, e.g., when related to a specific task, awareness of one's ability to visualise rotating a molecule of ethanoic acid in one's head, or one's ability to see how an understanding of electronegativity allows one to understand several chemical phenomena in chemistry. MPK describes one's ability to implement a cognitive process, e.g., being able to visualise ethanol and understand how the electronegativity of atoms within the molecule influences its polarity. MCK refers to one's awareness of 'why' and 'when' to implement a cognitive process, e.g., 'when' and 'why' to visualise a molecule as part of understanding a chemical phenomenon, or 'when' and 'why' to apply one understanding of the relative electronegativity of atoms would help one's understanding of the polarity of a molecule and how it reacts.

Table 2.4 Metacognitive awareness/knowledge – Metacognitive declarative knowledge, procedural knowledge, conditional knowledge

Sub-component	Description	Examples
Metacognitive declarative knowledge (MDK)	Refers to epistemological understanding, or the student's understanding of thinking and knowing in general. Knowledge of one's skills, intellectual resources, and abilities as a learner	Knowing that one is good at remembering facts / or one is good at drawing. One's knowledge of the role of electronegativity in polar bonding.
Metacognitive procedural knowledge (MPK)	The application of knowledge for the purposes of completing a procedure or process. Knowledge about how to implement learning procedures (e.g., strategies). Procedural knowledge refers to knowing "how" to do things.	Knowing how to use the periodic table to find the atomic number of an element. Breaking long term goals into subgoals.
Metacognitive conditional knowledge (MCK)	Conditional knowledge refers to knowing the "why" and "when" aspects of cognition. The determination under what circumstances specific processes or skills should transfer. Knowledge about when and why to use learning procedures	Skim a chapter in a chemistry book because it gives the gist but does not require a lot of time; read a chapter of a textbook carefully to gain an understanding.

(compiled from Schraw et al., 2006; Ford & Yore, 2012; Young & Fry, 2008; Cooper & Sandi-Urena, 2009; Brown, 1987)

2.3.2 Metacognitive regulation

While metacognitive awareness is focused on one's awareness of one's cognitive processes, metacognitive regulation relates to the employment and control of one's cognitive processes. Metacognitive regulation involves controlling one's cognitive processes, including the management of learning, e.g., making changes to how one visualises or understands as a result of monitoring (Flavell et al., 2002; Whitebread et al., 2009). Metacognitive regulation is also described as the processes used to guide, monitor, control and regulate cognition (Schraw & Moshman, 1995; Veenman, 2012). For example, one might realise that memorisation is not achieving the results one estimated, so one decides to try a different cognitive process e.g. visualisation. The three common subcomponents of metacognitive regulation; MP, MM, and ME and examples are outlined in Table 2.5 (Flavell et al., 2002; Veenman, 2012; Cross & Paris, 1988; Paris & Winograd, 1990; Schraw et al., 2006; Whitebread et al., 2009; Wang, 2015).

Table 2.5 Metacognitive regulation - planning, monitoring and evaluation

Sub-component	Description	Example(s)
Planning (MP)	Involves setting goals, selecting appropriate strategies, making predictions, strategy sequencing and allocating resources before beginning a task, activating relevant background knowledge	When one formulates the goal of an assignment or problem, and decides which steps are needed to get the answer. For a calculation, plan the step-by-step successive calculation operations. For studying a text, the approach to reading the text can be devised beforehand
Monitoring (MM)	Overseeing of one's own cognitive processes which involves awareness and assessment of comprehension and task performance and progress towards the desired goal	In relation to a calculation, one checks whether every step has been calculated correctly and whether one has made any careless mistakes. In relation to a reading assignment, the student checks at every sentence or paragraph if they understand the contents well.
Evaluation (ME)	Entails an assessment of the products and efficiency of one's learning and thinking, for example through self-checking, reflection and re-evaluation, reviewing task performance, learning processes and learning products	In relation to a calculation, one compares the outcome of the calculation to one's initial estimate or does a recalculation. In relation to a reading assignment, one summarises the text in one's own words after having read it. One then decides whether the conclusion is plausible.

(compiled from Flavell et al., 2002; Schraw, et al., 2006; Schraw & Moshman; 1995; Veenman, 2012; Cross & Paris, 1988; Paris & Winograd, 1990; Whitebread et al., 2009; Wang, 2015).

Evidence of metacognitive regulation during a task includes following a plan or deliberately changing that plan, monitoring, checking, note-taking, and time and resource management, while at the end of a task, activities such as evaluating performance against the goal and reflection on the learning process are evidence of metacognitive regulation. The function of these activities is to guide and control the execution of the task at hand, evaluate and interpret the outcome, and to learn from one's cognitive processes for the future (Veenman, 2012).

2.3.3 Self-regulated learning and metacognition

As part of his social-cognitive theory, Bandura (1986) claimed that self-regulated learning (SRL) has three elements: personal, behavioural, and environmental. There is confusion in the literature regarding the relationship between and the use of *metacognition* and *SRL* (Pintrich et al., 2000). Metacognition is the "older" term defined and used in the late 1970s and into the 1980s by developmental and cognitive psychologists (Pintrich et al., 2000). Beginning in the mid-1980s and continuing into the

1990s the construct of self-regulated learning was proposed by educational and developmental psychologists to refer to the various ways individuals monitor, control, and regulate their learning (Schunk & Zimmerman, 1994; Zimmerman, 1986). Researchers have applied Bandura's (1997) social cognitive theory to school learning. These attempts led to the development of self-regulated learning theory which contends that learning is governed by a variety of interacting cognitive, metacognitive, and motivational components (Butler & Winne, 1995; Zimmerman, 2000).

Theories of self-regulated learning argue that learners should engage in both cognitive and metacognitive processes (Boekaerts, 1997; Nelson & Narens, 1994; Winne, 1995; Zimmerman, 2008). These processes differ in terms of both their object and function. Self-regulated learning (SRL) involves a combination of cognitive strategy use, metacognitive control, and motivational beliefs (Schraw, et al., 2006; Dori & Avargil, 2015). SRL is generally believed to include metacognitive knowledge/awareness, metacognitive regulation (Pintrich et al., 2000; Alexander, 1995; Boekaerts, 1995; Corno, 1995; Pressley, 1995; Schunk, 1995; Schunk & Ertmer, 2000; Winne, 1995; Azevedo, 2009). According to Pintrich et al. (2000) self-regulated learning (SRL) is an active, constructive process whereby students set goals for their learning and then attempt to monitor, regulate, and control their cognition, motivation, and behaviour guided and constrained by their goals and the contextual features in the environment, hence SRL is inclusive construct and subsumes metacognitive regulation. However, most of the models of self-regulated learning assume that the processes of monitoring, controlling, and regulating are related to, if not dependent on, metacognitive knowledge/awareness about the self and cognition (Pintrich & Garcia, 1994).

An important part of developing independent learning in students is fostering self-regulation; Kallio et al. (2021) argue that students' self-regulated learning is a central goal of education, helping students understand how they learn and take responsibility for their learning. Metacognition is part of one's self-regulatory skills, hence by its very nature metacognition involves the self-regulation of one's cognitive processes. Borkowski (1996) argues self-regulation represents the highest level of metacognitive activity. Zimmerman (2000, 2002) describes self-regulation as self-generated thoughts, feelings, and behaviours that are oriented to attaining goals by which learners transform their mental abilities into academic skills. Similar to developing other learning skills,

pedagogy which promotes self-regulating is important as it is viewed as an activity that students do for themselves in a proactive way (Zimmerman, 2000). Borkowski (1996) and Winne (1996) describe self-regulated learning as a metacognitively governed process aimed at adapting the use of cognitive processes to tasks. Dinsmore et al. (2008) argue that metacognition is closely aligned to self-regulation and has been implicated as a distinguishing factor of 'expert students'. Metacognition links to advanced self-regulation are evident, as one needs to have awareness and control of one's cognitive processes before addressing cognitive aspects of self-regulation.

For clarity, in the current research, SRL includes monitoring, controlling, and regulating cognitive processes (metacognition), but also monitoring, controlling, and regulating other factors that can influence learning such as motivation, volition, effort, and the self-system (Pintrich et al., 2000). Sperling et al. (2004) argue that there is limited knowledge about the relationships among metacognition and other self-regulated learning constructs, such as strategy use and motivation. Therefore, and again for clarity, my research and interest focus is on the metacognition in chemistry education, and I consider metacognition to be a subset of SRL.

As discussed in this section, there exists a considerable body of literature on theoretical explanations of metacognition and related cognitive processes like awareness of critical thinking, and the existence of two main components of metacognition, (i) metacognitive awareness/knowledge, (ii) metacognitive regulation. Literature exists which also suggests metacognitive awareness contributes to successful problem solving over and above the contribution of IQ and task-relevant strategies (Alexander, et al., 1995; Swanson, 1990). Since teacher and learner cognitive processes are central to chemistry education, it follows that one's awareness and regulation of one's cognitive processes should also be a central aspect of chemistry education, where metacognition is necessary for effective learning for individuals; the following sections discuss metacognition in science teaching and learning, and its specific relevance in chemistry education.

2.4 Metacognition in chemistry teaching and learning

Fleming, et al. (2012) argue that science is a quintessentially metacognitive activity; it continually questions itself, probing and testing the robustness of conceptual knowledge. Metacognition makes a unique contribution to individual students' learning performance in science, and supplements that produced by conceptual knowledge through the

student's awareness and regulation of their own cognitive processes and use of conceptual knowledge (Zohar & Barzilai, 2013). Previous research suggests that metacognitive instruction and reflective activities may promote students' attitudes toward science, enhance their learning experiences and strategies, and shape their self-perception as science learners at both second level and third level science education (Georghiades, 2004; Gunstone, 1992; Adey & Shayer, 1994; Young & Fry, 2008). Conversely, students' learning experiences and attitudes toward science can also influence their tendency to engage in metacognition (Akerson & Donnelly, 2008; Anderson et al., 2009; Lopes et al., 2011; Sandi-Urena et al., 2011). Metacognitive instruction also promotes scientific literacy by improving concept durability and the transfer of scientific knowledge from school to outside the classroom (Ormrod, 2011).

Chemistry is the study of the composition, structure, properties, and reactions of matter particularly at the submicroscopic level (atomic and molecular level). Metacognition is of particular importance in chemistry education, due to the abstract nature of many concepts in chemistry, especially the submicroscopic level. Despite this, in a review of studies on metacognition for science education conducted by Avargil et al. (2018), only 19.2% of the papers surveyed were in chemistry education, with a similar figure (15.2%) appearing in a review conducted by Zohar and Barzilai (2013).

Several researchers have specifically emphasised the relevance of metacognition in chemistry education (Rickey & Stacy, 2000; Crippen, et al., 2005; Francisco, et al., 1998; Tsai, 2001; Cooper, et al., 2008; Cook, et al., 2013). Rickey and Stacy (2000) describe metacognition as a key to deeper, more durable, and more transferable learning in chemistry. In a review on the use of internet-assisted activities that enhance metacognition, Tsai (2001) describes metacognition as required to achieve mastery of chemistry as a discipline. In the study of an instrument designed to assess the use of metacognition in chemistry problem solving, Cooper and Sandi-Urena (2009) agree that metacognition is fundamental in achieving understanding in chemistry. My own belief in the importance of metacognition in understanding chemistry is in agreement with this previous research, and in particular Rickey and Stacy (2000). I see chemistry as subject matter which involves a significant degree of different cognitive processes (e.g. understanding, learning, visualising) related to abstract concepts (e.g. orbitals, electron clouds etc.) at the submicroscopic level, hence being aware of and controlling our

cognitive processes in relation to such concepts must be central to chemistry teaching and learning.

As part of a developed framework for understanding and improving teacher skills in creating learning environments, Crippen, et al. (2005) describe an interactive compensatory model of learning which includes cognitive ability, knowledge, strategy, metacognition, and motivational components and they argue that each component contributes directly to learning in chemistry. In agreement with Crippen et al., (2005) I argue that metacognition and motivation play an important part of learning in chemistry, but link to this is the development of the students' confidence in, and awareness of, their own cognitive processes at a point in time as a basis to for learning in chemistry. Francisco, et al. (1998) argue that presenting material in different ways (lecture, concept mapping, class discussions, group work), reinforces the concepts in chemistry and they claim fosters the metacognition necessary for understanding chemistry. Reviewing this argument by Francisco, et al. (1998), the different ways of presenting material are known as good teaching strategies in general, therefore the distinguishing factor of metacognitive teaching and learning strategies must involve the addressing of metacognition as part of the processes embedded.

In chemistry, students or teachers do not directly see submicroscopic chemical phenomena or the chemical concepts which give rise to them, in what Reisberg (1997) describes as 'visual imagery', the mental production of an image of an object in its absence. As such, due to the submicroscopic nature of chemical phenomena, I believe that teaching and learning strategies should focus on developing metacognition related to how students visualise chemical phenomena.

2.5 Visualisation and representation in chemistry

This section discusses visualisation, modelling, and representation to provide context for their relevance to metacognition in chemistry and to this research. There is an overlap in the descriptions of 'visualisation' and 'representation' in the literature and this is also discussed in this section. A number of interpretations of visualisation exist in the literature, and visualisation has been defined as both mental images and images visible to the human eye. The difference arises out of the use of the word 'visualisation'; if 'visualisation' is taken to be a verb, then it means to visualise something is to mentally act on it, whereas if 'visualisation' is taken as a noun, a visualisation is that which can be

accessed by others e.g., a diagram (Gilbert, 2005). Gilbert (2005) describes two interpretations of visualisation, (i) visualisations as the understanding or, the meaning attributed to, an internal mental representation, and (ii) visualisation as a representation which others can access in either material, object, visual or symbolic form. The former explanation is the interpretation used in this work. Hence, visualisation can be interpreted as the creation of internal mental images, therefore as with other mental processes, it is possible to be aware of and control the visualisation.

In the interests of clarity, I use the term ‘representation’ to refer only to external representations observable by others, and of particular importance to me is the representation of one’s visualisations and understanding of chemical phenomena. While I use the term ‘visualisation’ to refer to one’s imagination of a chemical phenomenon or internal mental images which are not observable by others. This is further discussed as part of the development of my conceptual framework for this work in Section 6.6.

2.5.1 Visualisation

Visualising is a cognitive process involving visual (mental) imagery, visual memory, visual processing, visual relationships, visual attention and visual imagination (Kosslyn, 1994). Visualisation plays a major role in the study of chemistry through ideas of molecules, atoms, and subatomic particles, and the relationships between them (Hoffmann & Laszlo, 1991). The idea that chemical knowledge and understanding of our world is generated, expressed, taught, and communicated at the macroscopic, the sub-microscopic, and the symbolic levels, has been one of the most powerful ideas in chemical education in recent decades (Talanquer, 2011; Gabel, 1999; Gilbert & Treagust, 2009; Johnstone, 1982, 1991). One of the essential characteristics of understanding chemical phenomena is the constant interplay between the macroscopic and submicroscopic levels of thinking and visualising (Bradley & Brand, 1985). Metacognition is particularly important for chemistry learning because understanding chemistry concepts requires the conscious interrelation of macroscopic, the sub-microscopic, and the symbolic levels of chemical phenomena (Dori & Sasson, 2008).

In agreement with my own belief described earlier, Jones and Kelly (2015) argue the most fascinating level of chemistry is that which explores the complexities at the submicroscopic level. The chemists’ sub-microscopic level is an unobservable world, accessible only by imagination (Bucat & Mocerino, 2009). Imagination (forming new

ideas, or images or concepts of external objects which may not be present to the senses) is such a key component of rich student understandings of chemical phenomena that its significance cannot be underestimated. Personal construction of knowledge is supported by what is known of how the brain deals with optical phenomena, for example, by the evidence that visual perception and visual imagery involve similar mental processes and that they are mutually supportive (Reisberg, 1997). A chemist can visualise a chemical reaction on the macroscopic level, what the reaction will look like to the human eye in the laboratory, and on the submicroscopic level, what changes are taking place in the atoms and molecules (Williamson, 2015). Bucat and Mocerino (2009) argue for the importance of raising our students' consciousness of imagination in order to develop their visualisation abilities. The high value placed on the cognitive process of visualising chemical phenomena as described above is in line with my own beliefs, however both teachers and students can use '*representations*' to share aspects of their visualisations and other cognitive processes related to chemical phenomena.

2.5.3 Representations in chemistry

An external representation of an individual's visualisation in chemistry through the use of diagrams can provide a window into the mind's eye of a students' or teachers' cognitive processes, particularly related to the submicroscopic level of chemistry. This provides insights and awareness of one's cognitive processes and use of knowledge in relation to a chemical phenomenon for others, which is an important part of metacognitive modelling and thinking aloud. In addition, I believe representations provide opportunities to develop metacognition as it increases awareness of one's own cognitive processes (e.g. visualisations, understanding) in relation to a chemical phenomenon, by making us convert our cognitive processes into an external representation. As such representations of visualisations of chemical phenomena (e.g., a reaction at the submicroscopic level) can be powerful as they can provide tangible evidence of one's cognitive processes while they also provide opportunities for further thought by oneself and others. This exemplifies the possible power of representations in chemistry education.

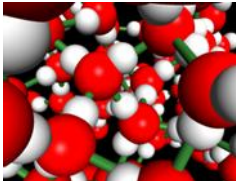
Through the generation and refinement of representations, students visualise the connections between representations and relevant concepts, and this provides students with opportunities to actively choose a representation suitable for different stages of understanding (Wu & Shah, 2004). Given students' difficulty translating between

representations and the fact that different chemical representations emphasise different aspects of chemical concepts and correspond to different chemical entities, this principle is likely to be particularly important for chemistry (Harrison & Treagust 2000). Chemistry has many important concepts that are primarily or partially understood in terms of entities that are not accessible to direct experience: molecules, ions, electrons, orbitals, etc (Johnstone, 1982). Hence students have to construct their own understandings, which become sufficiently similar to that intended to allow meaningful communication and understanding in chemistry. All of this depends upon teachers and students being able to represent their cognitive processes in ways that others can interpret. Non-verbal forms of representation are extremely valuable in teaching and learning of chemistry, not simply because an image can succinctly represent what would require a long verbal description, but also because the human cognitive architecture tends to use imagery and words as complementary - so working memory is considered to have distinct buffers for visual and verbal information (Baddeley, 2003).

Chemists have developed a variety of representations, such as molecular models, chemical structures, formulas, equations, and symbols (Hoffmann & Laszlo, 1991). Several studies suggest a full understanding of a chemical phenomenon involves the ability to move fluently between three levels of representing it, namely (i) the macroscopic level (ii) the submicroscopic level (iii) the symbolic level (Johnstone, 1991; Gabel, 1999; Treagust & Chittleborough, 2001). Table 2.6 describes each of these three levels of representation in chemistry suggested by Johnstone (1991) and known as “Johnstone’s Triangle” or “chemistry triplet”.

An analysis by Talanquer (2011) of the chemistry triplet reveals that the components of the chemistry triplet are referred to in various ways by Johnstone and by other authors e.g. levels of thought (Johnstone, 1991), components or modes (Johnstone, 1993), and forms of the subject matter (Johnstone, 2000), levels of description (Gabel, et al., 1987), levels of teaching (Gabel, 1993), and levels of representation (Gabel, 1999).

Table 2.6 Representations of the *Chemistry Triplet*

Macroscopic level	Submicroscopic level	Symbolic level
This is a representation of what is met directly during observational experience in the laboratory and everyday life.	This is the representation of the inferred nature of chemical entities (as atoms, ions, or molecules) and the relationships between them. These representations are expressed in the concrete, visual, or verbal, modes.	This is the representation of the identities of entities (atoms, ions, or molecules), for example those involved in a chemical reaction (producing a 'chemical equation') or of the quantitative relationships between them (producing a 'mathematical equation', for example in calculating equilibrium constants).
		$\text{H}_2\text{O}_{(l)}$

(Submicroscopic image from Wellings, 2007)

A view that has become more dominant in recent years describes the components of the triplet as levels of representation (Gilbert & Treagust, 2009). A necessary condition for students to understand a representation in chemistry, i.e., be able to interpret specific aspects of a representation of the submicroscopic, symbolic and macroscopic level, is that the conventions of representation should be both stated and adhered to by the generator i.e., teacher or student. A sufficient condition for students to understand a representation is that they have explicitly learned these conventions (Gilbert, 2005).

The necessary thought and representation of a chemical phenomenon at the submicroscopic level are of particular importance. A representation by a student or teacher at a submicroscopic level must unavoidably be accompanied by a degree of associated thinking and visualising of the chemistry at the submicroscopic level as long as they are generating the representation using their own conceptual knowledge. Wu & Shah, (2004) argue further opportunities for thinking and visualising of chemistry at the submicroscopic level could be achieved through explaining, revisiting and manipulating representations generated by the teacher or the student at the submicroscopic level.

Harrison and Treagust (2002) point out that for many second level students, and even for some second level science teachers, their understanding of sub-microscopic level is poor.

Research shows that many second level and third level students, and even some teachers, have difficulty transferring from one level of representation to another (Gabel, 1998).

Tytler et al. (2013) argue for a particular approach to guided inquiry in science learning with a strong emphasis on student generated representational work through sequences of representational challenges accompanied by negotiation and refinement of the produced representation. Refinement of representations can follow e.g., a lapse in time, further thinking, discussion with another, further reading, etc. Tytler et al. (2013) argue there is an impressive range of research findings on conditions that enable students to learn from interpreting and interacting with expert representations, but research on productive use of student's own representations for learning is less developed. They argue that shifting the role of the learner from being just a receiver and interpreter of representations, to being a generator and refiner of representations, is an important development. The results of a thematic review by Tippet (2016) suggests that both interpreting and constructing representations can lead to a better understanding of science concepts, however more research is needed on learning 'with' rather than 'from' representations. Prain and Tytler (2012) suggested that representational construction affordances might provide a framework to explain how learning is enhanced with representations. Through the development in the AR cycles, my work examines the opportunities that can arise for development of awareness and regulation of cognitive processes from the use of representations in chemistry.

Recent empirical research has provided evidence for the important role of representational or visualisation competence in modelling practices and started to propose and investigate the core representational competences needed for different topics of scientific modelling (e.g., Chang, 2018; Griffard, 2012; Halverson & Friedrichsen, 2012). As discussed in Chapter 1, the term modelling is not used in this thesis as it can describe both internal modelling and external modelling. Introducing the term may confuse the distinction drawn in this research between representations (external, observable by others) and visualisations (internal, unobservable by others).

2.5.4 Chemistry and metavisualisation

Gilbert (2005) suggests that 'metacognition in respect of visualisation' can be referred to as 'metavisualisation'. Locatelli, et al., (2010) argue that it is possible and necessary to develop a metavisual capability in all levels and modes of representation to really

understand concepts in chemistry. Gilbert (2005) proposes several requirements that we should consider when we deal with chemistry instruction's environments and calls for more research in this area in order to give comprehensive explanations about these issues. For example, according to Gilbert (2005), for students to become metacognitively capable in visualisation, they should:

- (i) know the conventions of macroscopic, symbolic and submicroscopic representations that they generate or observe; and
- (ii) know the scope and limitations of what aspects of the macroscopic, symbolic and submicroscopic can and cannot be represented.

Locatelli, et al., (2010) assume visual thinking as a background for concept thinking if we consider that mostly all phenomena in chemistry education are related with students' imagination particularly due to the submicroscopic level of chemical reactions (Locatelli, et al., 2010; Gilbert, 2008). Locatelli, et al., (2010) recommend a substantial amount of research is required in this area in order to better understand the processing of metavisualisation and its importance in learning in general.

2.6 Teachers' metacognition

Metacognition is an important aspect of education reforms (e.g. OECD, 2018; DES, 2015; NCCA, 2023a); hence metacognition must also be central to teacher education. Teacher cognition has long been a research focus in education (e.g., Wittrock, et al., 1986). Similarly, teacher knowledge and teachers' use of discipline knowledge in teaching and pedagogical knowledge have received much attention (e.g. Munby, et al., 2001). It has been suggested that effective teachers are 'more metacognitive' or possess 'adaptive metacognition' which involves both the adaptation of self and environment in response to classroom variability (Duffy et al., 2009; Lin et al., 2005; Manasia, 2015). Teachers' understanding of metacognition can be interpreted as their theoretical knowledge of metacognition as a concept, including its subcomponents. However, teachers' knowledge of metacognition could also relate to their own metacognition as applied, and how they understand student metacognition in the context of their subject. Therefore, it is possible that while a teacher may be able to define metacognition and its subcomponents, they may not be able to implement or model metacognition in a meaningful way. Kallio et al. (2021) argue that teachers require knowledge of metacognition i.e., how do they reflect themselves, where should they pay attention and

what should they develop, while students require knowledge of metacognition when aiming for success in learning outcomes, further studies, and employment. Teachers need to know their own abilities in this area before they can help their students to improve their use of metacognition. Ryan (2014) argues that in order to facilitate the transfer of students' thinking to other areas of learning, teachers must first be aware of the thinking the students engage in, and that this requires a sound understanding of metacognition. There is also a dispositional aspect to being metacognitive in teaching (Duffy et al., 2009). That is, to be an effective teacher, one must be disposed to being thoughtfully adaptive in response to complex and unanticipated problems that arise in one's own thinking, or the thinking of students (Melothe & Deering, 1999). Seraphin et al. (2012) argue that if teachers become more metacognitive it could help both teachers and students understand the complex nature of the scientific process and participate in the discipline of science.

Prytula (2012) argues that teacher metacognition significantly affects the procedure of teaching and student learning, while in agreement Hartman (2001) argues that the method to maximise instructional effectiveness was 'teaching with metacognition'. In order to teach metacognition successfully, science teachers need sound knowledge of metacognition as well as sound pedagogical knowledge in the context of teaching metacognition (Zohar & Barzilai, 2013).

Seraphin et al. (2012) introduced metacognitive strategies into their '*Teaching Science as Inquiry pedagogical framework*' for professional development courses for teachers as a way to help teachers bridge inquiry and pedagogy in the implementation of curriculum and content in the classroom. As part of this framework, teachers are taught to help students evaluate and decide which inquiry techniques to use during their investigations; metacognitive strategies were scaffolded, beginning with explicit discussions of metacognition and building towards automatic, internalised practice of metacognition in both teachers and students. From evaluations, they suggest that teachers' metacognitive abilities were enhanced by scaffolding metacognitive skills, starting with reflection and recognition of the complex process of science and building towards an application and regulation of their behaviour. Seraphin et al. (2012) argue that teachers need to be supported and taught metacognitive strategies, but they also need sufficient time to

practise these strategies in professional development courses before they are asked to teach them to their students.

Zohar and Barzilai (2013) conducted a review in the field of metacognition in science education and they argue that there are very few studies of pre-service and in-service teachers' knowledge and professional development regarding metacognition. A large body of research which addresses various components of teachers' knowledge and distinguished between subject-matter knowledge, general pedagogical knowledge, and pedagogical content knowledge (Shulman, 1987; Wilson et al., 1987; Verloop et al., 2001; Wolffe et al., 2021). However, since the classic discourse in this area usually applies to teaching subject matter rather than metacognition, the meaning of these components of teachers' knowledge is not straight forward when teachers try to incorporate metacognition (Zohar & Barzilai, 2013). According to Zohar and Barzilai (2013), in order for teachers to have a sound knowledge of metacognition, they need to have (i) a general theoretical knowledge about metacognition, especially to be familiar with and to understand definitions of the concept of metacognition and its various components; and (ii) the personal ability to practise metacognitive thinking with respect to classroom activities. Hence, they argue that teachers need to understand metacognition and to practise metacognition with respect to the varied, context-specific intellectual activities that take place in the classroom. For example, when teaching a thinking strategy, teachers' need to have the required metacognitive knowledge while also being capable of verbalising that knowledge using adequate 'language of thinking' (Tishman & Perkins, 1997; Tishman, et al., 1995). The shared language of thinking in chemistry should reflect the three levels of representation of chemical phenomenon, that is the macroscopic, submicroscopic and symbolic levels, so that students might consciously and appropriately structure their chemistry understanding and improve their chemistry learning processes (Davidowitz & Chittleborough 2009; Thomas & Anderson, 2014).

Teachers also need the ability to skilfully think about planning, monitoring, controlling, and evaluating cognitive processes during classroom activities (Zohar & Barzilai, 2013). Teachers' own metacognition and metacognitive pedagogical knowledge in the context of teaching are still areas of research which are less studied, compared with research on students' metacognition (Schraw & Dennison, 1994; Bransford, et al., 2000; Tanner, 2012; Thomas 2012; Kallio et al., 2021). In line with this, there is an emerging theory

practice gap which highlights the value of metacognition for science learning but research on attempts to bring metacognition into ordinary classrooms and science teacher education are rare (Georghiades, 2004, Thomas, 2012; Kallio et al., 2021).

2.6.1 Metacognition and the learning environment

Williamson (2015) argues that traditionally, chemistry at all educational levels has been taught as a mathematical course that emphasised algorithmic problem solving almost exclusively. In metacognitively-oriented learning environments, teachers have expectations that in addition to students thinking about the material to be learned, they will also think about how they learn the material, their difficulties in learning such subject material, and how they could improve their learning of that material and so become better learners (Thomas, 2003). To develop metacognition there is a need to establish a social climate in which students feel that it is legitimate and beneficial to express concerns about any impediments to learning and in which students can discuss these with the teacher (Taylor, et al., 1994). Changing the classroom environment can be difficult; Sternberg (1998) noted that students might not be too enthusiastic about engaging in developing metacognition, especially if they have been rewarded over the years for rather passive and mindless learning. Nuthall (2005) highlights practices in the visible cultural context of the public teacher-managed activity routines and rules, for example the ‘question-answer-comment sequence’, where a fixed pattern has been identified in a multitude of countries and that it arises from ‘Ritualised Routines’. These routines dictate certain roles and limitations where students and teachers alike negotiate the most expedient approach to arrive at the desired answer (Nuthall, 2005).

Findings in literature highlight the effect of the goal orientations that teachers promote in the classroom (Ames & Archer, 1988, Graham & Weiner, 1996; Schraw, 1998). For example, placing an emphasis on performance may lead to environments which only focus on students proving their competence (Midgley, et al., 1995). In contrast, focusing on increasing students’ current level of performance, rewarding increased effort and persistence and strategy use, may create a metacognitive environment where the goal is on students improving their own competence. One potential advantage of classrooms that promote such an environment is that students may acquire a broader repertoire of strategies, may be more likely to use strategies, and acquire more metacognition in using strategies (Schraw et al., 1995).

Driver et al. (1994) suggest that students' reasoning and their metacognition might be considered as a consequence of the practices of the community within which they learn to reason, rather than as a deficit that reflects their individual capabilities. In addition to this, Thomas (2002) has argued that students' metacognition is socially mediated, and that the nature of the classroom learning environment is an important factor influencing the development of students' metacognition. Hence, it could be argued that pedagogical approaches which lead to discussions form part of incorporating metacognition into classrooms. Teachers need to incorporate events into classroom environments that provoke metacognitive awareness in students (Thomas & Anderson, 2014; Flavell, 1979).

2.6.2 Metacognitive teaching and learning strategies

Teaching and learning strategies which promote student metacognition have been reported across a range of subject areas. Within the fields of reading, mathematics and problem-solving it has been reported that metacognitive training and instruction had positive effects on students' performance (e.g. Kramarski & Mevarech, 2003; White & Frederiksen, 1998; Zohar & Ben-David, 2008). Metacognitive instruction is applied with the aim of improving students' metacognitive thinking, for improving students' skills (such as reading skills, problem-solving skills or higher-order thinking skills) or for improving students' knowledge and conceptual understanding (Zohar & Barzilai, 2013). Teaching metacognition is considered one of the main three recommendations for improving instruction that emerged from over three decades of research about how people learn (Bransford, et al., 2000). Historically, classroom teaching has been described in procedural terms, where certain routines and behaviours are repeated over and over (Nuthall, 2005). Based on the results of process-product research from the 1970s, certain routines, such as well-managed lessons that include introductions, detailed description of content, teacher-directed questions, and independent practice are strongly associated with students' achievement (Brophy, 2006). Brophy (2006) argues such routines can be considered the "What works?" view of teaching. The drawback to this approach is that it assumes that improved classroom teaching is limited to procedural methods and techniques when, in reality, classrooms produce unpredictable situations requiring something beyond established procedures (Brophy, 2006). While the role of routines in teaching is reasonable up to a point, research conducted since the 1970s has revealed much more sophisticated dimensions of effective teaching such as promoting cognitive

conflict, and development of metacognition (Brophy, 2006). Carter (1990) describes teachers and teaching using terms such as ‘thoughtfulness’, ‘decision-making’, and ‘thinking-on-one’s feet’. Close examination of teachers in classrooms suggests that while teachers do employ routines and procedures ‘that work’, they also engage in complex mental activity that goes well beyond procedural application. In the context of senior cycle chemistry, such complex mental activity could include development of the teachers’ own metacognition, while also having consciousness of the metacognitive aspects of teaching and learning strategies which improve student understanding of chemical phenomena.

Seraphin and Baumgartner (2010) argue that metacognition facilitates the process of teaching and learning science in a multidirectional, authentic way because it encourages students to become aware of their cognitive processes and mirror the behaviours of professional scientists. Cook, et al. (2013), describes strategies which directly use metacognitive skills, such as paraphrasing and rewriting, preview-attend-review-study-assess study cycle, group study, and students teaching other students. Metacognition teaches students that learning is a process that requires time; time to make mistakes and learn from them; time to see how one problem is similar to and different from another (analysis); and time for the material to gel (Cook, et al., 2013). Cook, et al. (2013) argue that the students in third level general chemistry are quite motivated to perform well and are ready to try new strategies when the strategies are presented as based on cognitive science research. However, if students are never taught that there is more to learning than recall, they have no way of knowing how to develop higher-order thinking skills (Cook, et al., 2013).

Subject-matter knowledge tends to have a high level of domain specificity. However, because metacognition has both domain-specific and domain-general features, neither the term ‘subject-matter knowledge’ nor the term ‘general pedagogical knowledge’ is appropriate to describe teachers’ pedagogical knowledge in this area. In order to prevent confusion and to delineate the unique nature of metacognition, Zohar and Barzilai (2013) substitute the term ‘subject-matter knowledge’ with the term ‘knowledge of metacognition’. The dual nature of metacognition in terms of its domain generality and domain specificity does not allow a categorisation as either pedagogical content knowledge which tends to be embedded in specific subjects, or as general pedagogical knowledge which tends to be independent of specific subjects (Zohar and Barzilai, 2013).

Avoiding this problem of categorisation, Zohar (2007) addresses teachers' pedagogical knowledge in relation to instruction of metacognition as a teacher's 'pedagogical knowledge in the context of teaching metacognition'.

There is a consensus within the reported literature that in order to teach metacognition successfully, teachers who have the pedagogical knowledge in the context of teaching metacognition use numerous teaching strategies. Teaching and learning strategies which are identified as addressing metacognition also address many other aspects of teaching and learning. The determining factor of whether a strategy is metacognitive or not often depends on how it is implemented. The main metacognitive teaching and learning strategies reported are summarised in Table 2.7 (Zohar & Barzilai 2013; Brown, et al., 1984; Tishman, et al., 1995; Veenman, et al., 2006; Zohar & Ben-David, 2008; Wang, 2015; Cooper et al., 2008).

Table 2.7 Metacognitive teaching and learning strategies

Instructional practice	Description
Explicit instruction	Explanations and demonstrations by the teacher regarding specific cognitive or metacognitive strategies and knowledge construction activities which require learners to construct their metacognitive knowledge.
Metacognitive prompts	Metacognitive cues, questions or checklists that are used by the students during activities such as problem-solving, experimentation, inquiry learning, reading science texts, writing reports and reflections, or discussing science topics.
Metacognitive modelling by the teacher	Refers to activities in which the teacher demonstrates how they activate and apply metacognitive knowledge and metacognitive skills in the course of learning, in order to model these practices for students.
Concept mapping and other visual representations	The use of concept maps, graphic organisers, flowcharts, and additional visual representations in order to help learners represent and share their thinking and learning. Concept maps used in order to help learners reflect on changes in their conceptual understanding, annotated drawings used in order to help learners think about their conceptual understandings, graphs used in order to help students monitor their scientific inquiry strategies, and graphic organisers used in order to help learners visualise their thinking.
Reflective writing	Students are asked to write diaries or journals about their thinking and learning, reflective essays, or written responses to reflective prompts.
Practice and training	Repeated training and practice which provide opportunities for activating and applying metacognitive awareness and metacognitive regulation in multiple tasks, problems and contexts.
Teacher led metacognitive discussions	Whole class and group discussions of thinking and learning processes, discussions in which teachers talked with their students about their thinking and learning in order to encourage and develop metacognitive thinking.
Think aloud protocol	One method used to establish on-the-spot thinking for an individual is the ‘think aloud protocol’, where one verbalises one’s thoughts while completing a cognitive task.
ICT use for metacognitive instruction	Software-based metacognitive scaffolds, as well as use of web-based portfolios and concept mapping software for developing learners’ metacognition.

(compiled from Zohar & Barzilai, 2013; Brown, et al., 1984; Tishman, et al., 1995; Veenman et al., 2006; Zohar & Ben-David, 2008; Reigeluth & Stein, 1983; Swanson, 1984; Henter & Indreica 2014; Wang, 2015; Cooper et al., 2008).

As with many teaching and learning strategies scaffolding often plays an important role. Stone (1993) described a Vygotskian-inspired analysis of scaffolding where learning first takes place on a social (intermental) level before it takes place on an individual

(intramental) level. In Stone's view, the student is not a passive participant in teacher–student interaction but scaffolding is seen as a fluid, interpersonal process in which both participants are active. Both participants actively build common understanding or intersubjectivity through communicative exchange. Because scaffolding is such a dynamic intervention finely tuned to the learner's ongoing progress, the support given by the teacher during scaffolding strongly depends upon the characteristics of the situation. According to Stone (1998), the learner does not literally internalise a support structure or scaffolding interchange but, rather, appropriates the essence of a support structure or scaffolding interchange. I interpret scaffolding as part of metacognitive teaching and learning strategies from its theoretical background in which the student is seen as an active participant (Van de Pol et al., 2010). To stay close to this idea of scaffolding I interpret the metacognitive strategies aiding scaffolding in face-to-face interactions and in particular teacher–student interactions. Two other characteristics of scaffolding include fading or the gradual withdrawal of the scaffolding, and where responsibility for the performance of a task is gradually transferred to the learner (Van de Pol et al., 2010). While fading the support, the teacher can also transfer the responsibility to the student so that the learner will take more and more control over his/her learning.

2.7 Conclusion

This chapter has summarised and discussed aspects of the literature I reviewed before, during, and after each of the five AR cycles in this research, contributing to my scholarly reflection on both theory and practice. This AR describes my work in bringing metacognition into senior cycle chemistry lessons and my practice as teacher educator, which according to previous research is rarely addressed in research (Georghiades, 2004; Thomas, 2012; Lavi, et al., 2019; Kallio et al., 2021). As outlined in Chapter 1, this research addresses the incorporation of metacognition in chemistry education in two studies: a senior cycle study and a preservice chemistry teacher education study conducted through five cycles of AR.

I acknowledged from the planning stages of AR Cycle 1 the challenge I faced was specifically promoting metacognition for students of chemistry using metacognitive teaching and learning strategies which, in themselves, are good teaching strategies. The conceptual framework for this work, particularly my interpretation of metacognition in chemistry, was refined through reflection on both theory and practice and is presented and discussed in Chapter 6, Section 6.6.

My development as a researcher is exemplified in the following three chapters, which present the research methodology, methods, and data analysis. The next chapter, Chapter 3, discusses the methodological approach to both the senior cycle study and the PST study.

Chapter 3 Methodology - Research Approach

3.1 Introduction

This chapter describes the focus of this research, the methodological approach, and the research paradigm in this study. The methodological approach taken in this research reveals part of my journey as a researcher, from a natural sciences background with a positivist viewpoint, before embarking on the journey of this research. In line with pragmatism, I see the key being the level of appropriateness of the methodological approach to the research being conducted, and the intertwining of philosophical ideas where possible.

When choosing a methodology to address a research problem, Starks et al. (2007) argue it is important that the researcher selects an approach that aligns with their philosophical assumptions, the study purpose, and the current state of knowledge in the area under investigation. Aligning with this argument, this research was conducted through my philosophical beliefs as a pragmatist (see Section 3.2) and employs an AR methodology (see section 3.3). For clarity, in this thesis the term, ‘student(s)’ is used to identify the senior cycle student(s), while the acronym ‘PST(s)’ refers to preservice chemistry teacher(s).

3.1.2 Focus of the current research and research questions

Occurring at a time of significant change in Irish second level education, where there is an emphasis on embedding the development of student cognition and metacognition as part of Junior and Senior cycle reforms, this research is timely and is focused on my practice and development while investigating the affordances and limitations of metacognitive teaching and learning strategies in senior cycle chemistry and preservice chemistry teacher education in the Irish context. Specific research questions, as well as the examples of data used to address them, are shown in Table 3.1.

Table 3.1 Research questions, relevant data/evidence gathered, and the corresponding AR cycle in the senior cycle study (green) and PST education study (blue)

Senior cycle overall research question What are the affordances and limitations of integrating metacognitive strategies in senior cycle chemistry lessons in the Irish context?			
AR Cycle ()	Sub questions	Data/evidence	Findings Chapter
TY Pilot Studies & fifth-year study (1, 2 & 3)	What metacognitive strategies are particularly appropriate for the incorporation of metacognition in senior cycle chemistry classrooms?	Literature review Observation My reflections	6 & 7
TY Pilot Studies & fifth-year study (1, 2 & 3)	What are the affordances of metacognitive strategies in a metacognitive environment for senior cycle chemistry lessons?	Student generated work; Audiovisual recordings; student discussion; MAI; MSLQ.	6 & 7
TY Pilot Studies & fifth-year study (1, 2 & 3)	What are the affordances of representations for the incorporation of metacognition in senior cycle chemistry lessons?	Student generated representations; observation; student discussion; my prompts; my reflections.	6 & 7
PST study overall research question What is the impact of explicit use of metacognitive strategies on preservice chemistry teachers' (PSTs') awareness and planning in chemistry teaching in the Irish context?			
AR Cycle ()	Sub questions	Data/evidence	Findings Chapter
PST study: Pilot and methodology module (4 & 5)	What is the PST experience of metacognitive strategies in their own senior cycle chemistry experience?	MOLES-S survey Audiovisual recordings Workshop discussion, PST interviews My reflections	8, 9, 10
Pilot and methodology module (4 & 5)	How can a chemistry PST methodology module be designed to incorporate metacognitive strategies in a domain specific way?	MOLES-S survey Audiovisual recordings PST feedback PST interviews	8, 9, 10
Pilot and methodology module (4 & 5)	How can the metacognitive use of representations be embedded in a chemistry methodology module?	Audiovisual recordings PST Assignments My reflections	8, 9, 10
Pilot and methodology module (4 & 5)	What environmental factors are important in providing affordances for metacognition in a chemistry workshop for PSTs?	MOLES-S survey Audiovisual recordings Workshop dialogue and PST interviews, My reflections	8, 9, 10
Pilot and methodology module (4 & 5)	How can the PSTs incorporate metacognition in their planning of lessons?	PST assignments Audiovisual recordings PST interviews after school placement	8, 9, 10

3.2 Researcher paradigm

AR begins with values (McNiff, 2017). As part of the planning phases of this AR, I became conscious of the need to transition into a social sciences researcher, making a purposeful shift in my worldview from what I was used to in the natural sciences, based on objectivism and positivism, toward subjectivism and interpretivism. I realised this move was essential because human beings are at the centre of this research, the students, the PSTs, and in particular myself as the action researcher, and our actions and purposes are not discrete experiments but part of an emergent process of life (Reason, 1997, Reason & Brady 2001, Reason 2006).

I became increasingly conscious that in research which incorporates qualitative approaches, reflexivity takes precedence over reliability and validity (Porter, 2007). Reflexivity involves the process of critically considering how my own actions, beliefs, and values may have influenced both the research situation and its interpretation. This emphasis on reflexivity acknowledges the subjective nature of qualitative research and emphasises the importance of self-awareness in navigating and interpreting the research context (Porter, 2007). In contrast to natural sciences, the phenomena in social sciences, including this research, already possess meaning before the research process begins. This pre-understanding or pre-judgment serves as the foundation for both quantitative and qualitative research, guiding researchers in the selection of research questions and variables (Ma, 2012). Saunders et al. (2009), Johnson and Onwuegbuzie (2004), and Ma (2012) argue that it is impossible to be completely free of our own values and experiences. As part of my own development as an action researcher I became increasingly aware how this can be a strength in research rather than a weakness. Maarouf (2019) argues prior knowledge or perceptions should ideally enhance research by enabling researchers to gain additional insights and explore various aspects of the shared reality.

3.2.1 Ontology

I developed a pragmatic stance in relation to this research, because I increasingly agreed with Kaushik and Walsh (2019), where I believe human actions can never be separated from the past experiences and from the beliefs that have originated from those experiences. I see pragmatism as a worldview that arises out of actions, situations, and consequences, where I am concerned with ‘What works and the solution to problems’. Pragmatism “*is pluralistic and oriented towards ‘what works’ and practice*” (Creswell & Plano Clark, 2011, p. 41), and as such contributed to the selection of the AR methodology

for this research. Morgan (2007) has argued that pragmatism implies that pragmatic research is ‘intersubjective’ which means being subjective and objective at the same time, accepting both the existence of one reality and that individuals have multiple interpretations of this reality. According to Maarouf (2019), there is only one reality that exists in a certain context at a certain point of time, however reality depends on the context to exist and continue existing, which means that changing the context changes the reality and the existence of multiple contexts means the existence of multiple realities. Maarouf (2019) proposed a reality cycle in which social actors perceive reality differently, leading to continuous change: reality is perceived variably by humans; these perceptions influence behaviours; interactions among these behaviours create a new context over time, and this evolving context generates a new reality (Maarouf, 2019). Although these changes in the context happen continuously it does not have an immediate practical effect, however, it creates notable changes in reality after a considerable period of time. As a result, the reality cycle embraces a practical and pragmatic standpoint, presuming that reality remains stable most of the time but undergoes periodic changes (Maarouf, 2019). The interpretation by Maarouf, (2019) provides for the pragmatic researcher, like myself, to switch between the two views of the one external reality and the multiple perceptions of reality in social actors’ minds and thus between the quantitative and qualitative in AR. In relation to affordances in the current research, I see affordances as possibilities for action within an environment as perceived by the observer (Gibson, 1977). A crucial feature of this definition is the link it makes to identity. An individual’s propensity to perceive affordances in any given environment is dependent upon his or her identity. Different people will see different opportunities for action or view them in different ways. In the current research I interpret affordances as possibilities for action/interpretation that an environment or strategy offers to the student/PST, where I acknowledge that what one learns is dependent on, but not determined by the environment or strategy. In addition, while I interpret evidence of student or PSTs metacognition, I am conscious that the evidence or data gathered in this research may be perceived differently by others in other contexts, and that their perception of the evidence may be equally valid.

3.2.2 Epistemology

Epistemology is a way of understanding and explaining how we know what we know (Crotty, 1998). The philosopher Martin Heidegger in particular stresses the importance

of active engagement with things as a means through which knowing occurs. Heidegger (1962) makes the distinction between types of engagement in his terms 'presence-at-hand' (*Vorhandenheit*) and 'readiness-to-hand' (*Zuhandenheit*) (Heidegger, 1962). Engaging with something in a 'present-to hand' way is to observe it from a distanced perspective, Heidegger argues that positivist science engages a 'present-to hand' relationship with the world, attempting to engage with it as an objective onlooker, set apart from the things being studied. He suggests this is only one way of 'knowing', and that there is a kind of knowing that can only be obtained through active engagement. In *Being and Time*, for instance, he writes:

The kind of dealing which is closest 'to us... nor a bare perceptual cognition, but rather that kind of concern which manipulates things and puts them to use; and this has its own kind of 'knowledge', (Heidegger, 1962, p. 95)

Readiness-to-hand is the kind of quality which something, the being of which is about its use, cannot be comprehended by looking at it, it has to be used to be appreciated, which means we only know about something through using it. The notion of readiness-to-hand is appropriate for action researchers when the 'thing' being used is of a non-material nature (Ladkin, 2005). For example, I acknowledge 'Metacognition', as a concept, can only be understood in a limited capacity by considering it cognitively. To fully understand the nature of influence, one must be within its realm, either as the party hoping to be metacognitive, or as the one whose metacognition is being addressed. Examining the 'nature' of a concept such as metacognition then, has limited potential for deepening knowledge unless it is experienced as a lived phenomenon.

A major underpinning aspect of the development of my epistemological beliefs during AR Cycles in this research is that knowledge is always based on experience. One's perceptions of the world are influenced by our social experiences, while each person's knowledge is unique as it is created by her/his unique experiences. Nevertheless, much of this knowledge is socially shared as it is created from socially shared experiences. Therefore, it could be argued that all knowledge is social knowledge (Morgan, 2013). Johnson et al. (2007) argue that pragmatism is an advanced philosophy that provides the epistemology and the logic for combining the quantitative and qualitative methods. Pragmatist epistemology does not view knowledge as reality (Rorty, 1981). Rather, it is constructed with a purpose to better manage one's existence and to take part in the world (Goldkuhl, 2012). Several leading pragmatist scholars have studied the works of Dewey

and offered their view that epistemology essentially draws from Dewey's concept of inquiry which links beliefs and actions through a process of inquiry (see Biesta 2010; Feilzer, 2010; Goldkuhl, 2012; Morgan, 2013; Ormerod, 2006). The data collection in this research incorporates this epistemological stance, drawing on evidence from students, PSTs and my experiences in this AR. Inquiry is one's conscious response in situations in which the course of action is not immediately clear. In such situations, before taking any action, a pragmatist considers the consequences of different actions and the potential benefits of one action over another (Biesta 2010; Morgan 2013). This forms the basis for my reflective practice and learnings during each of the AR cycles.

In the realm of social sciences, including this research, knowledge differs significantly from that in natural sciences, given that a substantial portion of it is inherently unobservable by nature, e.g. one's metacognition. Acknowledging this was an important part of my own development as a researcher. Many variables we encounter in areas such as thoughts, emotions, beliefs, attitudes, and intentions are not external entities that can be measured in the same manner as objects in natural sciences (Ma, 2012). Instead, they need to be expressed in order to be understood. For example, examining non-experimental quantitative methods such as surveys, it becomes apparent that they do not primarily engage with observable knowledge; rather, they predominantly deal with unobservable mental variables, akin to unstructured or semi-structured qualitative interviews. The key distinction lies in quantitative researchers employing quantitative techniques to handle this knowledge source, constraining human responses to a specific set of structured answers to enable measurement (Maarouf, 2019). Likewise, depicting social reality through qualitative observation of human behaviours does not involve unobservable knowledge; rather, it engages with observable human actions, akin to quantitative experimental research. The distinction lies in qualitative researchers focusing on detailed descriptions of these actions. Maarouf (2019) argues the assertion by quantitative and qualitative researchers that they can only accept either observable or unobservable knowledge is essentially a distinction in their perspectives, not a result of inherent observability or unobservability of the knowledge itself. As a pragmatic researcher, I acknowledge that both the existence of a single reality and the significance of social actors' perceptions of this reality may vary. Sometimes, the aim is to describe reality akin to law generalisations for practical benefits, while other times it involves examining social actors' perceptions for a more detailed and profound understanding of

this reality (Maarouf, 2019). Therefore, as a pragmatic researcher I am flexible in employing various methods that suitably align with their research objectives across different sources of knowledge. Following my ontological stance, I shift between objectivity and subjectivity, hence this shift often involves moving between accepting observable and unobservable knowledge (Maarouf, 2019).

3.3 The research methodology: action research

This research follows my practices, development, and my subsequent theorising in relation to my incorporation of metacognition in chemistry. Deciding what counts as good practice (or praxis) involves more than the application of theory or the exercise of skill (Coulter, 2002). Determining what is the right thing to do in the right way at the right time, and actually doing it, involves a particular kind of judgement: phronesis, a term variously translated from Greek into English as ‘prudence’ (Beiner, 1983), ‘practical wisdom’ (Reeve, 1995) and ‘practical judgement’ (Steinberger, 1993). Phronesis is not a form of knowledge or skill derived either from theory or experience that can be applied to accomplish some predetermined end, but an amalgam of knowledge-perception, reason and virtue that enables people both to decide what they should do and to do it. A practitioner aiming to research with phronesis like myself, must not only know what to do; they must do it (Coulter, 2002).

AR has been described as “*a form of science in the realm of practical knowing*” (Coghlan, 2011, p. 55). Central to AR is the rejection of the epistemology that equates knowledge with unmediated objectivity, or with the researcher as a spectator rather than an agent in the reality being dealt with (Greenwood, 2015). From pragmatism, particularly the views of John Dewey and Richard Rorty, AR takes the idea that research cannot construct significant meanings without engaging in practical action, or as Kurt Lewin wrote “*There is nothing so practical as a good theory*” (Lewin, 1943, p.121). AR is an established inquiry methodology that rejects a divide between subjects and objects. Action researchers assert that objectivity as the only process of understanding is “fundamentally wrong” because it supports the “*hegemonic moves of social researchers*” who may only consider their own theories and interpretations as valid (Greenwood, 2015, p. 205). Action researchers argue that many scientific studies can be meaningless for practical experts with a genuine issue to resolve because scientific studies are so reductionist (Baskerville & Pries-Heje, 2015).

I adopted AR as my research involves incorporation of metacognition in a domain specific way in chemistry teaching and learning through a number of cycles of planning, action and observation, and reflection while also aligning with my pragmatic philosophy. According to the Zuber-Skerrit and Fletcher (2007), a good AR thesis should address a real and complex problem while the reflection should be to find out what is the gap in knowledge. Previous authors (Baskerville, 1999; Baskerville & Wood-Harper, 1996) have described AR as originating, in the 1940s, from two distinct strands of action-based social psychology: The work of Kurt Lewin, who developed a field-theory version of AR, and the endeavours of the Tavistock Clinic, that used a similar but independent approach to study human psychology. AR is a dynamic and ongoing process that systematically evolves, continuously changing both the researcher and the situations in which they are involved (Heydenrych, 2001). The natural sciences do not share this double aim: living the dialectic of researcher and researched (Kemmis & McTaggart, 2014), and this arguably is why I held a positivist view of research as a natural scientist before my journey in this research.

AR treats theorists as practitioners and practitioners as theorists, both roles involve theoretical and practical activities (Kemmis & McTaggart, 2014). From this realisation, the concept emerged of a researcher immersing themselves in a human situation, observing and following its natural progression over time. In this approach, the primary focus of research becomes the change process itself. This concept challenges those (including myself) eager to apply hypothesis-testing methods to social research, however, this approach is familiar to anthropologists and sociologists (Checkland & Holwell, 2007). Action researchers can systematically address the improvement of the rationales for their practice and, in this way, can link theory and practice into the one whole as ideas-in-action (Heydenrych, 2001).

AR has demonstrated its worth, with increasing acknowledgement of its breadth as a field of research practice and its depth as a discourse of theoretical insight (Altrichter et al., 2002). While the literature on AR covers various aspects, and it does not have one neat, widely accepted definition, however there is agreement on several key elements (da Cunha, & de Figueiredo, 2002; Altrichter et al., 2002);

(i) It acts on an existing situation with the dual aim of improving it and expanding the knowledge on the subject. In this research I explore the incorporation of metacognition in chemistry as a teacher and teacher educator in the Irish context.

(ii) It possesses a cyclic nature: a number of steps are performed repeatedly. This research follows five cycles in a spiral AR.

(iii) It possesses a reflexive nature: a critical reflection on the research process itself as well as on the results obtained is an important part of each cycle. Reflection forms part of each lesson, PSTs workshops, and overall analysis of data collected in this research.

(iv) It is predominantly qualitative, although quantifications are possible in some situations. The data in this work was substantially qualitative, with additional insights and triangulation drawn from quantitative sources i.e. metacognitive inventories.

3.3.1 Education action research

This research is centrally about what can be learned from my educational practices and development as a teacher, teacher-educator and researcher. Kemmis and McTaggart (1988) make particular reference to educational practices where they define AR as a form of *“self-reflective enquiry undertaken by participants in social situations in order to improve the rationality and justice of their own social or educational practices and the situations in which these practices are carried out”* (P.5).

Relevant to my practice as an educator and understanding as a researcher, educational AR attempts to intentionally remove the division between researchers/scientists, on the one hand, and educational practitioners, on the other (Brock-Utne 1980). This is a division of which I was acutely aware before carrying out this research.

Educational AR has its foundations in the writings of John Dewey who believed that professional educators should become involved in community problem-solving. Bassey (1998) describes educational AR as an inquiry which is carried out to understand, to evaluate and then to change, to improve some educational practice. Heydenrych (2001) defines educational AR as a deliberate, critical, and emancipatory enquiry undertaken systematically in order to understand and improve the rationality and justice of their educational practices.

There have been critics of AR in the context of schools. Heydenrych (2001) argued that AR should go beyond merely reflecting on practice and improving performance. Instead,

it should centre on scrutinising widely accepted and universally justified practices and arrangements within education, and then challenging them.

Zuber-Skerritt and Fletcher (2007) argue quality AR needs to meet certain requirements, including the following which were addressed in my research:

- practice-oriented e.g. there was focused on the incorporation of metacognitive strategies in lessons and workshops
- participative – I acted as the teacher and teacher education in the research, while the students/PSTs data influenced the decisions made in relation to each successive AR cycle.
- focussed on significant issues relevant not only to researchers but also to their community/organisation or fellow human beings in the wider world. E.g. This work provides an insight into how I incorporated metacognition in chemistry lessons and preservice education for others to critique and learn from.
- using multiple perspectives of knowing, triangulation of appropriate methods and theories, and connecting their own judgements to discussion in the current literature. E.g. my interpretation of metacognition in chemistry based on scholarly reflection of literature and experience in the AR cycles (See section 7.4).

AR was selected as the most appropriate for the current research due to the nature of metacognition, my worldview, the number of iterations (AR cycles) with different groups of participants, which were linked by the learnings and theorising as a result of successive iterations, and my embedded reflections and analysis throughout. Based on my pragmatic worldview, I characterised AR in this work as; *Engaging in the process of reflection and challenging practice, intricately intertwining theory, action and reflection. Furthermore, it involves the sharing of these experiences openly with individuals concerned and interested in the particular practice (through this thesis) which contributes to the broader scope of research practice and enriches the depth of theoretical insights.*

3.3.2 Action research model

The research followed the action research spiral proposed by Kimmis and McTaggart (2000) where each cycle involved (i) *Planning*, (ii) *Action and observation* (iii) *Reflection*. Central to the spiral in this research is that my reflections on each cycle informed the next cycle's planning and action (Figure 3.1).

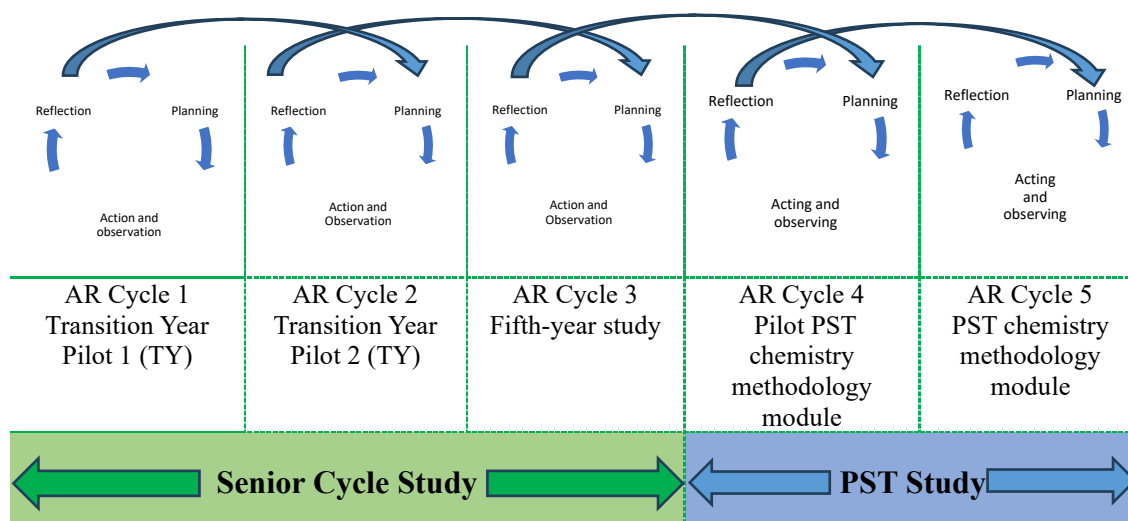


Figure 3.1 Action research cycles in the current research

Planning involves a period of exploration and analysis of the issue before formulating a strategic action plan based on forward-looking constructive action. It must recognise that all social action is to some degree unpredictable and therefore somewhat risky, the general plan must be flexible enough to adapt to unforeseen effects and constraints (Kemmis & McTaggart 2000; Heydenrych, 2001). This involved my continuous review of literature in relation to metacognition and implementing learnings from previous AR cycles.

Acting and observing phase involves acting and implementing the strategic plan. The execution of this action is not solely governed by plans; it only refers back to the planning phase for its justification. The implementation of action plans will assume the character of a material and social struggle towards improvement. Due to this flexibility, negotiation and compromise may be necessary. Change may be slow and build in small steps. Fundamentally, observation revolves around recording the outcomes of thoughtfully informed actions through predetermined and agreed-upon methods and techniques. Careful observation is necessary as action will always be limited by constraints of reality that may not be known in advance. Observation must be guided by the intent to provide a sound basis for critical self-reflection. All observation phases should be persistent about monitoring, collecting compelling evidence is essential to ensure the establishment of learnings and advancing theory (Kemmis & McTaggart 2000; Heydenrych, 2001). Observation data in this study included the audio-visual recording of lessons and PST workshops, lesson notes, student/PST generated material, survey data.

The *reflection* phase involves the researcher engaging in reflection on both the evaluation results and the overall trajectory of the action and research process, seeking to make sense of the evidence. Reflection included my own reflection notes during lessons/workshops, reviewing lessons/PST workshops, audiovisual recording analysis, and descriptive analysis (See Appendix A). Reflection may, in turn, lead to the identification of a new problem or problems and hence, a new cycle of planning, acting, observing and reflecting begins (Kemmis & McTaggart 2000; Heydenrych, 2001).

The cycles are continued in a spiral of cycles of planning, acting and observing, reflecting ... and re-planning, further implementation, observing and reflecting, etc. (Heydenrych, 2001). This self-critical activity and constructive action, aims to create a developed, tested and critically examined rationale for practice. AR studies can, thus, depart from a fuzzy situation and converge to a clear solution as knowledge is built up from one cycle to the next (Heydenrych, 2001). Through each of the AR cycles I was conscious of my roles as the ‘researcher’ and the ‘participant’ e.g. I assume the ‘participant’ in the lessons and workshop as the teacher/teacher educator, while I assume the role of ‘researcher’, in the study of the literature, planning of lessons and workshops, reflection, collection and analysis of the data, and the writing of this thesis.

3.3.3 Criteria to judge Action Research

AR, like any research approach, has its criteria to be judged and an awareness of such criteria helped me to develop as a researcher while designing and conducting the research. I purposely did not use the word limitations here as that may imply, I had taken an objective or positivist stance to this AR.

3.3.3.1 Subjectivity

A frequent criticism of AR is that it is perceived as anecdotal and subjective. This critique often originates from individuals (like me before this research), who have been trained to think within the positivist scientific tradition. In the positivist scientific tradition, the concept of objectivity is associated with the idea of a value-free researcher, a stance deemed practically unattainable in reality (Whitehead, 2017).

In agreement with this I acknowledge a number of issues of subjectivity in action research.

- i. Placing importance on the day-to-day world we live in rather than the abstract world of scientific measurement and principles.

- ii. The importance of ‘doing’ in developing knowledge – the stance that there are certain things which can only be known through their enactment.
- iii. The aim is to add to theory in a way which reveals the ‘truth’ and acknowledging the way in which our subjectivity contributes to that truth.

3.3.3.2 Generalisability and Transferability

Fundamentally positivist views reject AR because the methods and findings of any one study are not replicable in another situation, and that therefore AR lacks generalisability (Badger, 2000). Greenwood (1984) presents a counterargument, suggesting that while a situation may be individual, unique, and specific, it still shares commonalities or is 'of a kind.' Through the construction of theory, some findings can be generalised to other situations. This perspective highlights the potential for broader applicability and transferability of insights gained from specific contexts. AR often produces experiences that seem highly idiosyncratic. Yet action researchers learn a great deal from them and are able to apply what they have learned to future cases and to the interpretation of problems in other locations. Hence, we learn something general from highly particular experiences (Greenwood, 2015). My work was highly particular, in that it was conducted by me where I was both the researcher and the practitioner, with a limited number of groups, and in the Irish context. However, much can be learned from my experience of researching and incorporating metacognition in chemistry in this context.

3.3.3.4 Rigour

Rigour is a concept often used as a weapon against any kind of socially engaged research (Greenwood, 2015). Although the term ‘rigour’ implies precision, it has also been defined as "*the proper application of methods and analyses suitable for the specific task*" (Benbasat & Zmud, 1999, p. 5). AR has been recognised for its value; however, it continues to face criticism for perceived shortcomings in rigour (Chapman, et al., 2011). From the perspective of the objectivist, spectator academic researchers, rigorous research requires objectivity and distance from the subject lest researcher biases invade the process and make it “unscientific”. However, from the perspective of AR, rigour involves demonstrating that the interpretations and designed actions really take place or work in context (Greenwood, 2015). Guidelines from Davison, et al. (2004) were used to guide my planning of this AR, including the need for a cyclical process, they are guided by theory, change was driven by the importance of improvement, and learning is established through a reflective process. I included several strategies proposed by a number of

authors to ensure rigour in this AR, that is, to guarantee the quality of the data and, thus, of the conclusions or findings that are made based on it (Baskerville, 1999; Baskerville & Wood-Harper, 1996; Checkland & Holwell, 1998; Dick & Swepson, 1994). I addressed rigour in this AR using the following strategies:

1. A conceptual framework must be part of the process. It is in light of this framework that new knowledge arising from the research will be identified (Checkland & Holwell, 1998). As part of this research, I carried out a review of the relevant literature, and a synthesis of the literature on various relevant aspects of metacognition and chemistry education was discussed in Chapter 2. The evolution of the conceptual framework formed part of the development through the AR cycles and is discussed in Section 6.6.
2. The use of cycles. In each cycle the researcher should try to falsify the emerging interpretation. Using several short cycles allows more opportunities for such, e.g. the TY Pilot studies in the initial AR Cycles of this research. This thesis discusses the fifth-year study (AR cycle 3) and the second iteration of the PST methodology module (AR cycle 5) in greater detail as these were significantly influenced by the preceding AR cycles within the senior cycle study and PST study respectively.
3. Research methodology, as well as the research questions, should be critically analysed and refined in each cycle. The research questions for the current work are discussed in Section 1.2 and Section 3.1.2, where the research questions were refined following each cycle, for example following the identification of the value of representations in the TY pilot studies (AR Cycle 1 and 2) research questions based on representations were incorporated in later AR cycles.
4. Data collection and interpretation should be a part of each cycle. This allows both to be challenged in later cycles. I collected both quantitative and qualitative data during each of the AR cycles. Data analysis took place both during (e.g. analysis and transcription of audiovisual recording of lessons/workshops) and after (e.g. deductive analysis of events, descriptive data analysis, analysis of my reflections) AR cycles.
5. In each cycle, the researcher should focus only on agreements and disagreements, ignoring the idiosyncratic data. Apparent agreements should be tested, and apparent disagreements explained. I used a deductive approach when analysing the qualitative data which involved and was guided by the research aims, where the data was analysed to determine the relevance and importance of significant trends and events.

6. Divergent data should be deliberately sought. This increases the chances that any piece of data or interpretation be challenged. Existing literature can also play an important role in this effort. Through the incorporation of metacognitive strategies, difficulties in implementation were discussed while relevant literature is discussed in the findings of each AR cycle.

7. Multiple sources of information should be sought (or different perspectives concerning the same source). Ways to do this include the use of different data collection methods, different informants, different researchers and redundant data collected near the same informant, among other possibilities. As discussed, a number of sources of both qualitative and quantitative data that were collected and analysed in each AR cycle by me and often concurrently discussed with the supervisors of this research.

8. Results from change induced into the research situation should be used as an additional source of information for challenging emerging theories (since the planned actions have been grounded on previous data and interpretations). In this study, I made changes to the incorporation of the metacognitive strategies, and data collection/analysis techniques were adjusted as relevant during and following each AR cycle were relevant.

3.4 Conclusion

This chapter introduced my development as a researcher from one who held a positivist stance to one who holds a subjectivist stance, and where I conducted AR with a pragmatic paradigm. My pragmatic paradigm transcends the research approach, data analysis, and choice of the AR as the methodology for the research. This chapter has also addressed the AR methodology in this research and the criteria to judge this AR, including addressing rigour in the current research. The next chapter discusses the procedures and methods used in the research.

Chapter 4 Methodology; Procedure and methods

4.1 Procedure and data collection

An overview of the five cycles of this AR is given in Figure 4.1. As outlined in Chapter 3 this AR involved the collection and analysis of both quantitative and qualitative data.

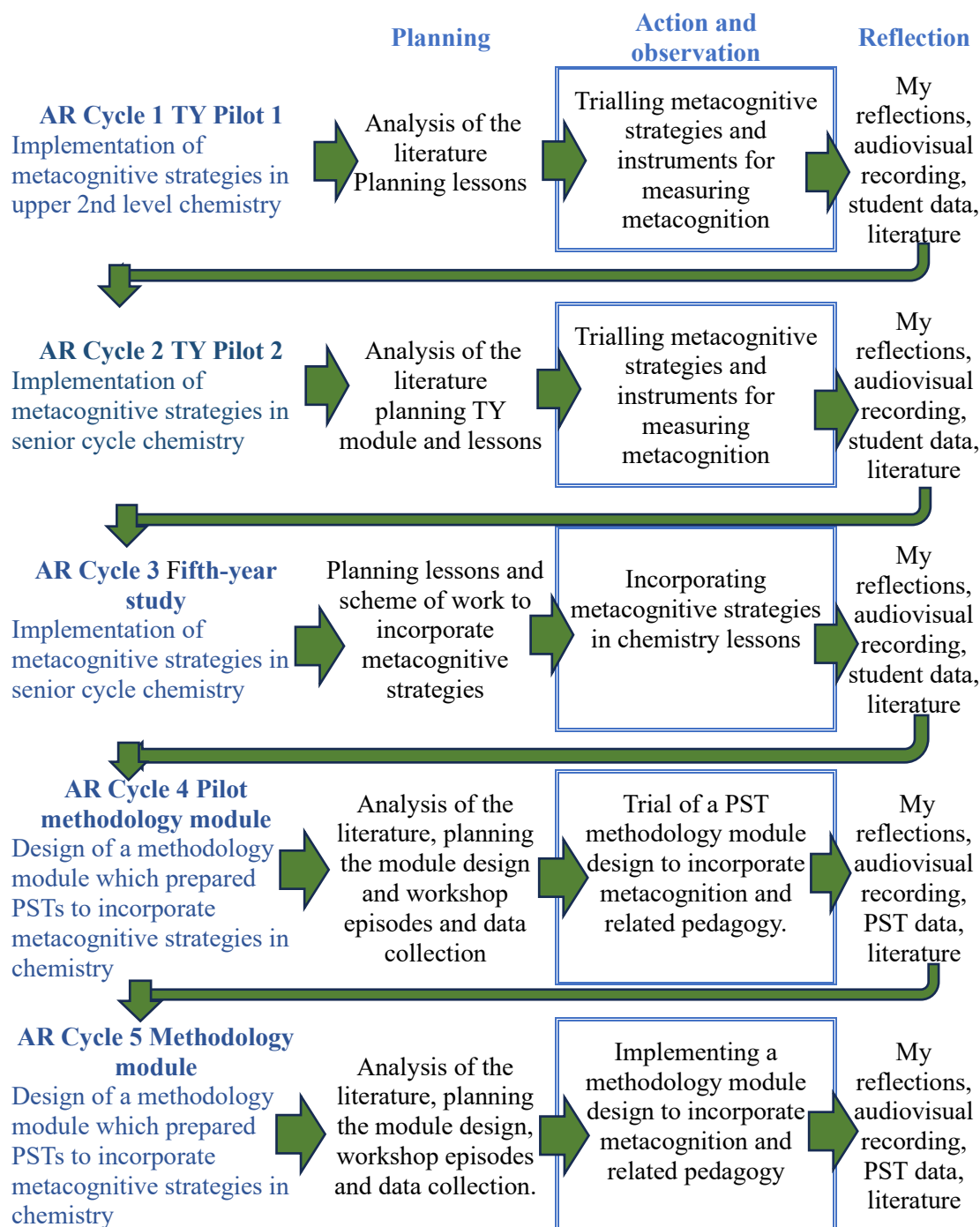


Figure 4.1 A summary of the phases within each AR cycle

4.1.1 The senior cycle study - AR Cycles 1, 2 and 3

The senior cycle study was concerned with my incorporation of metacognitive strategies in chemistry lessons. As shown in Figure 4.1, the senior cycle study consisted of two pilot studies with Transition year (TY) students (AR Cycles 1 & 2) and a fifth-year study (AR Cycle 3).

I conducted the TY pilot studies to determine which metacognitive strategies and instruments from the literature were appropriate for implementation in chemistry lessons, prior to incorporating them into the fifth-year study. The TY pilot studies also provided me with the opportunities explore metacognition in a domain specific practical chemistry context. The implementation and findings of the TY pilot studies (AR Cycles 1 and 2) is discussed in Chapter 6.

Insights gained from reflecting on and analysing the TY pilot studies were used to plan the fifth-year study (AR Cycle 3) with a class of students studying chemistry for the Leaving Certificate. The implementation and findings from the fifth-year study are detailed in Chapter 7, while the relevant research questions overall findings from the second level study (AR cycles 1-3) are also detailed at the end of Chapter 7.

4.1.2 Preservice methodology module - AR cycle 4 and 5

After reflecting on the senior cycle study (AR Cycles 1–3), my aim was to design a PST methodology module that prepares PSTs to incorporate metacognitive strategies into their chemistry teaching. This was done through the development and implementation of two iterations of a PST methodology module. In line with the AR spiral approach, the learnings from the senior cycle study informed the design of the first iteration of the methodology module (Cycle 4) and the reflection and findings of this in-turn informed a second iteration of the methodology module (Cycle 5).

4.2 Data collection techniques

AR does not specify that any one particular method of data collection should be employed. Instead, as an action researcher my focus is on:

knowledge may be advanced through reflection and research, and qualitative and quantitative methods may be employed to collect data...theory may be generated and refined, and its general application explored through cycles of the action research process (Waterman et al., 2001, p. 11)

4.2.1 Triangulation

As a researcher, I understand my responsibility to instil confidence in the reader regarding the study. Therefore, I have employed triangulation, which is described as 'the combination of methods and the collection of various data to ensure trustworthiness (Cohen et al., 2007, p.112). The issue of triangulation is extensively covered in the literature (e.g., Miles et al., 2014; Patton, 1990; Yin, 2012). Mills (2011) indicated that, despite qualitative methods often aligning more closely with AR, research questions may necessitate the use of both qualitative and quantitative data sources, particularly when teacher-researchers need to incorporate student data to complement classroom observations and qualitative narratives. Richardson and Reid (2006) describe triangulation of multiple data sources as a core element of AR, emphasising how it integrates quantitative data with more nuanced qualitative insights. James et al. (2008) argued that in AR, practitioners leverage all available data, both quantitative and qualitative, to build rigorous and cohesive conclusions.

In this study, I employed multiple techniques for collecting both quantitative and qualitative data to support triangulation, thereby enhancing the interpretive strength of the findings. Consistent with my pragmatic stance, Maxcy (2003) argues that pragmatism rejects the notion that quantitative and qualitative methods are inherently incompatible and justifies their combination in a single study to find the best answers to the research questions. However, I was conscious of the potential disadvantages of triangulation, including (i) the increased time required compared to single-method strategies, (ii) challenges in managing the vast amount of data, and (iii) difficulties in fitting quantitative data into a qualitative mould, and vice versa (Thurmond, 2001).

The various types of data collection methods are discussed below.

4.2.2 Participant observation – Audiovisual recording of lessons and workshops

Observation was used as a method in the present study, and audiovisual recording was used to document lessons and workshops. Participant observation involves methods that allow researchers to document, identify, and examine the target verbalisations as they occur in real time during an authentic event or situation (Cleary, 2011). Evaluating students' metacognitive activities 'on the spot' rather than pro- or re-actively using audiovisual recording, allows access to particular metacognitive actions, information that otherwise may not be retrieved (Clarebout, et al., 2006). While researchers may have

concerns about the presence of a recording device, research indicates that participants generally become accustomed to the presence of any kind of recording device (Duranti, 1997). Participants may at times modify their conduct due to the presence of an audiovisual recording device. However, as Duranti (1997) and other scholars have emphasised, people usually do not invent social behaviour, including language, spontaneously. While participants and researchers may still feel apprehensive about audiovisual recording, participants' comfort with the presence of the audiovisual recorder depends more on the researcher's own behaviour than on the mere presence of the device (Clemente, 2008). The rationale for the inclusion of audiovisual recording in the current study was that it allowed for real-time accurate recording of the lessons and workshops while also providing further opportunities for me to reflect on the lessons and metacognitive strategies as part of the AR methodology. This identification of the development on my part is in agreement with literature which demonstrates how video stimulus sessions can also assist educational practitioners to become more aware of their own practices, strategies and their effect (e.g. Roth, 2007).

4.2.3 Researcher reflections

There is wide agreement in the literature that reflection is critical to meeting the dual mandate of action research (AR): addressing a real-life problem through intervention together with the research objective of making a contribution to knowledge (Costello, et al., 2015). Reflection in this research is about practice and change for both myself and the students/PSTs. The model for reflection I used in this research is the Schön's Reflective Model (1991a, 1991b). Schön identifies that the role of reflection-on-action is not only one of learning and informing action, but also the building of theory. Schön based his work on that of Dewey and is most widely known for his theory of 'reflecting in' and 'reflecting on' one's practice. His theory was grounded in reflection from a professional knowledge and learning perspective. This process involves two stages. First, the researcher becomes more thoughtful and self-aware as they perform their actions. They engage in 'reflection-on-action', which involves processing and thinking about their experience. Second, they develop the capacity for 'reflection-in-action' whereby they have a different relationship with their actions based on their emerging reflexive capacity: that is to say, their actions are transformed (Freshwater, 2000). As McNiff and Whitehead (2002) argue, people do research on themselves rather than on others; they do research

with others in order to understand and improve their social practices. An adaptation of the Schön Reflective model is shown in Table 4.1.

Table 4.1 An adaptation of the Schön Reflective model used as part of the current research

Reflection in Action ‘Thinking while doing’	Reflection on Action ‘Thinking after the event’
Reflecting in the moment as actions happen, making judgements and changes to one’s actions based on past experiences of a similar situation and any new information gleaned. The experience itself. Thinking during the event Deciding how to act at the time. Informal feedback from participants. Acting immediately	Reflection takes place after the actions, where the knowledge is used to inform changes. Reflection on something that has happened. Recording in a reflective log. What would one do differently if it happened again? Reading scholarly literature Discussion with a supervisor New information gained and/or theoretical perspectives studied that inform experience and help process feelings and actions.

A possible criticism of my reflections in this AR is that it is too personal and thus unreliable. However, Lees (2001) argues all research incorporates personal bias. The basic argument is that any approach to research, even a clinical trial reveals as much about the researcher as the researched. In view of this, reflexive AR attempts to make a virtue out of necessity by adopting an approach to research which places the personal experience of the researcher at the centre of the project. This characteristic, along with the instability of the field, has important consequences for validity and reliability (Lees, 2001). For example, the positivist notion of internal validity, or its qualitative equivalent, credibility, are dependent on a stable field (Lincoln & Guba, 1985). The qualitative researcher may attempt to assess whether the project has done what it has set out to do by taking the study back to the participants “*so that they can judge the accuracy and credibility of the account*” (Creswell, 1998, p.203). However, in terms of reflexive AR, this is a fruitless exercise since both the participants’ and researcher’s perception of the field will have changed by the time they revisit it because of its unstable nature and the transformational nature of the research. In the words of Heraclitus: “*we cannot step in the same river twice*” (Fragment XXII, cited in Geldard, 2000, p.53).

In addition to reflecting on myself as a teacher and how I could incorporate metacognition in chemistry in a domain-specific way, I also reflected on my identity as a researcher, considering my positivist natural science background and how I approach researching the primarily interpretivist and social science concept of metacognition in chemistry education. This also included reflecting on the data collection techniques and sources I used.

4.2.4 Student and PST generated work

Various types of students and PST generated work were part of the data collected in the research, including works during lessons/workshops and also exams/assignments which can be described as episodic artefacts and documents (Efron & Ravid, 2019). Student and PST generated work allows one to construct a layered and contextual understanding of the research. This formal and informal data provides historical, personal information that can provide knowledge about the individuals and the general characteristics of the educational process (Efron & Ravid, 2019). The student/PST-generated data also corroborated, expanded, or challenged findings from other data collection methods (Cohen et al., 2017).

4.2.5 Self reporting surveys/Questionnaires

The most common method used to assess metacognition as an aptitude is self-reporting questionnaires, with the aim of assessing a student's metacognition in a general way by using questions that are characterised by general conditions (e.g., not subject specific) and invite students to recollect a memory of some common metacognitive activities (Schellings & Van Hout-Wolters 2011). There are several self-report inventories used to study metacognition, shown in Table 4.2. The validity of self-report inventories has been criticised by some scholars for not assessing metacognition broadly enough (Schellings, et al., 2013). Virta (2005) found that self-report questionnaires reflect the readiness of the students, but not necessarily their metacognitive ability. Nevertheless, a validated and structured questionnaire has its benefits. Schellings and Van Hout-Wolters (2011) examined the pros and cons of self-report measures of metacognition instruments and concluded they are valuable for practicality. One of the problems they pointed out, which is not unique to metacognition, is that correlation estimates in research using these instruments are likely explained in part by background factors.

Self-reporting instruments can run the risk of provoking socially desirable answers, especially where questions inquire into specified knowledge. In these cases, participants' responses may be affected by their own expectations and the perceived expectations of others (Thorndike, 2005). Respondent answers therefore may not reflect the knowledge that is actually used during task performance (Cooper et al., 2008). In addition, learners may use individually different reference points and standards for replying to questions with closed answers (limited set of possible answers e.g. a Likert scale 1-5), thus enhancing internal consistency but reducing validity at the same time (Veenman et al., 2003). However, given the prevalence and practicality of these instruments, they are useful indicators of metacognition (Berger & Karabenick, 2016; Dinsmore et al., 2008).

There are difficulties in assessment of metacognition which are often not taken into consideration in studies into metacognition (Veenman, 2011). For example, studies have employed self-report measures of metacognition as a single source of data (Cromley & Azevedo, 2006; Veenman, 2011). Researchers have called for the use of multiple instruments to assess and analyse the many facets of metacognition (Boekaerts & Corno, 2005).

As discussed in Section 4.2.1, my pragmatic stance supports the inclusion of quantitative data collected through self-reporting metacognitive inventories, as they serve as a data source for triangulating findings and conclusions. A number of these metacognitive inventories were selected for use in this study and are discussed in Sections 4.3.

Table 4.2 Inventories used in evaluation of metacognition

Instrument	Used with	Reference
Metacognitive Awareness Inventory (MAI)	Anyone	Schraw & Dennison, 1994
Metacognitive Activities Inventory (MCAI)	Third level students	Cooper & Sandi-Urena, 2009
Self-Efficacy, Metacognition Learning Inventory-Science (SEMLI-S)	Second level students	Thomas, et al., 2008
Metacognitive Awareness of Reading Strategies Inventory (MARSI)	Second level students or third level students	Mokhtari & Reichard, 2002
Motivated Strategies for Learning Questionnaire (MSLQ)	Third level students	Pintrich, 1991
Metacognitive Reading Awareness Inventory (MRAI)	Senior cycle students	Chen et al., 2009
Taxonomy of Metacognitive Activities	Senior cycle students and pre-university students	Meijer et al., 2006
Metacognitive Orientation Learning Environment Scale – Science (MOLES-S)	Second level students	Thomas, 2003
State Metacognitive Inventory	Third level students	O'Neil & Abedi, 1996
Reading Strategy Use	Second level students	Pereira-Laird & Deane, 1997
Metacomprehension Strategy Index	Lower second level students	Schmitt, 1990
Junior Metacognitive Awareness Inventory (Jr. MAI)	Primary level students, second level students	Sperling et al., 2002
Physics Metacognition Inventory	Third level students	Taasobshirazi & Farley, 2013
Learning and Study Strategies Inventory (LASSI)	Third level students	Weinstein et al., 1988
Metacognition Scale	Primary level students	Yildiz et al., 2009
Teacher Metacognition Inventory (TMI)	Teachers	Jiang et al., 2016
Metacognitive Awareness Inventory for Teachers (MAIT)	Teachers	Balcikanli, 2011

4.2.6 Interviews

Interviewing is a theoretical approach to data collection, an engaging form of inquiry, and an appropriate method for collecting data regarding human experiences (Kaufman, 1992; Kvale, 2003). According to Reinhartz (1992), “*interviewing offers researchers access to people’s ideas, thoughts, and memories in their own words, rather than the words of the researcher*” (p.19). Following learnings from the senior cycle study (AR Cycle 1-3), interviews were utilised to develop an understanding of the participants’ opinions of metacognitive strategies in the PST education study (AR cycle 4 & 5).

Interviews were chosen as a method due to their suitability in exploring participants' subjective experience (Mann, 2011), and of particular interest to this research, "*Interviews deal with thinking and talk that are later transformed into texts*" (Nunkoosing, 2005, p. 699). I selected semi-structured interviews as part of the PST Study (AR Cycle 4 and 5) as most appropriate because it allowed for an overview of the PSTs experience using particular questions, while it was not restricted as in a more structured format which may have hindered the depth and richness of the responses (Bryman, 2008).

I maintained an awareness of several important considerations throughout the research process. The first is that I may influence the data obtained in interviews, which might therefore affect the trustworthiness of the interview (Gunasekara, 2007). Indeed, according to Scheurich (1997), the researcher, intentionally or unintentionally, carries unseen baggage to the interview which may alter the way s/he would interpret and analyse the data. In this sense, it has been argued that interviews are a co-construction method in which the interviewer and the interviewee(s) are both contributing participants. A further issue is that of power; the authority of the interviewer as "*...a seeker of knowledge and methodological expertise*" (Nunkoosing, 2005, p.699) is a critical issue that must be engaged with, as it may impact the interview outcome. Additionally, interview participants might not correctly recall past events due to memory failures leading to distortions (De Massis & Kotlar, 2014; Golden, 1992; Nutt, 1986). It is suggested that using well-informed interviewees with different perspectives might mitigate these problems (De Massis and Kotlar) and enhance the confidence and trustworthiness of the findings (Graebner, et al., 2012).

Alsaawi (2014) argues although interviewing has limitations, its merits make it a tempting approach for qualitative data collection. As in the current research, the inclusion of both qualitative and quantitative data allows for cross-validation of the information supplied by different sources (Bryman & Bell, 2015; Creswell & Creswell, 2018; Patton, 2002).

4.3 Sampling method

Convenience samples were used in each cycle of this action research, with participants drawn from my normal class groups in both the second-level study (AR Cycles 1-3) and the PST study (AR Cycles 4-5). Convenience sampling is a kind of non-probability or

non-random sampling in which members of the target population are selected for the purpose of the study if they meet certain practical criteria, such as geographical proximity, easy accessibility, and proximity to the research (Dörnyei, 2007). Mackey and Gass (2005) point out that the obvious disadvantage of convenience sampling is that it could suffer from either under-representation or over-representation of particular groups within the population. It could also potentially be that the sample is unlikely to be representative of the population being studied and, therefore, limiting researchers' ability to make generalisations in terms of the findings to a wider population (Creswell & Creswell, 2018). However, Farrokhi and Mahmoudi-Hamidabad (2012) argue this should not prevent valuable and effective research using convenience sampling, rather the only thing required is to precisely report the circumstances in which the research was conducted.

4.4 Participants and data – Senior cycle study

The participants in the senior cycle study attend a single sex (all male) non-fee-paying school, drawing from diverse academic and socioeconomic backgrounds. Though student participants' socioeconomic backgrounds differ, the school is in an area designated as '*Marginally Above Average*' on the Haase and Pratschke Pobal Deprivation Index (Haase & Pratschke, 2022).

TY groups (AR Cycles 1 and 2)

Participants in AR Cycles 1 and 2 were from standard classes of TY students and were invited to volunteer for the study, who were taking a compulsory introductory sampling module in pre-Leaving Certificate chemistry as part of a year-long TY programme. There were 24 students in each TY group who were 15-16 years of age, mixed ability, and had varying levels of interest in studying chemistry; approximately 20% of the students in the TY pilot studies groups would go on to pick Chemistry as part of their Leaving Certificate studies. The TY chemistry module consisted of one 90-minute lesson each week for eight weeks.

Fifth-year group (Cycle 3)

The participants in the seven-month fifth-year study were a group of 24 mixed ability students between the ages of 17 and 18 years who had chosen to study chemistry for their Leaving Certificate programme (fifth and sixth year). The chemistry lessons for the fifth-year study consisted of three 45-minute lessons and one 90-minute lesson each week over 7 months.

A summary of the data collected in the senior cycle study is presented in Table 4.3. Chapter 6 discusses the details of students' responses as part of the incorporation of metacognitive strategies and the selection of data to be collected in each cycle of the senior cycle study. The 'pre' and 'post' in Table 4.3 indicates the instrument was used at the start (Pre) and at the end (Post) of the respective study.

Table 4.3 A summary of the data collected in the senior cycle study

AR Cycle 1- TY Pilot One (8 Weeks)	AR Cycle 2 -TY Pilot two (8 Weeks)	AR Cycle 3 - fifth-year study (7 months)
Student generated material	Student generated material	Student generated material
My reflections	My reflections	My reflections
Audiovisual recordings of lessons	Audiovisual recordings of lessons	Audiovisual recordings of lessons
Metacognitive Activities Inventory (MAI) Survey - Pre and Post	Metacognitive Activities Inventory (MAI) Survey - Pre and Post	Metacognitive Activities Inventory (MAI) Survey - Pre and Post
Metacognitive Orientation Learning Environment Scale Science (MOLES-S) survey - Pre and Post.	Metacognitive Orientation Learning Environment Scale Science (MOLES-S) survey - Pre and Post	Metacognitive Orientation Learning Environment Scale Science (MOLES-S) survey - Pre and Post.
Motivated Strategies for Learning Questionnaire (MSLQ) -Pre and Post.	Motivated Strategies for Learning Questionnaire (MSLQ) -Pre and Post.	Motivated Strategies for Learning Questionnaire (MSLQ) -Pre and Post.
Metacognition Learning Inventory-Science (SEMLI-S) - Pre and Post	Metacognition Learning Inventory-Science (SEMLI-S) - Pre and Post	
Metacognitive Awareness of Reading Strategies Inventory (MARS) Pre and post	Metacognitive Awareness of Reading Strategies Inventory (MARS) - Pre and Post	
Metacognitive Activities Inventory, MCAI - Pre and Post		

4.4.1 Qualitative data collected in the senior cycle study

The qualitative data collected consisted of the student generated work from lessons, audio/visual recordings of the lessons, and my reflections. The metacognitive strategies were predetermined as part of the planning phase of each AR cycle; hence I was aware of particular activities to observe and reflect on when implementing the specific metacognitive strategies. The metacognitive strategies which were trialled in the TY pilot studies (AR Cycles 1 & 2) were outlined in Chapter 2 Table 2.7. The metacognitive

strategies implemented in the fifth-year study were informed by findings and reflections from the TY pilot studies, and the selection of these strategies is discussed in Chapter 6.

4.4.1.1 Student generated material

The student-generated material includes in-class work, homework, and test responses. A '*Chemistry Metacognitive Journal*' for senior cycle chemistry was developed in the TY pilot studies and used in the fifth-year study. This journal contained the templates as part of metacognitive strategies incorporated in the fifth-year study. Examples of the templates are given in Appendix B and are discussed in Chapters 6 and 7.

4.4.1.2 Audiovisual recordings of the lessons

In the senior cycle study, the lessons were recorded using an audiovisual recorder (*Panasonic HC-V180EB-K Camcorder and Scandisk Memory cards*). During the pilot studies, boundary microphones and Dictaphones were used in attempts to record student-to-student dialogue during pair or group work. However, due to voice overlap, it was not possible to gather usable data. The audiovisual recordings from the fifth-year study were used to monitor the implementation of metacognitive strategies in the senior cycle lessons. They were also utilised to establish 'events' or 'instances' during the lessons that specifically highlighted metacognition as part of dialogue in lessons. The transcription of the audiovisual recordings of lessons also provided me with opportunities to reflect on the lessons. The audiovisual recorder was placed on my desk at the front of the laboratory, facing the students. This position was found to be the most effective for capturing both student dialogue and my own. As part of the reflection phase in the fifth-year study (AR Cycle 3), I analysed audiovisual recordings of lessons as part of refining my conceptual framework, refining observational rubrics, monitoring my implementation and refinement of the metacognitive strategies over the course of the study (see Chapter 5, Section 5.1.1.1).

4.4.1.3 Reflections in the senior cycle study

Aligned with the reflection-in-action model used throughout the action research cycles (Section 4.1.2), in the second-level study the '*Reflection in Action*,' included reflections on lessons and metacognitive strategies immediately after their implementation. For example, I recorded written reflections as part of lessons and at the end of lessons. As part of '*Reflection on Action*,' I reflected on my implementation of metacognitive strategies, my understanding of metacognition in chemistry, the data collection methods and sources used, and my development as a researcher after each week of the action and

observation phases and at the end of each AR cycle. The audiovisual recordings of lessons provided a rich source to aid reflection that continually influenced my own development in understanding metacognition in chemistry and contributed to how the metacognitive strategies were implemented. This formed part of my descriptive analysis of the audiovisual recordings of lessons in the fifth-year study. Reflections in each cycle (AR Cycles 1-3) played an important role as part of the evaluation and the refinement of the implementation of the metacognitive strategies in lessons.

4.4.2 Quantitative data collected in the senior cycle study

As discussed in Section 4.2.1, the quantitative data collected in the senior cycle study was used to support triangulation of the qualitative data. As part of the TY pilot studies six quantitative instruments for measuring students' metacognition were trialled and three of these were selected for use in the fifth-year study, i.e. the MAI, MSLQ and MOLES-S (Table 4.4). These instruments are now discussed, with a particular emphasis on the instruments which were selected following trialling in the pilot studies while the rationale for excluding the other instruments is also discussed.

Table 4.4 Quantitative instrument used in the TY and Fifth-Year Studies

Questionnaire	Acronym	Description	TY Study	fifth-year study
Metacognitive Awareness Inventory	MAI	Assessment of metacognition (Schraw & Dennison, 1994).	✓	✓
Metacognitive Orientation Learning Environment Scale-Science	MOLES-S	Describes the metacognitive orientation of the classroom environment and assignments given in science (Thomas, 2003).	✓	✓
Motivated Strategies for Learning Questionnaire	MSLQ	Assesses students' motivational orientations and their use of different learning strategies for a course (Pintrich, 1991).	✓	✓
Metacognitive Activities Inventory	MCAI	Designed to assess students' metacognitive skilfulness specifically during chemistry problem solving (Cooper & Sandi-Urena, 2009).	✓	
Metacognitive Awareness of Reading Strategies Inventory	MARSI	Assesses students' awareness of reading strategies when reading school-related materials (Mokhtari & Reichard, 2002).	✓	
Self-Efficacy, Metacognition Learning Inventory-Science	SEMLI-S	Designed to investigate aspects of science students' metacognition, self-efficacy and learning processes (Thomas, et al., 2008).	✓	

4.4.2.1 Metacognitive Awareness Inventory (MAI)

The general theoretical structure of metacognition informed the development of the Metacognitive Awareness Inventory (MAI) (Schraw & Dennison, 1994). I chose the MAI for use in the fifth-year study as it addresses both metacognitive awareness and metacognitive regulation. The MAI consists of 52 items addressing the two main components (awareness and regulation) and eight sub-components of metacognition. One main component is *metacognitive awareness* and includes the following sub-components: *Declarative Knowledge*, *Procedural Knowledge*, and *Conditional Knowledge*. The other main component, *metacognitive regulation*, includes the following components: *Planning*, *Information Management Strategies*, *Monitoring*, *Debugging*, and *Evaluating*. two additional subcomponents are included as part of metacognitive regulation in the MAI, 'debugging' and 'information management'. Schraw and Dennison (1994) describe 'debugging' as the strategies used to correct learning and

problem-solving errors. ‘Information management’ refers to specific strategies used by a student to help him or her solve problems more effectively. Each statement is answered on a 5-point Likert scale from “Always True” (5), to “Always False” (1). Examples of items from the MAI for each subcomponent are shown in Table 4.5.

Table 4.5 Examples of items in the MAI

	Subcategory	Example of an item	Response
Metacognitive awareness	Declarative Knowledge	I understand my intellectual strengths and weaknesses	1,2,3,4,5
	Procedural Knowledge	I am aware of what strategies I use when I study.	1,2,3,4,5
	Conditional Knowledge	I use different learning strategies depending on the situation.	1,2,3,4,5
Metacognitive regulation	Planning	I think about what I really need to learn before I begin a task.	1,2,3,4,5
	Information Management	I consciously focus my attention on important information.	1,2,3,4,5
	Monitoring	I consider several alternatives to a problem before I answer.	1,2,3,4,5
	Debugging	I change strategies when I fail to understand.	1,2,3,4,5
	Evaluating	I ask myself if there was an easier way to do things after I finish a task.	1,2,3,4,5

(from Schraw & Dennison, 1994)

4.4.2.2 Metacognitive Awareness Inventory (MOLES-S)

The Metacognitive Orientation Learning Environment Scale-Science (MOLES-S) (Thomas, 2003) was selected for use in the fifth-year study as it measures the metacognitive orientation of the learning environment of lessons which, as part of triangulation with the qualitative data, provides insights into the affordances for metacognition promoted in lessons. The MOLES-S is a 35-item instrument consisting of eight subcategories with each subcategory having five items. Each item is answered using a five-point Likert scale. A description of the subcategories of the MOLES-S is given in Table 4.6. Each of the subscales of the MOLES-S provides a measure of students’ perceptions in relation to a psychosocial dimension of the classroom environment, each of which is related to the development of metacognition.

Table 4.6 Description of the MOLES-S subcategories

Subcategory	Description
Metacognitive demands	The extent to which students are asked to be aware of how they learn and how they can improve their science learning
Student-student discourse	The extent to which students discuss their science learning process with each other
Student-teacher discourse	The extent to which students discuss their science learning process with each other
Student voice	The extent to which students feel it is legitimate to question the teacher's pedagogical plans and methods.
Distributed control	The extent to which students collaborate with the teacher to plan their learning as they develop as autonomous learners.
Teacher encouragement and support	The extent to which students are encouraged by the teacher to improve their science learning processes.
Emotional support	The extent to which students are cared for emotionally in relation to their science learning

(from Thomas, 2003)

4.4.2.3 Motivated Strategies for Learning Questionnaire (MSLQ)

The Motivated Strategies for Learning Questionnaire (MSLQ) (Pintrich, 1991) was selected for use as it measured students' motivational orientations and their use of different cognitive and metacognitive learning strategies which were not included in the MOLES-S or MAI. This provided insights into the students' use of metacognitive strategies before and after their experience during the implementation of the metacognitive strategies. The MSLQ is made of two sections, the motivation section and the learning strategies section. The motivation section consists of 31 items that assess students' goals and value beliefs for a course, their beliefs about their skill to succeed in a course, and their anxiety about tests in a course. The learning strategy section includes 31 items regarding students' use of different cognitive and metacognitive strategies and 19 items concerning student management of different resources. Students rate themselves on a seven-point Likert scale from (1) “*not at all true of me*” to (7) “*very true of me*”. A description of the subcategories of the MSLQ are shown in Table 4.7.

Table 4.7 Description of the MSLQ subcategories

	Subcategory	Description
Motivation	Intrinsic Goal Orientation	Refers to the degree to which the student perceives herself to be participating in a task for reasons such as challenge, curiosity, mastery
	Extrinsic Goal Orientation	Refers to the degree to which the student perceives herself to be participating in a task for reasons such as grades, rewards, performance, evaluation by others, and competition.
	Task Value	Refers to the student's evaluation of how interesting, how important, and how useful the task is ("What do I think of this task?")
	Control of Learning Beliefs	Refers to the belief that outcomes are contingent on one's own effort, in contrast to external factors such as the teacher
	Self-Efficacy for Learning and Performance	Refers to judgments about one's ability to accomplish a task as well as one's confidence in one's skills to perform that task
	Test Anxiety	Refers to students' negative thoughts that disrupt performance, while the emotionality component refers to affective and physiological arousal aspects of anxiety
Learning strategies	Rehearsal	Strategies that influence the attention and encoding processes, but they do not appear to help students construct internal connections among the information or integrate the information with knowledge e.g., reciting, or naming items from a list to be learned.
	Elaboration	Elaboration strategies help students store information into long-term memory by building internal connections between different topics or concepts, e.g., paraphrasing, summarising, creating analogies, and generative note taking.
	Organisation	Strategies that help the learner select appropriate information and construct connections among the information to be learned. e.g., clustering, outlining, and selecting the main idea in reading passages
	Critical Thinking	Refers to the degree to which students report applying previous knowledge to new situations in order to solve problems, reach decisions, or make critical evaluations with respect to standards of excellence
	Metacognitive Self-Regulation	Refers to control and self-regulation aspects of metacognition. Planning, monitoring, and regulating.
	Time and Study Environment	Time management involves scheduling, planning, and managing one's study time. Study environment management refers to the setting where the student does her class work
	Effort Regulation	Reflects a commitment to completing one's study goals, even when there are difficulties or distractions
	Peer Learning	Dialogue with peers which helps a learner clarify course material
	Help Seeking	Managing the support of others.

(from Pintrich, 1991)

4.4.2.4 MCAI, MARSI, SEMLI-S

Following the trialling of the MCAI, MARSI, and SEMLI-S inventories in the TY pilot studies (AR Cycles 1–2), these instruments were excluded from use the fifth-year study based on analysis conducted during the reflection phases of the TY pilot study cycles, as discussed below.

Related to but distinct from the MAI, Cooper and Sandi-Urena (2009) developed the Metacognitive Activities Inventory (MCAI), an instrument designed to assess students' metacognitive skilfulness specifically during chemistry problem solving. They describe an application of the MCAI that allows identification of students who may be over- or underestimating their problem-solving abilities. The inventory consists of 27 items. Scores are reported as a percentage of the maximum attainable number of points, (MCAI %), with a higher percentage score therefore indicating a more metacognitive individual. The Metacognitive Activities Inventory (MCAI) was not selected for use in the fifth-year study as it was designed to specifically assess students' metacognitive skilfulness during chemistry problem solving which was too specific for the level of the students.

The Metacognitive Awareness of Reading Strategies Inventory (MARSI) is a self-report instrument designed to assess students' awareness of reading strategies when reading school-related materials (Mokhtari & Reichard, 2002). Mokhtari and Reichard (2002) argue the instrument is also designed as a tool for helping students increase metacognitive awareness and strategy use while reading, while the information derived from the MARSI can provide teachers with a useful means of assessing, monitoring, and documenting the type and number of the reading strategies used by students. The MARSI was not selected as the focus of the instrument was on metacognitive aspects of reading strategies and reading large texts was not a key element of the fifth-year scheme of work (see Appendix C).

Thomas et al. (2008) developed an instrument designed to investigate aspects of science students' metacognition, self-efficacy and learning processes. The Self-Efficacy, Metacognition Learning Inventory-Science (SEMLI-S) was designed for use in exploring students' metacognition and science learning processes by asking students to self-report on the frequency of their engagement in particular metacognitive, cognitive and behavioural processes and about their self-efficacy as science learners. The SEMLI-S

was not selected as it addressed broad aspects of science students' metacognition, self-efficacy, and learning processes, which overlapped with the MAI and MSLQ.

4.5 Data and participants in the PST study

The participants in both cycles of the PST study (AR Cycles 4 & 5) were a convenience sample of PSTs in a university where I am a part-time chemistry methodology lecturer. All PSTs in the PST study were in their final year of study for a Bachelor of Science (Hons) in Science Education and were all aged approximately between 21 and 23 years old. The pilot methodology module (AR Cycle 4) consisted of ten weeks of two-hour workshops each week with eight PSTs, while the PST methodology module study (AR Cycle 5) involved twelve PSTs over ten weeks of two-hour workshops each week.

A summary of the data collected during the pilot module and the methodology module is outlined in Table 4.8.

Table 4.8 A summary of the data included from the two AR cycles of PST study

AR Cycle 4 - Pilot Methodology Module	AR Cycle 5 - Methodology Module
PST generated material in workshops.	PST generated material in workshops.
Metacognitive Activities Inventory (MAI) Survey - Pre and Post	Metacognitive Activities Inventory (MAI) Survey - Pre and Post
Metacognitive Orientation Learning Environment Scale Science (MOLES-S) survey – Senior cycle chemistry and post module experience.	Metacognitive Orientation Learning Environment Scale Science (MOLES-S) survey – Senior cycle chemistry and post module experience.
Audiovisual recording of workshop discussions.	Audiovisual recording of workshop discussions.
PST reflections on tasks assigned on literature on metacognition	PST reflection tasks assigned on literature on metacognition
PST workshop assignments	PST workshop assignments
Post-teaching placement PST interviews	Post-teaching placement PST interviews
PR reflections	PR reflections
Teacher Metacognition Inventory (TMI)	
Metacognitive Awareness Inventory for Teachers (MAIT)	

4.5.1 Qualitative data collected in the PST study.

4.5.1.1 Audiovisual recording of workshops

Audiovisual recordings were made of the PST workshops to evaluate the implementation of the design of the methodology module and to gather data in relation to the episodes occurring within the workshops. The audiovisual recorder was placed on my desk facing

the PSTs in the workshop. A Panasonic HC-V180EB-K Camcorder was used due to its ability to capture high-quality audio recordings, as demonstrated in the senior cycle study (AR Cycles 1–3). Unlike the senior cycle study, recording of the methodology module was not used to determine the number of instances of use of metacognitive strategies but rather it was only to identify examples of how the metacognitive strategies were implemented and the associated responses from the PSTs and myself.

4.5.1.2 PST generated work

The work PSTs generated during the module such as written responses to workshop tasks, weekly assignments and end-of-module assignments formed part of the data collected and analysed for evidence of the PSTs' metacognition and pedagogical knowledge in the context of teaching metacognition in chemistry.

4.5.1.2 PST Interviews

The PSTs were asked to participate in interviews following the completion of both modules in the PST study. This was to ascertain the PSTs experience in the module in terms of the metacognitive strategies and their own understanding of metacognition in chemistry education. The PSTs were again asked to participate in interviews following the completion of their teaching placement, which took place the semester after they participated in the methodology module. The purpose of this interview was to establish the PSTs takeaways from the Methodology module, the perceived impact of their experience of the metacognitive strategies, and the extent to which they were then embedded as part of their teaching while on teaching placement. The interviews with the PSTs took the semi-structured approach outlined in Section 4.2.4 and the interview questions are given in Appendix D. The interviews were recorded online using Zoom where the PST and I were the only two on the recording with cameras and microphones switched on. Following the interviews, the dialogue was transcribed and analysed (see Section 5.1.2.3).

4.5.1.4 Reflections in the PST study

The reflection model used was outlined in Section 4.1.2. I planned each workshop in advance by dividing up the workshops into episodes, while I also kept written reflections for each workshop. These written reflections during and after each of the workshops in the PST study formed part of recording my 'thinking while doing' (see Section 4.1.2). In addition to these, each workshop was transcribed and divided up into episodes as per the workshop plan, this further promoted my '*Reflection on action*' (see Section 4.1.2) in

terms of the workshop and the PSTs experience. In addition, as part of the descriptive analysis generated following each workshop, I reflected on and interpreted the audiovisual recording (Example of an episode's descriptive analysis is given in Appendix A).

4.5.2 Quantitative data collected in the PST study

The MAI and MOLES-S surveys were completed by the PSTs at the start (Pre) and the end (Post) of the methodology module. Following the completion of the MAI and the MOLES-S, these were each used as part of discussions in the workshops.

4.5.2.1 MAI

The MAI survey was completed by the PSTs at the start (Pre) and the end (Post) of the methodology module. After completing the MAI, the PSTs in the AR cycle 5 participated in a workshop discussion to explore their thoughts on the survey's purpose and the items it addressed.

4.5.2.2 MOLES

At the start of both AR cycles in the PST study, the PSTs were asked to reflect on their senior cycle chemistry experience using the MOLES-S survey. Following its completion, the PSTs discussed their responses as part of a group discussion in a workshop episode. The PSTs also completed the MOLES-S survey at the end of the module in relation to their experiences during the methodology module.

4.5.2.3 MSLQ, TMI and MAIT

The MSLQ was not used in the methodology module as it did not specifically address the aims of the module, and time constraints within the module. The Teacher Metacognition Inventory (TMI) Metacognitive Awareness Inventory for Teachers (MAIT) were trialled in the pilot methodology module (AR Cycle 4); however, they were not selected for use in the PST methodology module (AR Cycle 5) as the items in both of these surveys were more applicable to in-service teachers as they related to the metacognitive aspects of teaching strategies currently being implemented by teachers in lessons.

4.6 Ethical considerations

Ethical issues in educational research and AR are extensively examined in the literature (Beach & Eriksson, 2010; Coghlan, 2013; Collins, 2004; Floyd & Arthur, 2012; Locke, et al., 2013; Mockler, 2014; Nolen & Putten, 2007; Puchner & Smith, 2008; Walford,

2005; Zeni, 1998). Nolen and Putten (2007) argue like a physician and the counsellor, the teacher cannot abandon the role of practitioner but must always exercise professional judgement and skill. During this research, I was conscious of the ethical considerations around my position as the teacher in the senior cycle chemistry study and the teacher educator in the PST study. Donnelly et al. (2014) have shown that the traditional role of teacher and student, and the various mechanisms used to maintain these traditional power relationships, were maintained in both direct and indirect ways. In their study they highlight the difficulty of enacting true inquiry within the complex power dynamics of the classroom, and they recommend studies should aim to develop teachers' awareness of such complex power relationships and their effects on student learning.

When participants in AR are under 18 some questions surface: Can they also opt out? Will that affect their grades? Will the project data be threatened if a learner decides to leave even after signing informed consent? Will parents force their kids to participate? Will a teacher manipulate the learners to obtain "positive" data? (Banegas & Villacañas de Castro, 2015). These were issues that I was conscious of during each phase within the AR cycles in this research. The ethical dilemmas with students also bring about the issue of power. Power is linked to pre-established roles, positions, and relationships, for example, my role as the teacher and teacher educator in the lessons and workshops in this research. Various situations arise in educational AR which exhibit an uneven distribution of power, such as the dynamic between a teacher functioning as an insider and a researcher in the role of an outsider within a school or university project.

A violation of confidentiality, typically defined as the inability to uphold the security of data that could potentially identify individual participants, can occur at different phases of a research project, encompassing data collection, processing, storage, and dissemination. Informed consent is one of three applications of the principle of respect for persons in the planning and execution of research projects (Nolen & Putten, 2007). Obtaining informed consent prior to the collection of data from participants can be quite problematic in the context of senior cycle education. At issue is the extent to which participants can give truly informed consent, when the nature of the proposed change is unknown and will be determined by an emerging research protocol (Nolen & Putten, 2007). In the current research, assent forms were provided for students and consent forms for parents/guardians in the senior cycle study, while consent forms were provided for PST participants in the PST study. As was the case in the current research, confidentiality

and anonymity are usually addressed together with informed consent and respect for participants (Locke et al., 2013; Mockler, 2014). I acknowledge that absolute confidentiality and anonymity in AR is difficult, as AR is supposed to be local and context responsive.

This AR was carried out in lessons and workshops in which both the students and PSTs would have expected to have me as their teacher or lecturer prior to the commencement of the research. In agreement with Spector and Pinto (2017), I felt this was a strength in the AR as the participants would be comfortable expressing their cognitive processes and my involvement enhances my adoption and modification of research-based practices, while also allowing me to theorise following data collection and analysis during each AR cycle. All data was stored in a password protected file on my *DCU Google Drive* and all hardcopies of data and data collection devices were stored in a locked filing cabinet. Participants were assigned codes, which were used in the recording of responses and in the data analysis. Ethical approval was obtained where participants were involved in the research from the Dublin City University Research Ethics Committee, while assent and consent were requested before any participant's data was included in the research (Appendix E).

4.6.1 Ethical considerations in the senior cycle study

I was aware of the students being in the class group in a school community where I was well known. However, as I had mostly senior cycle classes, the students in the class groups did not have me as their teacher for their Junior Cycle studies. As a researcher, I also was aware of the normal power balance within any student teacher relationship in senior cycle education. Any student generated material such as, in class worksheets, which are part of normal classroom procedure were reported in the normal way. For participants who volunteered, some of this student generated material was also used for the purposes of this research. The pre and post surveys and audiovisual recordings, were not used as part of any assessment, nor did they impact on the participants' end of term grades or reports and were only used for purposes of this study.

The research involved collecting data from normal practice hence the teaching and learning experience for the student was not impaired in any way during the period of data collection. Only students who volunteered to participate had their data collected and only

their data was analysed. It was made clear to students that there would be no negative consequences if they did not participate in the study.

The permission of the Board of Management of the school and the Principal of the school was sought firstly as they are the stakeholders who would be considered as the gatekeepers for the school. Each participant was made aware that having their data collected is entirely voluntary. They were also informed that data would be anonymised. Each student participant received a plain language statement, parental consent form and a student assent form (see Appendix E) before taking part in the research. Participants were reminded they can withdraw from having their data included in the study at any time without explanation and their withdrawal from the research would be kept confidential.

4.6.2 Ethical considerations preservice education study

The PSTs in the PST study (AR Cycles 4 and 5) were invited to participate during data collection periods and were part of my normal class group enrolled in the chemistry teaching methodology module. I was aware of the normal power balance within any PST - lecturer relationship. Any PST generated material such as, assessments, reflections, which are part of normal undergraduate classroom procedure were reported in the normal way. For participants who volunteered, this normally generated material was also used for the purposes of this research. The audiovisual recordings, pre and post surveys or interviews were not used as part of any assessment, nor did they impact on the participant's end of term grades or reports but were used for the purposes of this research only.

The research involved collecting data from normal practice, hence the teaching and learning experience for the PST was not impaired in any way during the period of data collection. The information in relation to the research was presented in a plain language statement (see Appendix E) and was made available to the PSTs (advertised) two weeks before the start of the semester, and they were asked to express their interest in participating in the research if they wished. Following this expression of interest, they could ask further questions of me about the research and if they wished to participate, they were asked to sign a consent form (see Appendix E). Each participant was made aware that having their data collected was entirely voluntary, participation in this research

(or otherwise) did not influence the academic assessment, and the PSTs were reminded that they can opt out of participation in the research at any time.

4.7 Conclusion

This chapter outlined the various data collection techniques used across the cycles of the AR which addressed the research questions. This chapter also described the types of data collected to provide comprehensive information, including both quantitative and qualitative data, used in reflective practice and grounded in my pragmatic philosophical foundation. The range of data collected in each AR cycle aligns with my approach of analysing multiple data sources to triangulate findings. Huxham, (2003) argues the strength of this kind of AR is that data collected can lead to generation of descriptive theory that captures the experienced world and because I, as the researcher, am involved in the action, it is also possible to get insight about the relationship between the intentions and outcomes. The next chapter describes how the data collected in each AR Cycle was analysed.

Chapter 5 Data Analysis

Burns (2010) states that “*analysing action research data is a continuing process of reducing information to find explanations and patterns*” (p. 104). In the context of AR, Waterman (1998) focuses on the analysis and report of the movement between theory, research and practice in examining the complexities of a situation as well as the analysis of the researcher’s exploration of their own biases, throughout the process of interpretation. The analysis in this AR involved examining and interpreting data from one AR cycle to gain insights that informed the next AR cycle, and any overall findings or conclusions made in this research. In addition to informing the refinement of actions, it also helped me gain a deeper understanding of metacognition in the context of chemistry (See Section 6.6) while also aiding the development of my practice, and awareness of my cognitive processes as a researcher. Many AR texts discuss the analysis of different types of quantitative and qualitative data (Hinchey, 2008; Kosky et al., 2011; Tomal, 2010). I analysed both quantitative and qualitative data in each of the AR cycles, which provided evidence for reflection in each AR cycle and triangulation (See Section 4.2.1) for the overall research findings.

5.1 Qualitative data analysis

I employed a deductive coding approach to analyse the qualitative data. This is a pragmatic structured approach for analysing the qualitative data to generate findings in relation to the research questions. The approach assumes that certain core concepts are in the data based on knowledge of the existing literature on the topic (Bradley et al., 2007). The deductive approach or content analysis uses an organising framework comprising themes for the coding process (Bradley et al., 2007; Braun & Clarke, 2006; Burnard et al., 2008; Miles & Huberman, 1994). A framework, often referred to as a start list, is applied in the analysis in anticipation that certain core concepts are in the data and related to the research questions and is used to capture the most empirically grounded and theoretically interesting factors (Miles & Huberman, 1994; Bradley et al., 2007;). A thematic analysis approach was not used, as it is largely inductive, with codes and themes emerging from the data itself. Instead, as outlined in the following sections, the qualitative data in this research was analysed for the presence of metacognitive elements using pre-generated questions, rubrics, and themes.

As discussed in Chapter 2, metacognitive and cognitive activities are cyclical processes, making it difficult to disentangle them in the assessment of metacognition (Veenman et

al., 2006). However, metacognition can be identified in students' verbalised self-instructions, but when it is not explicitly heard or seen during task performance, it needs to be inferred from evidence of certain cognitive activities (Veenman et al., 2006). This is the approach taken as part of the qualitative data analysis of the occurrence of metacognition in this research.

5.1.1 Qualitative data analysis – Senior cycle study

5.1.1.1 Analysis of audiovisual recordings of lessons

In the senior cycle study, all 20 lessons from the Transition Year (TY) Pilot Studies (AR Cycles 1 & 2) and 96 lessons from the fifth-year study (AR Cycle 3) that were audiovisually recorded were transcribed and analysed to develop a comprehensive understanding of metacognition within the context of my chemistry lesson. My analysis of audiovisual recordings as part of the identification of metacognitive 'events' was valuable in helping me gain a greater understanding of the relevance of metacognitive aspects of strategies I had planned. This process significantly enhanced my understanding of metacognition in a chemistry context, informed my practice, and guided the planning of subsequent lessons and AR cycles. This analysis also contributed to the development of the conceptual framework (see Section 6.6) and observational rubrics for identifying metacognitive events and strategies in the context of my chemistry lessons. The iterative development and refinement of the observational rubrics for analysing the audiovisual recordings of lessons involved reviewing the literature, concurrently applying the observational rubrics to events identified in the audiovisual recordings, and holding discussions with my supervisors, who are professors in STEM education. The developed rubrics are listed in Table 5.1 and are given in Appendices F, G and H.

Table 5.1 Rubrics for recording analysis developed in the Senior Cycle study (AR Cycle 1-3)

Rubric	Appendix
Analysis of the use of metacognitive strategies in lessons	<i>F</i>
Analysis of events which addressed metacognitive awareness in lessons	<i>G</i>
Analysis of events which addressed metacognitive regulation in lessons	<i>H</i>

Audiovisual recordings of lessons were analysed using QSR International's NVivo 12 (QSR International, 2018) qualitative data analytical software. A deductive approach to analysis was taken, in which initial codes for the rubrics were drawn from existing

literature. The rubric for the analysis of the metacognitive strategies in lessons was developed based on descriptions of each of the strategies from the literature and as discussed in Section 2.6.2. (Zohar & Barzilai 2013; Brown et al., 1984; Tishman, et al., 1995; Veenman et al., 2006; Zohar & Ben-David, 2008). Then, the rubric was refined during the identification and coding of metacognitive strategies in the audiovisual analysis. The developed rubric for recording metacognitive strategies which occurred in the chemistry lessons is summarised in Table 5.2 (see also Appendix F).

The observational rubrics developed by Whitebread et al. (2009) for the identification of metacognition in children in the 3- to 5-year-old age range were adapted for use as the rubrics which identified the events as aligning with the subcomponents of metacognitive awareness and regulation in chemistry lessons in senior cycle study. I deductively coded the identified metacognitive events using the rubrics and this was followed by cross coder discussion with the two supervisors of this research. This involved the coding of the events as they occurred during recording playback and comparing this with the descriptions from the rubric. A summary of the rubric for analysis of lesson events categorised as addressing metacognitive awareness are outlined in Table 5.3 (see also Appendix G), and a rubric for analysis of events which were categorised as addressing metacognitive regulation are shown in Table 5.4 (see also Appendix H).

While the rubrics I developed (Appendices F, G & H) require future development and wider use to ensure reliability, they nevertheless provide a basis for use by classroom teachers to assess chemistry lessons based on my experience and context. Whitebread et al. (2009) argue that the development of such observational tools, although containing methodological difficulties, allow for valid assessments of metacognition in students aged 3-5 years old. If they allow for valid assessment of metacognition in students of that age, then arguably they can be used as part of a valid assessment of metacognition in senior cycle students, especially as their verbal indicators would certainly be more advanced. However, it should be noted, I recorded in my reflections during the fifth-year study that it was challenging to categorise some events and there is a possibility that an event could be interpreted in more than one subcategory.

Table 5.2 A summary of the rubric for categorising instances of metacognitive strategies

Category Name	Description of event	Example
Metacognitive prompts	Teacher provides metacognitive cues, questions or checklists that are used during activities.	<i>You can't just write this stuff out; you need to think about it in your head. Think about a possible way you could do this, it's about thinking (PR)</i>
Reflective writing	Teacher asks students to write diaries or journals about their cognitive processes, reflective essays, or written responses to reflective prompts. Teacher asks students to write about their cognitive processes.	When students are asked to complete Pre and post lesson surveys. Including the prompts; <i>What do I already know or understand about this topic</i> <i>What have I learned about this topic?</i> <i>I still don't understand:</i> <i>Additional questions would like to know the answer to are;</i>
Teacher led metacognitive discussions	Teacher engages in a whole class and group discussions of thinking and learning processes, discussions in which teachers talk with their students about their thinking and learning in order to encourage and develop metacognitive thinking.	<i>You know, I sometimes think of learning chemistry like dropping breadcrumbs..... that if you don't leave a few breadcrumbs of how you get to an answer What's the can be problem with, doing similar problems 20 times, one after the other, or when you don't understand how you got from point A to point B. What other subject does this happen (S) Maths Yeah, what happens in maths if you do 20 of the same type of question. What happens after the second or third question? (S) You just look back at how you did the last question (T) yeah what are you just doing? (S) remembering (T) Yeah.</i>
Explicit Metacognitive instruction	Teacher uses explanations and demonstrations regarding specific cognitive or metacognitive strategies and knowledge construction activities which require students to construct their metacognitive knowledge.	<i>It's a bit like Hansel and Gretel and the breadcrumbs, in chemistry you must know how you get to the answer as well as the answer. It should be more than just getting the answer, it's about thinking about what your thought processes were while you were reaching your answer, how you could have altered the thought processes and be aware of other thought processes that could have been used (PR).</i>
Student representations of chemical phenomenon	Teacher or student uses visual representations in order to help students represent and share their thinking and learning. Teacher or student uses a representation to present their knowledge in relation to a chemical phenomenon.	<i>Based on the representations you already created, how you visualise polar substances and non-polar substances as a solid, liquid and gas at the submicroscopic level. (PR)</i>

Table 5.2 (continued)

Category Name	Description of event	Example
Teacher or student metacognitive modelling	Teacher or student refers to activities in which the teacher or student demonstrates how he/she activates and applies metacognitive knowledge and metacognitive regulation in the course of learning, in order to model these practices for the students.	<i>When you ask me a question in class, I always take a second to establish the answer in my own head. I realise I must give myself a chance to think and evaluate what I am going to answer with, before I respond. (PR)</i>
Think aloud protocol	Students are asked to self-report the cognitive and metacognitive processes being used to complete a task	<i>As you are drawing your representation of how you visualise the water of crystallisation, describe your thinking for the student [student]next to you as you draw your diagram. (PR)</i>
Strategic evaluation matrix	Students use the Strategic evaluation matrix for a reading task in chemistry	<i>Students are asked complete the Strategic evaluation matrix on the section in the textbook on types of covalent bonding</i>
Regulatory checklist	Students complete a regulatory checklist while completing a problem.	<i>Students complete a regulatory checklist when balancing an equation by inspection.</i>

Table 5.3 Summary of the rubric for categorising events under the subcategories of metacognitive awareness

Category Name	Description of event	Example
Declarative knowledge	Teacher or student: - refers to understanding of thinking and knowing in general. - refers to knowledge of their (or others), intellectual resources, and abilities as a learner. - examines their capabilities, strengths and weaknesses, or academic/task preferences; comparative judgments about their own abilities; knowledge of a given chemical phenomena. - analyses their knowledge of a chemical phenomenon.	<i>I think of it as I think about the equals sign in mathematics, I think of it as a balance between the two side of the [chemical] equation (Student DJC)</i> <i>I don't know if there are any exceptions made in the modern periodic table (Student, BGN).</i> <i>I like drawing it out, that's the way I think about it anyway (Student KQN)</i>
Procedural Knowledge	Teacher or student: - applies knowledge for the purposes of completing a procedure or process. - discusses knowledge about how to implement learning procedures (e.g., strategies). - refers to their own or others expression for their own long term memory knowledge in relation to elements of the task. - reflects on the nature of the task at hand and the similarities and differences between the current task and other tasks. - compares across tasks identifying similarities and differences. - makes a judgement about the level of difficulty of cognitive tasks or rates the tasks on the basis of previous knowledge	<i>I know how to calculate the molarity of acids and bases from titration results and to use the ratio of acid to base from the chemical equation (Student LKN).</i> <i>Look at the valence electrons. Draw a basic shape where electrons are bonded. Find the lone pair if there are some. Organise the shape so that the lone pairs push bonds away. Find the greatest distance between bonds. (DJC, Describing their thinking on VSEPR Theory)</i> <i>I learned how to use the formula $PV=nRT$ and how to do the experiment correctly. I also learned more about the stoichiometry steps involved in the calculation and what they mean. (Student FJT)</i>
Conditional Knowledge	Teacher or student: -refers to knowing the “why” and “when” aspects of cognition. - asks under what circumstances specific processes or skills should transfer. - or students discuss when and why to use learning procedures. - demonstrates the explicit expression of their own knowledge in relation to strategies used during a cognitive task. - defines, explains, how she/he has done or learned something.	<i>The solutions were easier to find if I lean on a picture in my head rather than just numbers (Student FRK)</i> <i>“You Must consider that molarity (M) is expressed in Moles/Litre and you must calculate the amount of molecules in a given amount using division” (BGN)</i> <i>When do you think you would use an electron cloud representation? Why would you use it, what chemistry would you be trying to represent? (PR)</i>

(Adapted from Whitebread et al., 2009)

Table 5.4 Summary of the rubric for categorising events under the subcategories of metacognitive regulation

Category Name	Description of event	Example
Planning	Teacher or student: -decides on procedures necessary for performing the task, individually or with others. - sets or clarifies task demands and expectations. - individual roles and negotiates responsibilities. - sets goals and targets. - decides on ways of proceeding with the task.	<i>I know how the number of atoms is calculated from moles grams and litres; I need to be able to use the ratio from the equation. (Student FRK).</i> <i>Represent what you already know about chemical equilibrium, use whatever type of drawing you like, include notes to explain your thinking. (PR)</i>
Monitoring	Teacher or student: - assesses the quality of task performance (of self or others) and the degree to which performance is progressing towards a desired goal. - review progress on task (keeping track of procedures currently being undertaken and those that have been done so far) - rates effort on-task or rates actual performance. - rates make comments on current memory retrieval. - checks their behaviours or performance, including detection of errors - Self-corrects	<i>“You must dilute a strong acid before using it in a titration as otherwise you will need too much base. Precise measurements and practice is required for titrations” (Student BGN)</i> <i>I know I am not going to solve it by staring at the numbers, I need to try something else (Student DHE)</i> <i>I am thinking about if the number of molecules actually equal at a given volume, temperature, and pressure, or is the difference just too insignificant to matter (Student BTB)</i> <i>“I need to be more careful with the conversion of moles and grams” (Student DEH)</i>
Evaluation	Teacher or student: - verbalises reviewing task performance and evaluating the quality of performance (of self or others) - explains their own learning or explains the task. - evaluates the strategies they used. - rates the quality of their performance. - observes or comments on task progress, or to test the outcome or effectiveness of a strategy in achieving a goal.	<i>I still don’t know if HCL and water is an acid or an acidic solution? (Student BGN)</i> <i>I am confused about the positive result for the flame test for sodium. I didn’t have enough time to complete all the equations (Student BTB)</i> <i>“Still a little confused on how to do the equations (Student FJT)</i> <i>“I need to think through questions more carefully” (Student BTB)</i>

(Adapted from Whitebread et al., 2009)

As a relative indication of the frequency of metacognitive strategies and metacognitive events in the fifth-year study lessons, purposive sampling (Patton, 2014) was employed to select a subset of 40 lessons, using the developed observation rubrics. The selection was guided by specific criteria:

- i. A minimum of two lessons were chosen from each of the 24 weeks in the fifth-year study, ensuring a diverse representation of instructional contexts (incorporating elements of stratified sampling).
- ii. Lessons involving student assessments, such as tests, were excluded to avoid data that might not represent typical metacognitive engagement.
- iii. Lessons with fewer than half of the students present, often due to external participation events, were also excluded.

This purposive sampling strategy, resulting in a sample of 40 out of 96 lessons (42%), provided a robust yet manageable dataset, enhancing both analytical rigor and practical feasibility.

5.1.1.2 Student generated material analysis

Student generated material included student entries into the ‘Chemistry Metacognitive Journal’, and homework assignments. A deductive approach was taken to analyse the student generated material, where the analysis was guided by the research questions and the metacognitive strategies implemented. The primary purpose of the deductive approach was to analyse the dominant or significant themes inherent in the raw data specifically related to the research questions and the metacognitive strategies being implemented.

The student material was read ‘horizontally’, which involved grouping segments of text or diagrams by metacognitive strategy employed and linking this to the audiovisual recording. Similarities and differences across the group of students were explored. Following my reflection on the analysis, literature, and discussion with the supervisors for the research, examples of the student work were extracted from the raw data.

5.1.1.3 Reflections in the senior cycle study

My reflections in the senior cycle study were analysed using a deductive approach based on the research questions and as part of triangulating evidence of metacognitive events planned or occurring in lessons. This included analysing my lesson reflections, monthly reflections and end of study reflections. The analysis of my own reflections also

encourages my metacognitive development in terms of understanding my cognitive processes while implementing the metacognitive strategies in the context of my chemistry lessons. Analysis of my reflection's was also linked to my wider development as a researcher by maintaining an interpretive stance while analysing my reflections and what they mean in the context. Questions I asked while analysing my own reflections included *Why did I feel this way? What influenced my decisions? What alternative approaches could I have taken? How do my experiences fit within a broader research context?* In line with the AR methodology, analysing my reflections also involved what Van Maanen (1988) described as individualistic reflexivity which focuses on my personal experience and evolving thoughts throughout the research process. A challenge I faced was to maintain the academic rigor by linking these reflections to broader theories and methodologies (e.g., metacognition, educational research, action research cycles). This included triangulation with other data sources (e.g. student data), theory integration (learnings described in Chapter 2), and contextualisation (see Section 1.1).

5.1.2 Qualitative analysis in the PST study

5.1.2.1 Visual and audio recording

The workshop recordings were transcribed and analysed for evidence of my practice and implementation of the module design, as well as the PSTs' metacognition in a chemistry context and their incorporation of metacognition into their teaching. A deductive approach was used to analyse this data, with the data sources providing examples of metacognitive discussions and other metacognitive events throughout the module. As part of enhancing the rigor of the analysis, the research supervisors provided feedback on my interpretation of metacognitive events in the workshops. Each workshop was divided into episodes in the module design, (see extract in Appendix I), and after each workshop, a descriptive analysis using audiovisual recordings was generated (see extract in Appendix A). This analysis promoted my reflective practice and provided insights into the actual implementation of the module design. By reviewing each episode, I identified areas for improvement and made modifications to the design. In line with the AR methodology, this iterative process allowed me to continuously refine the module design and implementation.

5.1.2.2 PST generated material.

The PST generated material (e.g. workshop notes, reflective assignments) were analysed for evidence of metacognitive awareness or regulation on the part of the PSTs. A

deductive approach to the analysis of the PST generated material was guided by the research questions and the module design. As part of this process, I examined the PST generated material, linking it with the workshop recordings and the plan for the relevant episode. Before finalising the analysis of the PST generated material, I discussed examples with my research supervisors. This included categorisation of the PST generated material based on the research questions for the PST study or specific metacognitive strategies, ensuring that the analysis remained consistent and relevant. For example, I analysed workshop audiovisual recordings for evidence of the PSTs own metacognition or how they incorporated metacognition into their planning for the teaching of chemistry.

5.1.2.3 Interview data analysis

Interviews with the PSTs took place following their teaching placements, which was approximately twelve weeks after the PSTs completed the Methodology module central to this research. Following requests to volunteer following, two PST interviews were conducted with PSTs in AR Cycle 4 and two PST interviews were conducted in AR cycle 5. The analysis of interview data is a complex process due to the huge amount of data recorded (Carey, 1994), which included transcribing the data from the audiovisual recording of the interview in this research. Analysis of the interviews took a deductive approach where the interviewees' responses were analysed for evidence which address the research questions. I reviewed the interviews and isolated sections that described distinct incidents or expressed opinions relevant to the research questions. I then analysed the meaningful content and re-read the interviews to test, revise, and refine the initial classifications. This is in line with Braun and Clarke (2006), where they caution that analysis is not a linear process, but rather a recursive one, where the researcher moves back and forth between the entire data set, the coded data extracts, and the overall analysis. I also looked for issues of potential interest/conflict in the data. One key question I posed was: What descriptive and evaluative ideas and opinions are presented when the PST discusses metacognition in chemistry? Insights emerged through a careful examination of the transcripts. I looked for threads and patterns to unify the analysis, focusing on interesting elements that emerged and selecting relevant excerpts to highlight those features. For example, I looked for direct mentions of awareness of student cognitive processes or their awareness of their own cognitive processes and mapped these against the conceptual framework (Section 6.6).

5.1.2.4 Reflections in the PST study

I analysed my reflection notes from each workshop using a similar approach to my reflections on lessons in the senior cycle study, where I applied a deductive approach to identify excerpts relevant to the research questions. I focused on finding patterns and themes emerging from the reflections that aligned with the research questions. This process also involved triangulation of data, comparing my reflections with other data sources (e.g., workshop recordings, PST materials) to strengthen the findings and ensure they were well-grounded in the evidence. As discussed above the descriptive analysis completed after each workshop also formed part of the reflective and development process. This involved each relevant episode being described under the headings *Purpose, Description, Interpretation*, and the relevant PST generated work was also inserted in the episode in the same document along with the workshop transcription from the audiovisual recording. An example of the descriptive analysis for an episode, *Week 1 Episode 2 Discussion Related to the MOLES-S Survey*, is given in Appendix A. I wrote the descriptive analysis in the week following each workshop. This generated a substantial amount of data based on my ‘reflection on action’, which was then deductively analysed for aspects which addressed the research questions at the end of each AR Cycle in the PST study.

5.2 Quantitative data analysis

The occurrence of instruments used to collect quantitative data presented and analysed in this thesis included the MAI, MOLES-S and the MSLQ as shown in Table 5.5. The quantitative analysis of these instruments was used as evidence to triangulate both the implementation of metacognitive strategies and the inferences about their effects on participants' experiences with metacognitive strategies in lessons and workshops.

Table 5.5 Quantitative instrument occurrence at the start (Pre) and at the end (post) in the AR cycles

	Senior Cycle Study (AR Cycles 1-3)		PST Study (AR Cycles 4-5)	
	Pre	Post	Pre	Post
MAI	✓	✓	✓	✓
MSLQ	✓	✓	✗	✗
MOLES-S	✗	✓	✓	✓

The analysis of the quantitative data presented in this thesis using descriptive statistics, where the mean values were determined and used in addition to the raw data and as part of triangulating findings (see section 4.2.1).

As part of the analysis of the MAI and MLSQ pre and post scores, I considered a 10% change in students'/PSTs' scores to be a notable indicator of change. This threshold was chosen as it is not influenced by the performance of others, which I choose as suitable for the relatively small groups within this study. This is a criterion-referenced measure due to adopting an absolute value (10%) as a measure of change, which contrasts with relative measures of change used in, for example, norm-referenced measurement (Popham, 1971).

The scores for the MAI are represented in this thesis as a mean score, which was recorded by the students/PSTs on a Likert scale between 1-5 (1-Always False, 2-Sometimes False, 3-Neutral, 4-Sometimes True, 5-Always True).

Students were asked to score each item on the MSLQ on a Likert scale 1-7, from 1- Strongly disagree, to 7- Strongly agree. The results for the MSLQ are presented in this thesis as the mean score for the student responses for each of the items in the subcategories of the MSLQ. There is no overall score represented for the MSLQ as its use is based on two sections, namely a motivation section and learning strategies section.

The participant MOLES scores represent the mean scores for the participants as they responded to the items in the MOLES-S survey on a Likert scale from 1 to 5 (5 = Almost Always, 4 = Often, 3 = Sometimes, 2 = Seldom, 1 = Almost Never).

5.2.1 Senior cycle study quantitative data analysis

The students in each cycle of the senior cycle study (AR cycles 1-3) completed the MAI at the start (Pre) and the end (Post) of each cycle to provide additional data in relation to students' metacognitive development as part of experiencing the metacognitive strategies, while it also helped me reflect on the specific metacognitive aspects of the strategies I was incorporating in lessons (see Section 7.5). The recorded MAI results include scores for the eight sub-components, two main components, and an overall MAI score (overall mean score).

The students in the senior cycle study completed the MSLQ (Pintrich, 1991) pre and post of each cycle to provide evidence of the students' use of cognitive and metacognitive

strategies as measured by the MSLQ. I chose not to use the MLSQ in the PST study due to the limited time available with each group.

The MOLES-S survey in the fifth-year study was used to assess the extent to which students perceived the lessons as a metacognitively oriented environment (Thomas, 2003). The MOLES-S can be used as a mechanism to reflect on past experiences of an educational setting; thus, it was also used for promoting awareness of possible metacognitive aspects of those experiences. To this end, the students in the fifth-year study were asked to reflect on their experience in lessons across the fifth-year study while completing the MOLES-S survey at the end of the research period.

5.2.2 PST study Quantitative data analysis

The MOLES-S survey in the PST study was used to assess and discuss the extent to which PSTs perceived their lessons in second level chemistry (completed at the start of the module) and the workshops as part of this research (completed at the end of the module) as a metacognitively oriented environment (Thomas, 2003).

The PSTs in the PST study (AR cycles 4-5) completed the MAI at the start (Pre) and the end (Post) of each cycle to provide additional data in relation to PSTs' metacognitive development as part of experiencing the metacognitive strategies, while it also aided workshop discussions on specific metacognitive aspects of the metacognitive strategies.

5.2.3 The use of quantitative data in the current study

As is typical in AR, the quantitative data collection in this study involved participants (students and PSTs) known to me, with whom I had positive relationships. This aligns with my belief in creating an encouraging and supportive environment to promote metacognition in chemistry. However, I was mindful of this positive relationship when administering the quantitative inventories. Participants might have been aware of my focus on developing their metacognition in chemistry and may have been inclined to respond in ways that align with this focus rather than reflecting their actual experiences. The principle of participants' tendency to answer in a socially desirable way, known as acquiescence, is long-established in research (e.g. Messick, 1966). This is notwithstanding the fact that none of the items in the quantitative instruments explicitly use the word metacognition as part of any question they contain. Therefore, these factors were carefully considered in the analysis of the quantitative data, which was primarily

used as a source for triangulation in discussing the analysed qualitative data and any inferred findings.

5.3 Validity, Reliability, Trustworthiness

All of the quantitative instruments used in this study have been previously established and validated. While validity and reliability are typically used to evaluate quantitative data, trustworthiness is generally the quality indicator for qualitative data (e.g. Beck, 2019).

Guba & Lincoln (1989) establish the relationship between validity, reliability and trustworthiness. For example, internal consistency which is an assessment of the degree of isomorphism between a study's findings and the '*real world*' cannot have meaning as a criterion in a paradigm that assumes realities exist in mentally constructed form hence it does not make sense to look for this type of isomorphism (Guba, & Lincoln, 1989). Similarly external validity which embodies the very essence of generalisability has little meaning if the '*realities*' to which one might wish to generalise exist in different forms in different minds, depending on different encountered circumstances and history and based on different experiences. Credibility criterion is parallel to internal validity in but where the isomorphism is between the constructed realities of the participants and the reconstructions attributed to them. The focus is on establishing a match between the constructed realities of the participants and those realities represented by the researcher (Guba, & Lincoln, 1989). A number of techniques for increasing the probability that such isomorphism as described in the literature were employed in this research, some of which are described below.

- (i) It is necessary to immerse oneself in an understanding of the context's culture and prolonged engagement (Lincoln & Guba, 1985). The TY pilots (AR Cycles 1 & 2), the fifth-year study (AR cycle 3), pilot methodology module (AR cycle 4) and the final iteration of the methodology module (AR cycle 5) each took place over the course of academic years, hence the data collection took place over four academic years, which allowed for substantial engagement and emersion during which my planning, action and observation, data collection, reflection and data analysis were carried out in tandem over an extended period.

- (ii) Lincoln and Guba (1985) argue for the importance of carrying out sufficient persistent observations to enable the researcher to identify those characteristics and elements in a situation most relevant to the issue being pursued. My observations during lessons/workshops were documented in my reflections, while I reviewed lessons/workshops using the audiovisual recording which provided for enhanced observations during the data collection periods.
- (iii) Progressive subjectivity is the process of monitoring my own development or my own prior mental constructions because no researcher engages in research as a blank slate (Guba, & Lincoln, 1989). To address progressive subjectivism, the researcher records their prior constructions before engaging in any activity. In the current research this was continually done in my reflections prior to any data being collected and prior to the implementation of each AR cycle and before lessons and workshops.
- (iv) Negative case analysis may be thought of as parallel to statistical tests for quantitative data (Kidder, 1981). As part of the qualitative data analysis, it wasn't expected that all the metacognitive strategies or metacognition inventories would necessarily be suitable for incorporation in chemistry lessons/workshops. However, a reasonable number did, and a negative case analysis of those that did not provided confidence that equal attention was given to rejecting unsuitable strategies as to accepting appropriate ones (Guba, & Lincoln, 1989).
- (v) Member checks can be formal and informal (Lincoln & Guba, 1985). Member checks were conducted using several strategies across the AR cycles in this research, including, discussing my interpretation of student/PSTs responses to surveys or metacognitive strategies, students/PSTs being asked to use a number of modes of describing a particular chemical phenomenon, e.g. written description, accompanied by a representation followed by explaining their cognitive processes through think aloud protocol, pre and post lesson surveys, interviews with PSTs.
- (vi) Trustworthiness is also increased by sharing research or having several researchers on the project, which gives greater scrutiny (Hales et al., 2006). In the current research, the supervisors provided support to me by cross checking data and the data analysis. As part of the increasing the scrutiny

through the sharing of my research, I presented and reported my progression in several conference proceedings and presentations (Trimble, et al., 2019; Trimble, et al., 2020a; Trimble, et al., 2020b; Trimble, et al., 2021a; Trimble, et al., 2022).

5.4 Conclusion

This chapter outlined the various approaches to analysing the data collected in this research across the AR cycles. Rubrics were developed as observational tools for the analysis of the visual and audio recordings for use in the fifth-year study. While they require more widespread use and reliability checks, they may provide a basis for observation tools for teachers in analysing metacognitive events in senior cycle chemistry classrooms. The quantitative data analysis was conducted as part of the triangulation process to support the findings. The validity, reliability, and trustworthiness in this research were also addressed in this chapter. The next chapter, Chapter 6, discusses the TY pilot studies (AR Cycles 1 & 2).

Chapter 6 TY Pilot Studies (AR Cycles 1 and 2)

6.1 Introduction

While reviewing literature during the planning stages of the first AR Cycle, I developed a more nuanced theoretical understanding of the critical role metacognition could play in chemistry education. My ‘sound understanding of metacognition’ (Ryan, 2014) evolved through the planning and reflection phases of the AR cycles, whereas my ‘metacognitive pedagogical knowledge’ (Zohar and Barzilai, 2013) was cultivated through the ‘action and observation’, and ‘reflection’ phases of these cycles.

The senior cycle study (AR cycles 1-3) was concerned with my practice while incorporating teaching and learning strategies which promoted metacognition in chemistry lessons (Figure 6.1). This chapter discusses the implementation, reflections and findings of the TY pilot studies (AR Cycles 1 & 2). The planning phase for both TY pilot studies involved planning of lessons while analysing literature on metacognition and metacognitive strategies, as summarised in Chapter 2. The action and observation phases of the TY studies focused on exploring my interpretation of metacognition in chemistry and trialling the incorporation of metacognitive strategies described in the literature (see Table 2.7).

The analysis of student generated material and audiovisual recordings in the pilot studies provide opportunities to develop my own quantitative and qualitative data analysis experience. This analysis of the TY pilot studies gave rise to several conference presentations and publications (e.g. Trimble et al., 2019).

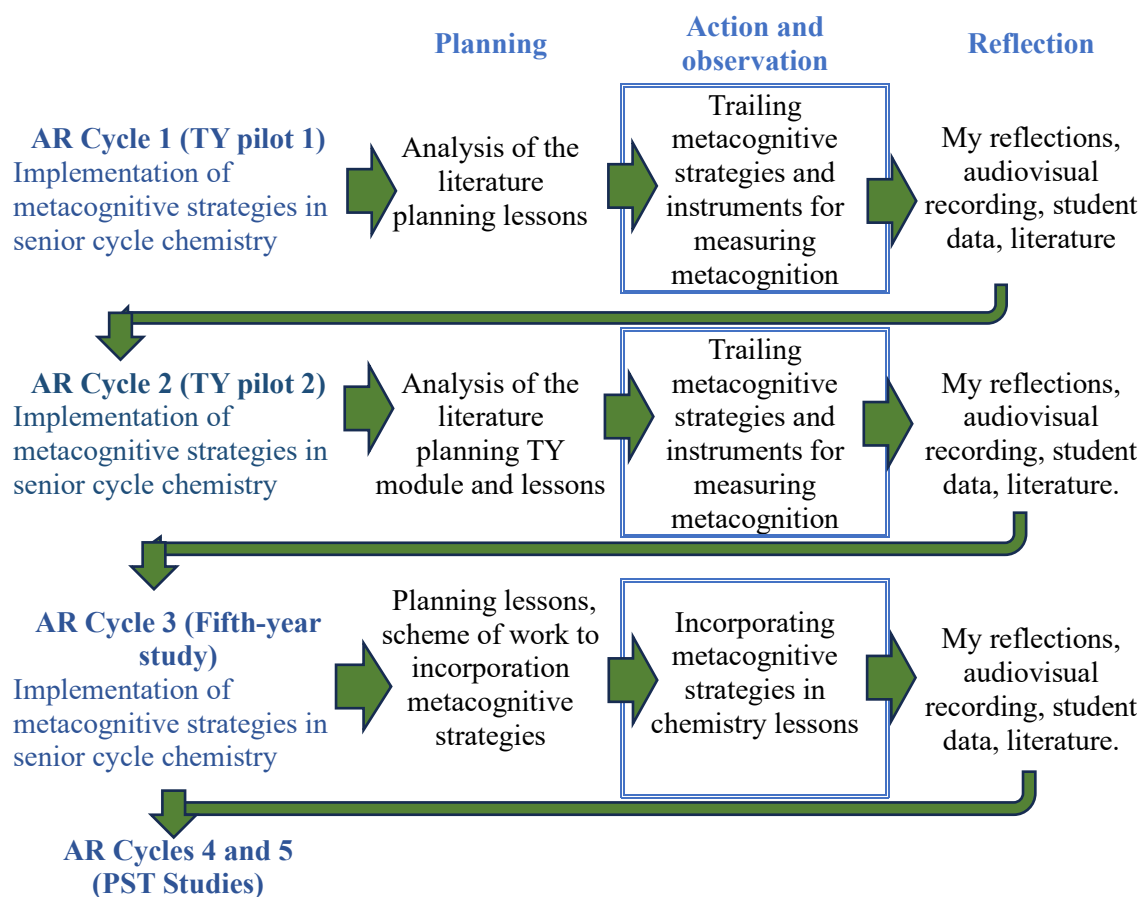


Figure 6.1 An outline of the phases in the senior cycle study

6.2 Implementation TY Pilot studies (AR Cycle 1 and 2)

The TY pilot studies provided opportunities for the trialling of metacognitive strategies (outlined in Table 2.7). Some strategies were identified as particularly suitable for the fifth-year study, while others were deemed less appropriate in the context of this work. I trialled each of the metacognitive strategies in the TY lessons by reviewing the literature on the strategy, incorporating it into my lesson planning, noting reflections on the implementation, and reviewing the audiovisual recordings and associated student-generated material. I noted during the TY Pilot studies that reflecting on my implementation of the metacognitive strategies, using multiple sources, supported the development of my practice in terms of viewing teaching and learning strategies through a metacognitive lens (discussed in Chapter 11). This aligns with previous research suggesting that the determining factor in whether a strategy is metacognitive depends on how it is implemented (Zohar & Barzilai, 2013; Brown et al., 1984; Tishman et al., 1995; Veenman et al., 2006; Zohar & Ben-David, 2008). As the TY module progressed, I was able to reflect on my analysis of previous implementations of the metacognitive strategies

and relevant literature. This reflection was part of the process undertaken before subsequently incorporating the different metacognitive strategies. This ongoing review of the literature and my practice regarding the incorporation of metacognitive strategies in chemistry lessons served not only to enhance my teaching but also to support my development as an action researcher. I learned to analyse data from a subjective and interpretative stance, moving away from the positivist and objectivist perspectives to which I was accustomed as a natural scientist.

The chemistry topics included in the first TY Pilot study are outlined in Table 6.1. When planning this pilot study, my rationale for selecting these topics was based on my awareness that students would have varying initial interest levels in chemistry. These topics were selected for their relevance to Junior Cycle Science and their connection to students' daily experiences, and I thought this would facilitate rich discussions about the students' prior use of cognitive processes related to these topics.

Table 6.1 Chemistry topics included in TY Pilot study one

The atom and flame tests
Electronegativity
Rates of reactions
Acid base reactions
Water (Pollution) Chemistry
Electrochemistry
Carbon Chemistry 1 Properties of Organic Substances
Carbon Chemistry 2 (Separation Identification methods, soap making)

My experience in the first TY Pilot Study highlighted the possible metacognitive value of 'chunking' using underlying concepts. Working memory refers to the brain's system for temporarily storing and manipulating information required for cognitive processes like thinking, understanding and learning (Baddeley, 1992). Chunking, the process of combining smaller units into meaningful wholes (Miller, 1956), enhances working memory capacity and reduces cognitive overload (Afflerbach et al., 2008). The conceptual framework (see Section 6.6) outlines my interpretation of metacognition in this work which includes awareness of cognitive processes. In my reflections at the end of the first TY pilot study, I noted that *"they [underlying concepts] provide opportunities to incorporate metacognition through students and I discussing and prompting how we thought about, learned, and visualised applying the chemistry concept to explain chemical phenomena we had already studied"*. This informed the order and selection of

topics in the second TY pilot study. For example, rather than introducing electronegativity as an isolated concept, I introduced and revisited it through chemical phenomena. This involved using electronegativity to foster awareness of cognitive processes such as thinking, visualising, and understanding chemical behaviour at the submicroscopic level. Examples included exploring the states of matter of substances at specific temperatures, as well as acid-base and redox reactions. The topics included in TY Pilot study two are given in Table 6.2.

Table 6.2 Chemistry topics included in TY Pilot study two

States of matter – polarity of molecules
Oxidation and reduction – transferring electrons
Acids and bases – transferring protons
Rates of reactions
Water chemistry
Electrochemistry (electroplating)
Carbon chemistry - soap making
Analytical chemistry - separation identification methods (MP. BP)

6.3 Reflections TY Pilot Study One (AR Cycle 1)

As discussed in Chapter 1, there is limited research on incorporating metacognition in a domain-specific way within the context of Irish chemistry education. This was something I noted in my initial reflections during TY Pilot study one where I wrote;

“It is curious that, in a subject largely focused on the abstract submicroscopic level, awareness of one’s thinking appears infrequently, at least in a meaningful way. I think such awareness allows thinking to be directed, enabling students to identify underlying concepts that explain chemical phenomena in their own minds. I think it is the chemist’s mind, therefore, that lies at the centre of making chemistry meaningful to human beings”.

This reflection demonstrates how my perspective on knowledge in chemistry was shifting from a positivist to an interpretivist viewpoint.

As part of my reflections in the first TY Study I noted the procedural nature of student discussions *“The conversations I overheard during group work was almost all procedures not about concepts”* and *“Student-student interactions were mostly on what to do next”*. I noted that I would need *“to make the tasks in lessons more related to how aware students are of their thinking at a particular point and using this as a base to modify and evolve their thinking”*. Similar to previous literature (Berthold et al., 2007), I noted the

“importance of metacognitive prompting” students to describe their cognitive processes in writing, or to each other, as a way of increasing awareness of their own cognitive processes for themselves and others.

Reflections at the start and end of lessons have been well established in the literature (e.g. Fowler et al., 2019), however through the use of pre and post lesson surveys (see Appendix B) my aim in TY Pilot study one was to promote metacognitive aspects and to provide evidence of metacognition. I noted that the post lesson reflections were not necessarily focused on *“What have students learned in a lesson”* rather it was on *“How has the students’ thinking changed in this lesson?”*. This approach embeds reflection in pedagogical context in chemistry, emphasises how both reflection and metacognition regularly co-occur, suggesting a strong link between them (Schön, 1991a; Moon, 2013). For example, Boud, et al. (1985, p. 141) argue that *“Reflection is thus ‘meta-thinking’”* and Sandars (2009, p. 688) asserts that *“reflection is a metacognitive process”*. I recognised the metacognitive value of the pre- and post-lesson surveys and saw their value in their potential use in future AR cycles. This aligns with previous literature, which suggests that a teacher's experience in implementing strategies correlates with their continued incorporation (e.g. Shukla & Dungsungnoen, 2016; Wilson and Bai, 2010).

In a lesson reflection, I noted how students would benefit from my metacognitive prompting to scaffold increasing their metacognitive awareness before introducing strategies that require more independent student output. (e.g. think aloud protocols). In line with other research in the domain of learning (Van de Pol et al., 2010), I interpret the use of metacognitive prompts and metacognitive-led discussions as scaffolding that provides temporary support, enabling learners to complete tasks with a depth of thinking and awareness they might not otherwise achieve independently. I found that this support can be provided in various ways, including metacognitive modelling by myself and using prompt questions that foster awareness of both students’ and my own cognitive processes. Furthermore, I noted in a lesson reflection the long-term importance of moving from *“teacher led metacognitive prompts and tasks to students activating their own metacognition to increase the durability and flexibility of their understanding of chemical concepts as they apply to various chemical phenomenon”*

Research indicates that the types of goal orientations teachers promote in the classroom influence how students learn and how they think about learning, and this was something

I remained conscious of during the TY pilot studies (Dweck & Leggett, 1988; Midgley, et al., 1995). I reflected on the questions I asked in the workshops and noted *“difficulties relating to asking higher order questions specific to chemistry with students having limited chemistry conceptual knowledge at this point, and in some cases interest”*. I addressed this by reducing the emphasis on new information introduced and focused on students’ awareness of their cognitive processes about the chemical phenomenon at that point in time and then incorporating new ideas through discussion in the lessons. Jean Piaget described aspects of this as knowledge re-construction triggered by cognitive dissonance, where the students adapt or reorganise their understanding to integrate new insights (Choi et al., 2005). I noted addressing this aspect of student awareness through *“using questioning to prompt students to think about difficulties they have in chemistry and what I am introducing”*. This tension can lead to conceptual change, as students work to consolidate their cognitive processes (e.g. understanding). It can be discussed or described in class to promote metacognition, encouraging students to become aware of their thought processes and actively engage in re-evaluating their understanding.

I identified the benefit of providing additional wait time for students when reflecting on the audiovisual recordings of the TY lessons. I also noted in a lesson reflection *“the timing of metacognitive prompts and the use of written reflection questions is an important aspect of embedding metacognition in the lessons, I had to work on my own awareness of asking questions related to students thinking at a particular time and the strategies they use to overcome cognitively challenging questions”*. This is in agreement with literature which argues the art of asking the right questions at the appropriate time is not innate (Lorsch & Ronkowski, 1982).

The importance of *“getting students to represent visually through drawing representations of their thinking and then modifying their representations following discussions in class”* and doing this *“while also introducing less theory at the beginning of each class”* was something I noted and reflected on following a number of lessons. This aligns with the argument by Tytler et al. (2013) that students should be the generators and refiners of representations, rather than merely receivers or interpreters. My observations from TY Pilot study one presented the possible valuable role of representations in enhancing student awareness of their cognitive processes in chemistry through associated prompts, descriptions, and discussions. For example, while reviewing the first TY module I noted how *“giving students the freedom to generate representations*

based on their own interpretation of a chemical phenomenon provided opportunities for the students to become more aware of their own thinking in chemistry” and “how it provides opportunities to discuss and describe student thinking thereby increasing awareness of thinking in a domain specific way”. In agreement with this, following the completion of the first TY pilot study, I noted *“how representations might provide the domain specific approach to incorporating metacognition in chemistry and could be embedded in other metacognitive strategies, especially in relation to the abstract submicroscopic level of chemistry”.* I also highlighted the *“difficulty will be using the generation and refinement of representations of chemistry to go from their cognitive use to the metacognitive use”.* While I was conscious of the need for evidence of metacognition if I was to use representations in this way, I was also mindful of Veenman et al.'s (2006) argument that when metacognition is not explicitly observed or verbalised during task performance, it must be inferred from evidence of specific cognitive activities. These observations I made initiated and gave rise to the focus on the use of student generated representations in future AR cycles.

Similar to Baines and Gregson (2020), I found that concurrently combining practice and research, along with immersing myself in developing research skills and conducting research, fosters change in professional practice. In an example of the two-way flow in terms of my development as a practitioner and researcher, I noted during the first TY pilot how my own understanding of how metacognition was incorporated into chemistry lessons was becoming more established and domain specific with experience in the classroom. For example, I noted *“how it is important to see opportunities for advancing teaching and learning strategies such that they incorporate metacognition, being conscious of opportunities to get students to discuss, write down and describe their thinking, and how their thinking evolves in chemistry and using this as a basis to generate a deeper discussion of thinking”.* I also noted during the analysis of the audiovisual recording and transcription of lessons *“opportunities for incorporating metacognition were missed”*, but that experiencing the strategies was really helpful for my *“own understanding of the implementation of the strategies in domain specific ways”.* I noted the potential benefit of analysing metacognitive events within lessons by using audiovisual recordings and my own reflections. This approach could aid in identifying and confirming metacognitive events as they occur in lessons. As discussed in Chapter 2, evaluating in-lesson events such as students' or teacher metacognitive activities ‘on the

spot' through audiovisual recording and participant observation enables the documentation, identification, and examination of targeted verbalisations in real time during authentic classroom interactions (Cleary, 2011). At the end of the first TY pilot, I noted the need to clarify my understanding of metacognitive events in chemistry lessons and the concept of metacognition in chemistry education by developing a conceptual framework and a method of analysing metacognitive events in chemistry lessons.

From a technical point of view, I identified difficulties in terms of the recording of individual students in the classroom; for example, in a reflection I stated that the camera microphone I was using was *“Unable to pick up students’ conversation during experimentation and while working in groups”* and that it was *“not suitable for group work due to other sounds from other groups”*. As such I purchased a boundary microphone for trialling in the second TY pilot study.

6.4 Reflections TY Pilot Study Two (AR Cycle 2)

As part of the planning phase of the second TY pilot, I decided to develop a booklet containing the templates for some of the metacognitive strategies in the first TY pilot study. This was the origin of the student *“Chemistry Metacognitive Journal”* used and described in the fifth-year study (AR Cycle 3) (see Chapter 7). Research indicates reflective journals can develop student metacognition, because reflective journals can stimuli students to think about their cognitive processes (Swanson, 1984; Henter& Indreica 2014).

During the implementation of the metacognitive strategies in the second pilot, the use of representations to demonstrate thinking particularly at the submicroscopic level became more apparent and I recorded this in my lesson reflections: *“I find that students generating representations is really metacognitively rich in terms of being able to give them a blank page and the freedom to draw what they think at that point in time, but also in terms of them describing and verbalising their thinking in chemistry, especially at the submicroscopic level. I also noted “how it often provides evidence to me of thinking or misconceptions I was not aware students had, in even basic chemistry, but they were able to mask the misconceptions behind well learned off definitions or even calculations.”* I noted the importance of being aware of how both the students and I think at the submicroscopic level, as this is the most elusive level, yet it is the one where chemical reactions (through the rearrangement of atoms and electrons) actually take place. The

aspects of representations that make cognition visible are the concepts contained in a representation of a chemical phenomenon, which draw on students' knowledge and understanding. I noted following the completion of a lesson in the middle of the second TY pilot study how I *"introduced the three levels of chemical representations, the submicroscopic, macroscopic and symbolic"* of a chemical reaction *"but students can be encouraged to think beyond their representations, to where they come from in their own minds using discussion, refinement and reproduction of their representations and using metacognitive prompts, teacher metacognitive modelling and metacognitive discussions"*. In relation to the aspects of representations that reveal metacognition, the main aspects I noted were (i) the students' voicing their cognitive processes through their descriptions, explanations and the discussion of their generated representation (ii) the opportunities to metacognitively prompt using the generated representations in a domain-specific way, and (iii) the generation and refinement of representations allowed students to demonstrate the evolution and consolidation of their cognitive processes in chemistry. While other studies (e.g. Renkl et al, 2013) have highlighted the use of analysing multiple representations, the emphasis which became evident to me while reflecting on the second TY pilot study was the metacognitive use of the generation and refinement of representations by students in chemistry.

Following my reflections and analysis of the first TY pilot study, I identified a need for a conceptual framework and observational rubrics for categorising metacognitive events in chemistry lessons. I found the conceptual framework was necessary to clarify my own understanding of metacognition in the context of chemistry. I also began to develop rubrics, based on scholarly reflection for categorising metacognitive events and identifying metacognitive strategies during chemistry lessons in the second TY pilot study. At the end of the second pilot study, I noted that the rubric required further refinement while analysing audiovisual recordings in the fifth-year study (AR Cycle 3) (see Section 5.1.1.1).

I noted for future AR cycles the importance of ensuring a supportive and encouraging environment where *"students have freedom to express their thinking in chemistry so that they can become more aware of their own thinking rather than trying to replicate the thinking of others"*. In addition, I noted how this in turn can be used to help students construct their own understanding and can be promoted through linking chemical phenomena through underlying concepts. Schraw (1998) argued metacognitive adeptness

does not exist in a vacuum. The importance of teachers helping students develop metacognition by creating supportive learning environments or through metacognitive strategy training has been researched in other contexts (Georghiades, 2004; King, 2011; Lin, 2001).

At the end of the second TY Pilot Study I noted that student engagement and interest was an issue in both TY pilot studies. In particular, “*at least the type of engagement that the students need to discuss their deeper thinking in chemistry*” was often lacking. This is understandable, considering that only approximately 20% of the students in the TY pilot studies planned to study chemistry in the last two years of the senior cycle and their engagement was sporadic due student participation in TY activities, which occasionally took some students out of my lessons. In addition, as discussed in Chapter 2, changing the classroom environment can be difficult and takes time as students might not be too enthusiastic about engaging in developing metacognition, especially if they have been rewarded previously for rather passive learning (Sternberg, 19980).

6.5 Summary of findings from TY pilot studies (AR Cycle 1 & 2)

In the TY Pilot studies, I noted how the metacognitive strategies I implemented often overlapped when being incorporated in lessons. Notably, I identified the metacognitive use of generating and refining representations of how students and I engaged in cognitive processes, such as thinking, visualising, learning, and understanding, in relation to chemical phenomena. The metacognitive dimension involved increasing awareness of each of these cognitive strategies, and this use of generating and refining representations was frequently embedded within other metacognitive strategies. My growing recognition of the value of the language of Johnstone’s Triangle (Johnstone, 1991) in addressing students' metacognitive awareness in chemistry prompted me to incorporate its language into discussions of cognitive processes in relation to chemical phenomena.

During the TY pilot studies, I gained an understanding of the significance of sequencing topics in schemes of work as part of incorporating metacognition in chemistry, grounded in an appreciation for the metacognitive application of underlying concepts. I consider an *underlying concept* to be a concept which helps explain a chemical phenomenon, often applicable to many chemical phenomena. For example, in the second TY pilot study, I encouraged students to think about and visualise how electronegativity can explain the behaviour of different substances in solid, liquid, and gas states at given temperatures,

while it can also be used to explain the tendency of different species to act as oxidising agents, reducing agents, acids, or bases. The use of concepts within metacognitive processes was described by Shea (2019) as 'concept-metacognition.' Shea (2019) argues that concepts function as cognitive tools, where one requires concepts that are sufficiently reliable for the induction of new knowledge. Concept-metacognition holds the potential to establish connections among distinct knowledge structures, including topics, exemplars, theories, etc. (Shea, 2019).

A student 'Chemistry Metacognitive Journal' was developed during and following reflection on the TY pilot studies to act as a teaching and learning aid for incorporating metacognition in chemistry lessons (see Chapter 7, Table 7.1 & Appendix B). The templates included in the 'Chemistry Metacognitive Journal' were implemented in the TY pilot studies and were based on the metacognitive strategies outlined in Chapter 2, Table 2.7, with an additional strategy and template for 'Student Generation and Refinement of Representations'. The metacognitive strategies selected after implementing and reflecting on the TY pilot studies is presented in Table 6.3. Based on a review of the TY pilot studies data (including audiovisual recordings and personal reflections), the metacognitive components addressed by each strategy, as outlined in the conceptual framework in Section 6.6, are detailed in Table 6.3.

Table 6.3 Components of metacognition addressed by strategies implemented in the fifth-year study

	Metacognitive strategy	Components of metacognition particularly addressed in the strategy
a	Student generation and refinement of representations	Metacognitive awareness and regulation
b	Explicit metacognitive instruction	Metacognitive awareness and regulation
c	Metacognitive modelling	Metacognitive awareness and regulation.
d	Metacognitive prompts	Metacognitive awareness and regulation.
e	Pre and post lesson reflections	Metacognitive awareness - declarative and procedural knowledge. Metacognitive regulation - planning and evaluation.
f	Teacher led metacognitive discussion	Metacognitive awareness and regulation.
g	Think aloud protocol	Metacognitive awareness and regulation
h	Regulatory Checklists (RC)	Metacognitive regulation – Planning, monitoring, and evaluation.
i	Strategic Evaluation matrix (SEM)	Metacognitive knowledge - Declarative, procedural, and conditional.

During the TY pilot studies, opportunities for explicit metacognitive instruction, metacognitive modelling, and teacher-led metacognitive discussions were embedded into the lessons. These strategies provided opportunities for me to develop and reflect on my practice in terms of incorporating metacognitive language in chemistry lessons.

As discussed in Chapter 4 (Section 4.4.2), the TY pilot studies provided opportunities to plan, observe, and reflect on the suitability of metacognitive evaluation inventories for use in the fifth-year study. The TY pilot studies also offered practical experience in video recording of lessons, recording student generated material and documenting my scholarly reflection.

An additional finding from the pilot studies was that effective scaffolding for embedding metacognition requires the chemistry teacher's experience and understanding of metacognition, along with their ability to apply it in a domain-specific chemistry context. This insight is incorporated into the conceptual framework I developed during this research described in the next section.

The practicalities of recording lessons in the TY pilot studies led to the identification of the optimal location for the recording device. It was found that the audiovisual recorder placed on the teacher's (my) desk pointing towards the students gave the best results in terms of discernible dialogue of both students and me. A limitation of this approach was the difficulty in attaining group work dialogue. The use of a boundary microphone did not work well during the TY pilot studies and so was discontinued.

6.6 The development of a conceptual framework

Similar to previous research (e.g. Claesgens et al., 2009), the iterative process (AR Cycles) proved important to the ultimate formation of my conceptual framework. It is for this reason that I present the conceptual framework, and in particular my interpretation of metacognition in the context of chemistry, at this point in the thesis for the reader. The formation of this conceptual framework was a key part of my development throughout the AR cycles, with many foundational ideas emerging during the TY pilot studies. I continually revisited the literature on metacognition to refine and reflect on my interpretation in the context of chemistry and following my experiences as part of the AR cycles. The type of continuous scholarly reflection (Du Toit, 2012) that I engaged in constitutes an integral and essential principle of AR. This reflection cannot occur effectively without a solid theoretical foundation, which includes the review and

synthesis of literature summarised in Chapter 2, along with practical experience (De Boer et al., 2013). The conceptual framework includes my interpretation of cognition, metacognition, visualisations and representations, as they apply to chemistry.

6.6.1 Metacognition in chemistry education

In this work, cognition in chemistry refers to the performance of cognitive (mental) processes (see Chapter 2, Table 2.1) related to chemical phenomena, including thinking, visualising, understanding, attention, language, problem-solving, learning, memory, and perception, at the submicroscopic, macroscopic and symbolic levels of chemistry (See Figure 6.2). Metacognition is interpreted as the awareness and regulation of cognitive processes and the submicroscopic, macroscopic and symbolic levels in relation to chemical phenomena; for example, an awareness and regulation of visualisations related to a chemical phenomenon and awareness of understanding of relevant knowledge. Figure 6.2 illustrates my interpretation of cognition and metacognition in chemistry.

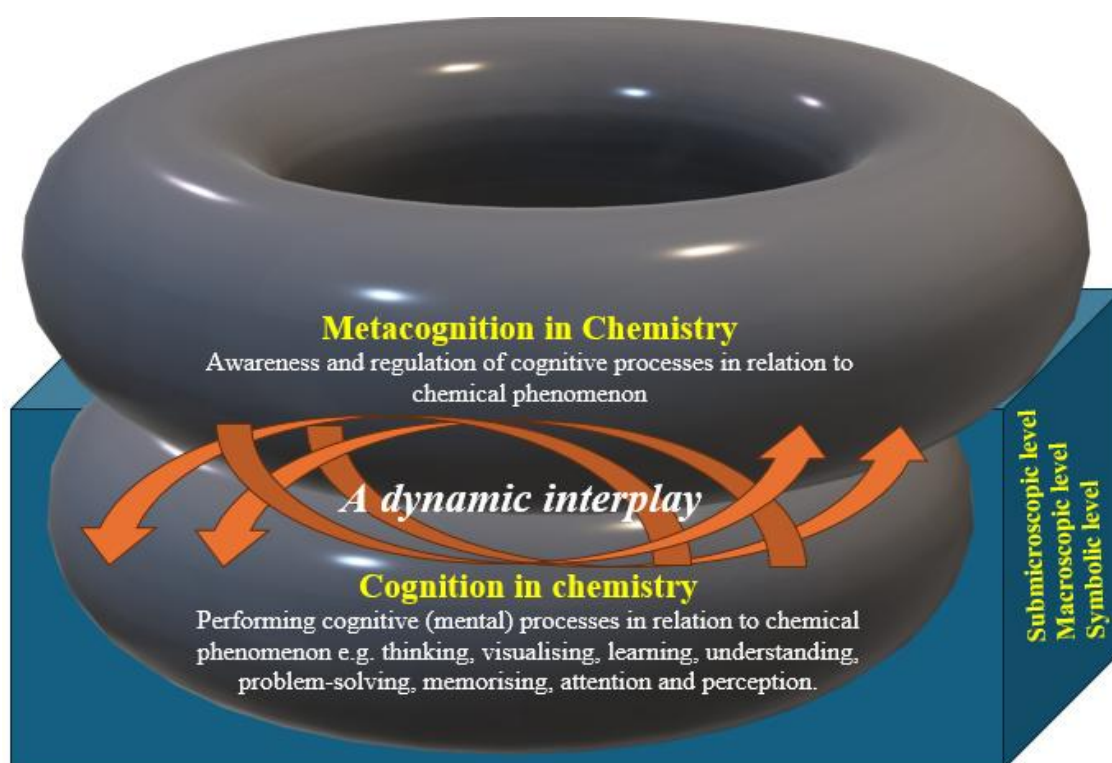


Figure 6.2 Cognition and metacognition in chemistry

‘Visualisation’ in the context of this research is interpreted as a cognitive image (e.g., imagining the electron cloud in a water molecule), which is only truly experienced by the individual themselves and is unobservable by others. The mental creation of a visualisation of a chemical phenomenon is interpreted as the cognitive process of

‘visualising’. A ‘chemical phenomenon’ is interpreted as a fact or thing related to matter or changes in matter. A ‘chemical phenomenon’ is specific e.g., the acid and base reaction between ethanoic acid and water, and ‘knowledge’ is used to think about and to explain the chemical phenomena to oneself and others. The use of ‘knowledge’ here includes underlying concepts that contribute to the understanding of a particular chemical phenomenon, e.g., in explaining how ethanoic acid acts as a weak acid with water, knowledge of the concept of electronegativity as it influences the polarity within water and ethanoic acid molecules and the resulting effect on the interactions between these molecules. Knowledge and visualisations related to a chemical phenomenon can be presented in a domain specific way using representations. “Representations” in this work are interpreted as what one generates which is observable by others and external (e.g., in the example above, the drawing of molecules with a depiction of the electron cloud to show the polarity within a water or an ethanoic acid molecule). Following a synthesis of the literature described in Chapter 2, the current work’s interpretation of metacognition as it relates to cognition, representations and visualisations in chemistry is shown in Figure 6.3 and is an adaptation of a figure from Locatelli, et al., (2010). I include “Models” in Figure 6.3 to provide added context for the reader.

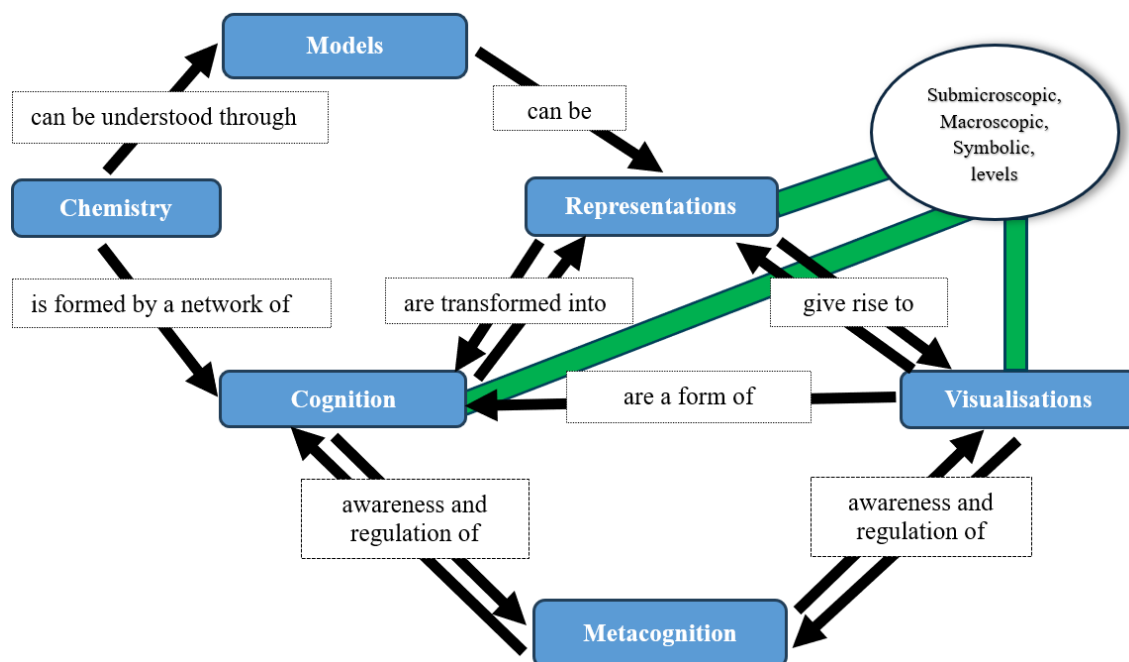


Figure 6.3 Metacognition and its relationship with cognition, visualisations and representations in chemistry in this study

The two main components of metacognition are taken in this research as metacognitive awareness and metacognitive regulation. As discussed in Section 2.3, metacognitive

awareness and metacognitive knowledge are used interchangeably in the literature. ‘*Metacognitive awareness*’ terminology was chosen over ‘*metacognitive knowledge*’ as I think ‘*awareness*’ better reflects the ongoing nature of cognitive processes, rather than a more static state inferred from the word ‘*knowledge*’. The subcategories of metacognition in the context of this thesis are shown in Figure 6.4 and are discussed in the following sections within the domain of chemistry.

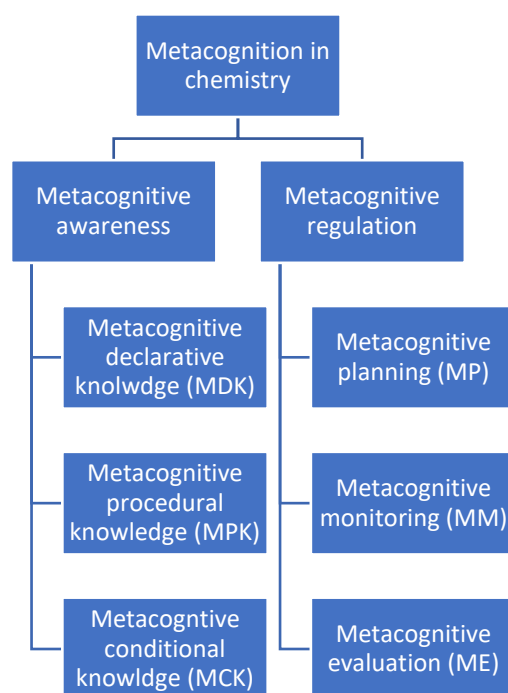


Figure 6.4 Subcomponents of Metacognition - as used in this study

6.6.1.1 Metacognitive awareness in chemistry education

Metacognitive awareness in this work includes one’s *metacognitive declarative knowledge* (MDK), *metacognitive procedural knowledge* (MPK), and *metacognitive conditional knowledge* (MCK) of one’s cognitive processes, specifically related to chemical phenomena. These subcomponents of metacognitive awareness were chosen over ‘*knowledge of persons*’, ‘*knowledge of task*’ and ‘*knowledge of strategies*’ because I found MDK, MPK, and MCK more distinct from each other, particularly when differentiating between them when analysing audiovisual recordings in the AR cycles.

In this thesis, MDK is interpreted as one’s awareness of cognitive processes related to chemical phenomena and awareness of the intellectual resources one has, including the knowledge one has. MDK includes an awareness of one’s visualisations of chemical phenomena at the submicroscopic level and awareness of the cognitive use of

representations to voice, evolve, and consolidate one's cognitive processes in chemistry. For example, awareness of the value of visualising the electron cloud and polarity in ethanoic acid and water molecules and generating representations of one's visualisations using the ball and stick representations, space-filling representations, Lewis structures, or Bohr diagrams to evolve and consolidate one's understanding. In addition, MDK includes awareness of relevant knowledge one has to use to think about a chemical phenomenon, e.g. in relation to the reaction of ethanoic acid and water, awareness of one's visualisations and other cognitive processes related to knowledge such as (i) electron density within the molecules resulting from the relative electronegativity of carbon, oxygen, hydrogen and how their electronegativity is a result of their atomic structure (ii) the polar single bond between oxygen and hydrogen resulting in polar water molecules in addition to the lone pairs on the partially negative oxygen giving rise to the proton accepting behaviour of water, (iii) the polar bonds along the chain of atoms from carbon, to oxygen and hydrogen in ethanoic acid giving rise to its proton donating behaviour (iv) the interactions between molecules of water and ethanoic acid resulting in a minority of collisions involving the transfer of a proton in the equilibrium mixture of the acid base reaction at the submicroscopic level. This example illustrates an awareness of one's understanding of the underlying concept of electronegativity, which one can use to explain chemical behaviour at the submicroscopic level.

MPK in this thesis is the awareness of how to use cognitive processes in relation to a chemical phenomenon. Where MDK is awareness of the need to carry out a cognitive process, e.g., visualising the electron cloud of a molecule of water to help think about reactivity, MPK relates to awareness of how a cognitive process can be carried out e.g., how to visualise the electron cloud and polarity of a molecule of water. To return to the example of the reaction between ethanoic acid and water, MPK includes awareness of

- (i) knowing how to visualise the chemistry of the reaction at the submicroscopic level;
- (ii) knowing how to visualise chemical bonds (e.g., the polar bonds of *O-H*, and how the atomic structure relates to the relatively high electronegativity of oxygen and relatively low electronegativity of hydrogen);
- (iii) knowing how to visualise the collisions between molecules of ethanoic acid and molecules of water;

- (iv) knowing how to apply one's understanding of electronegativity to explain the polarity of molecules e.g. the polarity that results from *O-H* and *C-O* bonds.

MCK refers to one's awareness of the 'why', 'when' and 'where' or under what circumstances specific cognitive processes should be applied to a chemical phenomenon. Examples of MCK include why and when one would visualise a chemical phenomenon in a specific way to aid the evolution and consolidation of one's cognitive processes or when to access particular aspects of one's understanding to aid learning. In the example of the reaction of ethanoic acid and water, MCK includes knowing why, when and where to (i) visualise the distribution of electron density within a molecule of ethanoic acid to understand polarity; (ii) visualise the electrons in the double *Carbon-Oxygen* bonds and single *Carbon-Hydrogen* bonds; (iii) awareness of one's understanding of electronegativity and electron density to explain the polarity and nonpolarity of different bonds in ethanoic acid or water molecules.

6.6.1.2 Metacognitive regulation in chemistry education

While metacognitive awareness is awareness of one's cognitive processes, metacognitive regulation is how one regulates one's cognitive processes in relation to chemical phenomena. Based on the literature discussed in Section 2.3.2 and as shown in Figure 6.4 metacognitive regulation includes *planning* (MP), *monitoring* (MM), and *evaluating* (ME) cognitive processes. Metacognitive regulation includes making changes to one's cognitive processes in relation to a chemical phenomenon as a result of monitoring, e.g. changing how one visualises an electron cloud or rotating a molecule or how one thinks about linking a chemical phenomenon to one's understanding of an underlying concept.

MP refers to setting goals and making plans to achieve those goals, selecting cognitive processes, activating relevant existing knowledge, and managing time and resources in relation to the study of a chemical phenomenon. For example (i) planning how one could visualise a chemical phenomenon and deciding on the most appropriate visualisation to begin with, (ii) establishing possible ways one can understand or learn about a chemical phenomenon by identification of one's relevant knowledge, and (iii) planning how to represent one's cognitive processes related to a chemical phenomenon. With reference to the reaction of ethanoic acid with water, such planning could include: (i) activating one's understanding related to the relative electronegativity of atoms within water and ethanoic

acid which give rise to the polarity and acid/base behaviour outlined in MDK above; (ii) planning visualisations based on electron cloud within ethanoic acid and water molecules to activate one's submicroscopic understanding of the possible interactions between water and ethanoic acid molecules; and (iv) activating one's understanding of the polarity and structure within molecules of ethanoic acid and water and the resulting inductive effect giving rise to the donation of a proton from an ethanoic acid molecule to a molecule of water in a minority of collisions in the equilibrium mixture.

MM is interpreted as the process by which one oversees one's cognitive processes in chemistry. This involves: (i) tracking one's cognitive processes in relation to the chemical phenomenon (ii) tracking one's knowledge used to explain a chemical phenomenon. To return to the example of a reaction between ethanoic acid and water, MM would comprise of (i) tracking visualisation types, e.g., visualising the electron density of the molecules when thinking about polarity in molecules of ethanoic acid or water, while actively switching ones thinking to a ball and stick visualisation when thinking about the type of bonds (double or single) that exists between the atoms in the ethanoic acid or water molecules; and (ii) tracking and switching between one's existing knowledge such as how electronegativity relates to the polarity of carbon-oxygen and oxygen-hydrogen bonds and the electron density related to the double carbon-oxygen bond in ethanoic acid molecules and visualising sigma and pi bonds in the double bond between carbon and oxygen.

ME refers to appraising the outcomes of cognitive processes, including assessing one's cognitive processes related to chemical phenomena. Returning again to the example of the reaction between ethanoic acid and water, ME would involve;

- (i) thinking about how one's visualisations of the distribution of electron density helped activate one's understanding of the polarity of the bonds and to explain the relative acidity of ethanoic acid;
- (ii) evaluation of the relevance of understanding the number of effective collisions between ethanoic acid and water molecules in the dynamic equilibrium mixture;
- (iii) evaluation of one's ability to represent and explain one's submicroscopic visualisations and understanding in relation to the reaction of what occurs between ethanoic acid and water;

6.7 Conclusion

As discussed in this chapter the TY pilot studies (AR Cycles 1 & 2) provided the context for the implementation and refinement of metacognitive strategies in my chemistry lessons, while also the trialling of data collection techniques and analysis ahead of the Fifth-year Study (AR Cycle 3). The planning, action, observation and reflection on the TY pilot studies (AR Cycle 1 & 2) provided a foundation for the later AR cycles by shaping my interpretation of metacognition in the context of chemistry, my implementation of metacognitive strategies in chemistry, and my scholarly reflections as an action researcher. My experience in the TY pilot studies, including my continuous review of literature, contributed to my development as an action researcher and my increasingly interpretivist stance, including an appreciation for the subjectivity of all knowledge, even in a scientific subject like chemistry. This represented a significant shift in my perspective as a natural scientist, and one I initially struggled with. Facilitating this shift were my reflections on how a student's verbal or visual representations can often differ significantly from what I intended to convey, or at least from the visualisation I had in mind while teaching the chemical phenomenon. For example, my thinking shifted to recognise that even statements I, as a chemist, assumed to be factual are open to unique cognitive interpretations by those I present them to, including in terms of language and visualisations. In addition, the TY pilot studies contributed to the formation of the conceptual framework for this work, which was discussed in this chapter to provide clarity regarding my interpretation for the reader throughout the rest of the thesis. The analysis of the TY studies (AR Cycles 1 & 2) contributed to addressing research questions relevant to the Senior Cycle study, which are discussed at the end of the next chapter, Chapter 7, which focuses on the fifth-year study (AR Cycle 3).

Chapter 7 Fifth-year Study (AR Cycle 3)

Building on the incorporation and reflective analysis of metacognitive strategies in the TY pilot studies (AR Cycles 1 and 2), a number of these strategies were embedded in the fifth-year study (AR Cycle 3). The implementation of the metacognitive strategies was continuously refined based on experience during the action and observation phases of the fifth-year study including my ongoing review of relevant literature (see Chapter 2). Table 7.1 shows the metacognitive strategies incorporated in the fifth-year study (AR Cycle 3) and those accompanied by a template in the ‘Chemistry Metacognitive Journal’. Descriptions of my incorporation of metacognitive strategies in the fifth-year study are provided in Section 7.2.

Table 7.1 Metacognitive strategies implemented in the fifth-year study

Metacognitive strategies implemented fifth-year study	Template included in the ‘Chemistry Metacognitive Journal’
Reflective writing: Pre and post lesson surveys	✓
Strategic Evaluation matrix (SEM)	✓
Regulatory Checklist (RC)	✓
Generation of representations	✓
Student Think aloud	
Metacognitive prompts	
Teacher led metacognitive discussion	
Teacher metacognitive modelling	
Explicit metacognitive instruction	

In addition to planning for the incorporation of metacognitive strategies, the planning for the fifth-year study also included developing a scheme of work, which is outlined in Appendix C and an outline of topics in the scheme of work is given in Table 7.2. Drawing on my reflections from the TY pilot studies and the Leaving Certificate Chemistry Curriculum (DES, 2002), I selected a specific order of topics for the fifth-year study based on my evolving belief that these topics offer opportunities to explore underlying concepts, which I saw as valuable in fostering metacognitive awareness in a chemistry context. For example, student awareness of their cognitive processes could be addressed using the underlying concept of electronegativity as it relates to chemical phenomena in topics like ‘states of matter’ ‘redox reactions’, ‘acid-base reactions’ etc.

Table 7.2 The chemistry topics in the fifth-year scheme of work

1	States of matter	11	Concentration of solutions
2	Gas laws	12	Volumetric analysis acids and bases
3	Atomic structure	13	Reaction rates
4	Ionic bonding	14	Factors affecting rates of reaction
5	Covalent bonding	15	Periodic table
6	Chemical compounds	16	Electronic structure of atoms
7	Chemical equations	17	Atomic radius and ionisation energy
8	Oxidation and reduction	18	Shapes of molecules
9	Acids and bases	19	Structure of aliphatic hydrocarbons
10	The mole concept	20	Exothermic and endothermic reactions

The fifth-year study provided a valuable opportunity to deepen my scholarly reflection on metacognition within the context of chemistry. For instance, lesson events interpreted as addressing the subcomponents of metacognition provided further context for my understanding and experience in incorporating metacognition in chemistry. Therefore, I detail these events in the next section.

7.1 Subcomponents of metacognition in the fifth-year study

As part of my scholarly reflection as an action researcher, I analysed and reflected on lessons to gain a deeper understanding of metacognition and its subcomponents in the context of chemistry and this analysis contributed to the development of the conceptual framework (See Section 6.6). As discussed in Chapter 5, Section 5.1.1.1, I developed and refined observational rubrics to identify events in chemistry lessons which addressed the subcomponents of metacognitive awareness and metacognitive regulation. I then used the observational rubrics to analyse the occurrence of events in a sample of 40 lessons, and the results are shown in Figure 7.1.

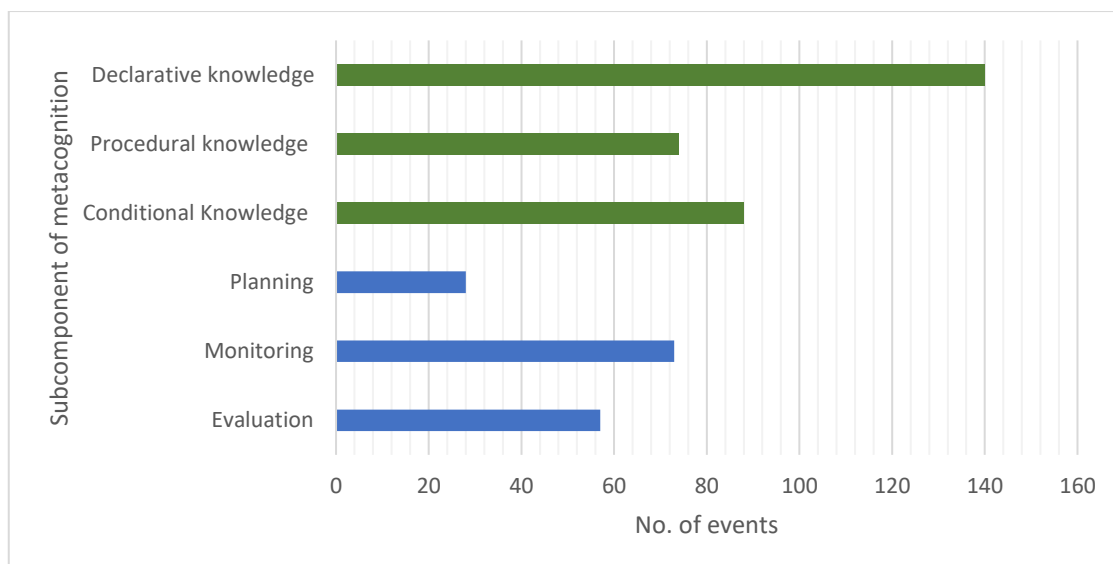


Figure 7.1 The number of lesson events which were categorised addressing different subcomponents of metacognitive awareness (green) and metacognitive regulation (blue)

Events which were categorised as MDK included when the teacher or student refers to their own understanding, or the student's understanding of thinking and knowing in general, or when the teacher refers to knowledge of their (or students) skills, intellectual resources, and abilities as a learner. For example, when I or a student described our own cognitive processes;

“For me unless I can visualise what a word like the mole is in chemistry, it is meaningless to me” (PR).

“I like drawing it out, that’s the way I think about it anyway” (Student KQN)

“I imagine the electrons being pulled by the bigger atom, I mean the atom with the bigger electronegativity” (Student DGD)

The relatively high value for MDK events can be partly attributed to the *“student responses included stating what they know, are often in short answers”* as I noted in a reflection. In addition, MDK was part of my focus on developing the *“students’ awareness of their cognitive processes in chemistry, with a particular focus on their awareness of understanding and visualising chemistry at the submicroscopic level and how they switch between that and the macroscopic level or symbolic level”*. This interplay in cognitive processes has been extensively discussed in the literature, emphasising the constant interplay between macroscopic and submicroscopic levels

as a fundamental characteristic of understanding chemical phenomena (Bradley & Brand, 1985) (See Section 2.3).

Events which provided evidence of teacher or student applying knowledge for the purposes of completing a procedure or process were categorised as MPK e.g., Students DJC and FJT explicitly stated their awareness of the cognitive process of problem solving related to MPK in chemistry.

“I learned how to use the formula $PV=nRT$ and how to do the experiment correctly. I also learned more about the stoichiometry steps involved in the calculation and what they mean.” (Student FJT)

“Look at the valence electrons. Draw a basic shape where electrons are bonded. Find the lone pair if there are some. Organise the shape so that the lone pairs push bonds away. Find the greatest distance between bonds.” (Student DJC, describing their thinking on VSEPR Theory using a representation)

As part of my reflections, I noted the prevalence of *“students just wanting to ask what are the steps to follow to find the concentration”* and the importance of prompting them to increase awareness of the variety of procedures related to their cognitive processes about *“chemistry at the submicroscopic level and what the numbers in chemistry mean at the molecular level”*. In addition, I noted in my lesson reflections *“the need to focus on the thinking related to the ‘why’ of procedures used”*. The focus on linking procedural knowledge and conceptual knowledge was emphasised as part of research in mathematics education by Braithwaite and Sprague (2021), whereas my aim was to go beyond that, to address students’ awareness of their cognitive processes related to their procedural knowledge and conceptual knowledge i.e. MPK.

I emphasised the importance of MCK as a fundamental aspect of metacognitive awareness, as noted in my reflection *“MCK plays a central role in awareness of the need to select appropriate MDK and MCK when attempting to understand a chemical phenomenon”*. Cromley and Kunze (2020) affirm this assumption where they argue the relationship between metacognition and learning particularly depends on MCK. Events which were classified as addressing MCK in the fifth-year study included events where I or students referred to knowing the ‘why’ and ‘when’ or ‘where’ aspects of cognitive processes. An example of this occurred when I asked student DJC to describe how they came up with their strategy following their description of their cognitive processes in relation to the conservation of mass and a balanced equation.

PR: *Did you come up with that yourself? How did you come up with that strategy, do you know when you can use it?*

Student DJC: *Yeah, I used the balancing equations from mathematics principle because it made sense to me. I knew the molecules have to balance so when I see the equals I think about the equality of both sides.*

PR: *So, you're pretty confident you are clear on the thinking process you have used.*

Student DJC: *Yeah, I know when to use the equality in maths and then I know what it means in these chemistry problems.*

In the above example DJC makes no link to the submicroscopic chemistry taking place in a reaction, while they appear to be clear on the ‘steps’ using equality. I noted in a lesson reflection the “*reliance on ‘mathematics steps’ can lead to a masking of a lack of understanding in chemistry, especially as students can be unaware of this reliance in their thinking and they very much think calculations are chemistry*”. This observation aligns with findings from previous research (Vladušić, et al., 2016; Goodney, 2006; Johnstone, 2006; Hinton & Nakhleh, 1999; Bodner, 2003). Students also displayed MCK in relation to when and why they would use visualisations in chemistry, for example “*The solutions were easier to find if I lean on a picture in my head rather than just numbers*” (Student FRK)

Student responses to metacognitive prompts demonstrate their MP as part of their metacognitive regulation, including an awareness of their cognitive processes related to deciding which procedures are necessary to complete a task;

“I know how the number of atoms is calculated from moles grams and Litres; I need to be able to use the ratio from the equation.” (Student FRK)

If I draw it out first it might be clearer, I can add in the electronegativity values and see if it makes sense to me” (Student DEH)

In my reflections, I highlighted the importance of tasks or prompts that encourage the development and elaboration of MP. I emphasised the need to “*give students time and encouragement to represent their thoughts on a specific chemical phenomenon when introducing it*”. I also noted that “*the focus should be on awareness of what they understand at that moment, through activation and discussion of their thinking, rather than a fear of having to be theoretically correct. What they think at this stage should be viewed as part of the journey, with theoretical correctness being part of the*

destination". Consistent with my view to address MP, Azizah and Nasrudin (2019) argue that empowering students in MP can improve their understanding of chemistry problems by helping them identify existing knowledge relevant to the phenomenon.

Examples of students verbalising MM included while they were thinking aloud and in response to metacognitive prompts, e.g., student DHE and student BTD responses metacognitive prompts indicate MM;

I know I am not going to solve it by staring at the numbers, I need to try something else (Student DHE)

I am thinking about if the number of molecules actually equal at a given volume, temperature, and pressure, or is the difference just too insignificant to matter (Student BTD)

ME was embedded in lessons through the use of various strategies, including pre and post lesson surveys, metacognitive prompts, metacognitive modelling by me etc. The incorporation of ME through self-checking, reflection, re-evaluation, and task performance review has been discussed in previous studies (e.g. Schraw et al., 2006; Schraw & Moshman; 1995; Veenman, 2012; Cross & Paris, 1988). In examples of a prompt question related to ME, students DHE and QUN were asked what additional questions they would like answered regarding a balancing equation problem for the combustion of methane. Their responses were;

"How do the molecules look before and after? Is there a set way or can we imagine it however we like?" (DHE)

"I understand molecules react, but I am still not sure how to understand the number of each type of atom when balancing an equation, this confuses me when I imagine full molecules made up of different atoms" (Student QUN)

DHE's questions indicate that they are evaluating how the submicroscopic level can be visualised and implies their awareness of both the abstract submicroscopic level of chemistry and how one thinks about and visualises this level.

The relatively low number of occurrences reflecting the metacognitive regulation subcomponents of MP and ME (Figure 7.1) can be attributed to these being captured as longer events during the lessons. For example, a pre-lesson survey was classified as a

single MP event, while a post-lesson survey was categorised as a single ME event. The relatively frequent occurrence of MM events, compared to other subcomponents of metacognitive regulation, aligns with the other data, particularly the high number of metacognitive prompts recorded (see Figure 7.3).

Analysing and categorising events in lessons as evidence of the subcategories of metacognition provided me with a valuable reflective experience, encouraging me to focus on metacognition in a domain-specific chemistry context. It is important to note that I am aware that I am drawing inferences regarding metacognition from evidence of specific cognitive activities and that this is often required (Veenman et al., 2006), however the above examples provide supporting evidence for my incorporation of metacognition in chemistry lessons, extending beyond the cognitive aspects of learning through the metacognitive strategies discussed in the next section.

7.2 Incorporation of metacognitive strategies in the fifth-year study

This section outlines and provides examples of how I incorporated metacognitive strategies in the fifth-year study. My use of a number of different strategies as part of teaching chemistry is in agreement with previous research which argues the use of multiple strategies reinforces the concepts in chemistry while also fosters the metacognition necessary for understanding chemistry and improves the chances for the teacher to tap into the cognitive strengths of students (Francisco, et al., 1998). The discussion of the implementation of the metacognitive strategies is based on an analysis of the audiovisual recordings of lessons and triangulated by student generated work and my reflections. Explicit metacognitive instruction, teacher metacognitive modelling, teacher-led metacognitive discussions are discussed first as they were part of my strategy to scaffold the incorporation of metacognition in chemistry lessons. Scaffolding using the teacher led metacognitive strategies in particular were based on the rationale provided in previous literature which indicates that development of such learning first takes place on a social (intermental) level before it takes place on an individual (intramental) level (Stone, 1993). Based on my experience and reflection on using the generation of representations as a domain-specific metacognitive strategy, which was integrated with other metacognitive strategies in the TY pilot studies and the fifth-year study, it is discussed separately in Section 7.3.

7.2.1 Explicit metacognitive instruction

Explicit metacognitive instruction involves using explanations and activities which require students to construct their understanding of metacognition (Zohar & Barzilai, 2013; Tishman, et al., 1995; Veenman et al., 2006; Zohar & Ben-David, 2008). I embedded explicit instruction on metacognition as part of lesson planning. Additionally, my experience in the TY pilot studies and continual review of the literature enabled me to make use of impromptu opportunities within chemistry lessons (e.g., Zohar & Ben David, 2008). Explicit metacognitive instruction was frequently used throughout the fifth-year study (see Figure 7.3), as I recognised the value of directly discussing with students why I ask them to go beyond merely answering conceptual questions. I was also mindful of the importance of ensuring that explicit metacognitive instruction was not overly theoretical or burdensome for students, and that they recognised its relevance to their chemistry understanding, particularly in terms of the transferability and flexibility of using their knowledge. For example, I described metacognition using an analogy from the story of Hansel and Gretel to illustrate the concept of being aware of one's own cognitive processes

“It’s [metacognition] a bit like Hansel and Gretel and the breadcrumbs. In chemistry you must know your own thinking on how you got to the answer or understanding of a chemistry concept. It should be about more than just getting the answer or understanding of a concept, it’s about thinking about what your thought processes were while you were reaching your answer or understanding, how you could have altered the thought processes and be aware of other thought processes that could have been used, or how you will use them in the future. For example, being aware that drawing a diagram helps me build up or bring together a mental image and think about what I already understand about the chemistry of H_2O , and now that I have drawn the molecule what chemistry can I include to represent my thinking” (PR)

In this description, I aimed to emphasise the importance of being aware of our cognitive processes when developing an understanding of a chemical phenomenon, and that it leads to a more flexible and transferable chemistry knowledge. While this description may not appear overtly clear out of context, I noted in a lesson reflection that I “*was often referring back to it [Hansel and Gretel analogy] by encouraging students to drop a few breadcrumbs in relation to describing their thinking when understanding particular chemical phenomena*”. While the above example does not cover all aspects of metacognition, it is an example where the language of thinking

and metacognition is embedded in a normal lesson using accessible language for students. I also noted this in the lesson reflection where I noted “*the importance of using accessible language when describing metacognition and the importance of keeping it aligned with the chemistry being studied*”.

7.2.2 Teacher led metacognitive discussion

To incorporate metacognitive discussions, I planned and engaged in whole-class conversations where I talked with students about their awareness of cognitive processes in chemistry. For example, rather than focusing on the correctness of students' answers to a task, I would plan to ask them about the origins of their cognitive processes regarding a chemical phenomenon, explore alternative cognitive processes, and encourage students to ask me about my own cognitive processes related to the phenomenon before evolving the discussion toward theoretical correctness. This approach aimed to encourage, normalise, and embed metacognitive discussion within a chemistry context. In agreement with literature (Tishman & Perkins, 1997; Tishman, et al., 1995), I noted in a post lesson reflection how the language used in teacher-led metacognitive discussions requires me as the teacher to understand metacognition and how it relates in the context of chemistry, while also being capable of verbalising that knowledge using adequate ‘language of thinking’. In a lesson reflection I emphasised the importance of language in describing the submicroscopic, symbolic, and macroscopic levels of cognitive processes in chemistry, particularly fostering awareness at the abstract submicroscopic level. An extract from a metacognitive discussion I led in a lesson is given below:

PR- *What you've done is perfect. You know why I ask 'why', why did you do it, right or wrong? I just want you to be able to understand the chemistry and think about the chemistry in the moment as you generate the answer. You know why I asked you BGN, I don't want you to have to memorise this after this lesson. You know, I sometimes think of learning chemistry like dropping breadcrumbs... that you need to leave a few breadcrumbs in terms of your thinking of how you get to an answer or an understanding. How you think about each stage or step is what is important to be aware of. What's the problem if you do the same thing over and over, and you might be still getting the correct answer and you might do it 20 times. But you don't understand how you got from point A to point B. What other subject does this often happen in?*

Student DHE - *Maths.*

PR- *Yeah, what can happen in maths if you do 20 of the same type of question. What can happen after the second or third question?*

Student DHE *You just look back at how you did the last question.*

PR - *yeah what are you just doing?*

Student DHE- *just repeating not understanding.*

PR- *Yeah. We want to think about what we are doing when trying to understand chemistry topics, thinking about concepts we already know, visualising what the chemistry looks like at the submicroscopic level, but also be aware of how we are thinking about it and just as important in controlling how we are thinking about it in the moment.*

The above extract of a teacher-led metacognitive discussion demonstrates how I wanted to highlight what can occur when repetition is used as a learning strategy rather than creating situations which encourage students to examine the ‘why’ of their cognitive processes including their thinking, visualisations and understanding of a chemical phenomenon. This extract illustrates the rationale I consistently provided to students for questioning their cognitive processes during lesson tasks, think-aloud protocols, or while generating representations of their visualisations. My aim was to develop students’ awareness of their own understanding of underlying concepts in order to ‘make sense’ of chemical phenomena. I noted in a post lesson reflection, how the careful use of asking the question ‘why’ as a prompt, can encourage each of the subcomponents of both metacognitive awareness and metacognitive regulation while completing a task. For example, by asking students ‘Why’ they think a certain way when they are describing a chemical phenomenon it requires students to explain where their cognitive processes (e.g. visualisations, understanding, learning) on a chemical phenomenon have come from (MDK). It could be argued that the above discourse is what Nuthall (2005) calls part of a ritual routine of a ‘*question-answer-comment sequence*’, however the aim of the dialogue was linking the theory of metacognition in practice which I embedded and was continually revisited in lessons.

7.2.3 Teacher metacognitive modelling

Planning for metacognitive modelling involved practicing how to verbalise my metacognitive awareness, such as thinking about how I would explain how I am aware of my cognitive processes related to a specific chemical phenomenon. Metacognitive modelling also took place on an impromptu basis, for example, in response to student questions, I would discuss my awareness of my cognitive processes related to their question, rather than simply give the conceptual answer. An example of this arose when a student asked about how to understand the conjugate acid-base pairs. In my response, I

aimed to address some common perspectives in the cognitive processes of others, such as focusing on 'sides of equations' or rote memorisation, which often overlook cognitive processes in relation to submicroscopic interactions. To contrast, I demonstrated my approach to understanding conjugate acid-base pairs by describing my cognitive processes related to the changes occurring to species at the submicroscopic level.

PR- *“Some people say if it is on this side conjugate [right hand side of the chemical equation] and if it's on the other side it's not. I don't think this way. I never went down that road of learning things off, because I just had no interest in learning things off. What I want to demonstrate here is, I don't have some sort of serious memory, it's more because I know I have to understand the chemistry, and to understand it I have to know how I think about it at the submicroscopic level, how the species involved are acting. And that's where I would like to get you guys as well. But it doesn't mean that you use the same thinking processes as me. You need to figure out the ways of thinking that work for you. If someone asked me how I got to this point here [calling Cl^- a conjugate base on a representation on the board], well I always thought that if I am calling it a base, then it must act like a base. Whether it is a conjugate or not, so going in this direction (accepting a proton), because I will teach you later about this (equilibrium), but the reaction can go in the backward direction. What will it be doing if it goes from being Cl^- to HCl , what would it be doing?”*

Student DGD- *“Acting as a base”*

PR - *“It's as simple as that. Now that might seem like a long way around, I guarantee you, in chemistry, because the content is actually small if you link through underlying concepts, to think about it a long way around is the best way, because it means you rely very little on your memory and more on your thinking in the moment. I am also aware that this approach takes time to think things out and I need to give myself time to figure the chemistry out”*

This example of my metacognitive modelling includes MDK in relation to awareness of my cognitive processes, the limits to my cognitive processes, how things make sense to me, and my presumptions of the cognitive processes of others. In addition, the example includes MPK in terms of the use of a procedure I use to think about the chemistry, while also modelling MCK in relation to when and why I would initiate a procedure. This extract captures a moment from a lesson where, although the metacognitive modelling could arguably have been more explicit, it demonstrates the consistent use of an embedded and scaffolded domain-specific approach to metacognition as part of broader, ongoing dialogue in lessons. Aligned with previous research (e.g., Stone, 1993), scaffolding often plays a crucial role as part of incorporating teaching and learning strategies (as discussed in Section 2.6.2).

7.2.4 Metacognitive prompts

Metacognitive prompts included providing metacognitive cues or questions that target the students' metacognition in relation to chemical phenomena. As part of planning to incorporate metacognitive prompts, I reflected on my use of such prompts and student responses in the TY pilot studies, as well as on literature regarding the development of metacognitive instruments including the MAI (Schraw & Dennison, 1994) and MOLES-S (Thomas, 2003). The literature on selecting items as part of the development of these surveys provided insights for my planning and reflection. Metacognitive prompts identified in lessons were for both the class as a whole, and for individual students. The aim of these prompts was to increase students' awareness of their cognitive processes at that moment in relation to a chemical phenomenon, especially their awareness of activating their existing understanding. Aligning with previous research in other contexts (Reigeluth & Stein, 1983; Scardamalia & Bereiter, 1985), I used the prompts in my chemistry lessons as strategy activators because they induce metacognition that the students are, in principle, capable of, but do not spontaneously demonstrate, or demonstrate to an unsatisfactory degree.

Metacognitive prompts were often short questions embedded in lessons for which opportunities often arose in an impromptu fashion as part of lesson dialogue, examples I used included;

“What is your understanding in relation to the motion of molecules of H₂O as a solid, liquid and gas, can you explain your thinking and what it is based on or where it comes from?”

What do you think is the underlying concept which helps to explain the donation of a proton from one molecule to another? Have you used a concept before that may explain it?”

“Based on what we have discussed, change or amend your representation of what you think the arrangement of H₂O molecules look like as a solid, liquid and gas?”

“Explain your thinking aloud while completing it [a representation] on the board?”

MM was often encouraged in lessons through the use of prompt questions while the students were generating representations of chemical phenomena. Examples of my in-lesson prompt questions which encouraged MM include,

“How did you get that number, think about how you thought of it?”

“What is confusing you in the diagram you have drawn for an acid?”

“Does it matter if you include that in your diagram, is that how you visualise it?”

“Is there a better way to represent a weak acid at the molecular level?”

Students were encouraged to evaluate their cognitive processes throughout the data collection period through the use of metacognitive prompt questions, e.g. *Is there something here that does not make sense based on what you already know about the chemistry involved?* In addition, prompt questions formed part of the template for generating representations of chemical phenomena e.g. *I would like to know the answer to.....* or *What I still do not understand about this topic is.....*

As shown in Figure 7.3, the number of occurrences of metacognitive prompts were the highest of all metacognitive strategies used in lessons and this would be expected as they were often embedded in other metacognitive strategies, e.g., think aloud protocol. Metacognitive prompt questions embedded in students' generation of representations also serve as scaffolding for the incorporation of metacognition (Van de Pol et al., 2010) and help students give a richer account and increase awareness of their cognitive processes and chemistry knowledge. For example, *“there is no rush, think about how the molecules exist at the submicroscopic level”* *“Are there other concepts at play which should be noted in your representation, think about what gives rise to the chemistry in your representation”*, *“Would someone be able to interpret your thinking from that representation?”* *“what knowledge have you generated your diagram from, how original is it to your thinking”*. Consistent with previous research, the metacognitive prompts I used were designed to encourage deeper cognitive processing, including increasing an awareness of the need to take time for such processing (King, 1998; Pressley, et al., 1992; Wong, 1986).

7.2.5 Reflective writing - pre and post lesson surveys

Reflective writing such as pre and post lesson surveys were included during lessons, and I created a template for the ‘*Chemistry Metacognitive Journal*’ following the trialling of the pre and post lesson surveys in TY pilot studies (see Appendix B). Reflecting on one's cognitive processes is an important aspect of developing metacognition, more specifically, but not limited to, the development of MDK, MP, MM and ME. The pre and

post lesson surveys asked students to reflect and respond to the following prompt questions at the start of a lesson; *“What do I know about this topic”* and at the end of a lesson; *“What have I learned about this topic”*; *“I still don’t understand”*; and *“Additional questions I would like to know the answer to are”*. The metacognitive element of these questions includes awareness of what one understands (MDK), awareness of what one has learned (ME), in relation to chemical phenomena.

I noted in a post lesson reflection how the detail provided by students in the pre and post lesson surveys increased as the fifth-year study progressed, and *“the surveys became normalised as part of lessons, as students become more accustomed to noting their cognitive processes”*. I also noted how they were not included in every lesson, but they are a tool which can be used to increase metacognitive awareness and metacognitive regulation. In an example from a post lesson survey in the last month of the fifth-year study student DGD displayed an awareness of MDK in terms of what they learned and also what they were still unsure of.

“I learned how to correctly measure the rate of a reaction taking place using the amount of gas evolved from the reaction. I learned how you can use the change in volume over time will give you the rate of the reaction. I still do not think I understand how a catalyst works and why H_2O_2 breaks down” (Student DGD).

In another example, student DHE displayed an understanding of important aspects of cognitive processes related to calculations in chemistry in a post lesson survey where they indicate they are learning the importance of *“understanding why you do calculations in chemistry and not just calculating to get a number”*. Student KQN described an awareness of their cognitive processes, particularly the difficulties they experienced in understanding the expression of concentrations, as noted in a post-lesson survey *“I have not learned a lot in this lesson, I just got more confused, I don’t understand how to identify and answer questions when I start to understand I just get re-confused”*. This is an example of where I reflected on a missed opportunity to expand the metacognitive strategy by asking DHE further prompts in the next lesson, such as: What is causing the confusion? What led to the confusion? This was an important learning experience for me that contributed to the planning and implementation of the PST study (AR cycles 4 and 5).

The above examples of reflective writing provide evidence for their use in increasing student MDK in particular as part of incorporating metacognition in chemistry lessons.

7.2.6 Think-aloud protocol

The think-aloud protocol is a useful technique for assessment and development of metacognition (Wang, 2015; Cooper et al., 2008). I noted in my reflections how I felt that by thinking-aloud, students verbalised their cognitive processes, which provides insights into their use of metacognition by giving them (and other students) an opportunity to develop awareness of the cognitive processes they use in chemistry. Student metacognitive modelling involved students thinking aloud in front of their peers, explaining the origins of their cognitive processes, how they imagine the chemistry at the submicroscopic and macroscopic levels, and describing alternative ways of thinking. The think-aloud protocol was embedded in lessons, for example, through students' explanations of their cognitive processes, such as problem solving or describing and generating a representation of how they visualise a chemical phenomenon. This often-required metacognitive prompts where I would ask students to articulate and explain their cognitive processes while they generated their representations in front of their peers.

An example of the think-aloud protocol was demonstrated when Student KQN described their cognitive process in solving a problem, specifically in calculating the % water of crystallisation on the board in front of the class, as shown below.

Student KQN- So I tried to separate it out into an acid first. Just to get everything laid out, the acid is 0.01 moles per litre, and we know the molarity of that and you've 25cm³ and that was 22.8cm³ and we know that this was 3.55 grams then I wanted to go and get the value of that. So, I used $V_a \text{ times } M_a \text{ over } n_a \text{ is equal to } V_b \text{ times } M_b \text{ over } n_b$ [KQN writes figures into formula on board]

PR – Where did you get those figures and what do you think they mean?

KQN - So the volume of the acid and then molarity of the acid from the question and I got this as the number of moles from the equation. So, there is the volume and there is the number of moles there. And to get rid of this and multiply everything by two, because both sides are equal. So, then I get 2.5 is equal to M_b . I get M_b is equal to 0.05 moles per litre so that's the sodium carbonate. We changed that to grams per litre so when you add the molecular mass up on the periodic table, it's equal to 106 grams for 1 mole. So, I thought about the amount of base, and I don't have 1 mole. I have 0.5 moles so 0.05 multiplied by 106 so that gives you 5.3 grams per litre. So that's how much base it is and that's how much I think reacted with the acid. That's the way I think about it. I think about what I really got and that it was

done in a 500cm³ volumetric flask. So, if you times up original mass of 3.55 by two you get 7.1 grams per litre so then to get the percentage of water of crystallisation you do that minus 5.3 grams and you get 1.8 grams per litre which is the H₂O and then basically after that then divided by 7.1 and then times it by 100 and you get 25%”

The above example provides evidence of the metacognitive use of the think-aloud protocol as the student demonstrated awareness of their cognitive processes in terms of MDK (e.g. *“That’s the way I think about it. I think about what I really got and that it was done in a 500cm³ volumetric flask.”*) but also through the rationale of each of the steps it demonstrates their MPK (*So I tried to separate it out into an acid first. Just to get everything laid out*) and they demonstrated MCK indicating why they used a certain procedure (e.g. *“I thought about the amount of base, and I don’t have 1 mole. I have 0.5 moles so...”*).

The description of the students' cognitive processes while solving the problem above provided opportunities for the metacognitive prompts for the whole class *“How did you visualise the water as part of the crystals in the substance?”* Examples of student responses (Students KQN, SUN, and BTD) to this prompt are shown in Figure 7.2. While these responses may not be theoretically accurate, they provide evidence of the students' cognitive processes related to submicroscopic level of chemistry at that time. The purpose of this type of prompt was to enhance students' awareness of their cognitive processes at the submicroscopic level while solving problems or constructing symbolic representations.

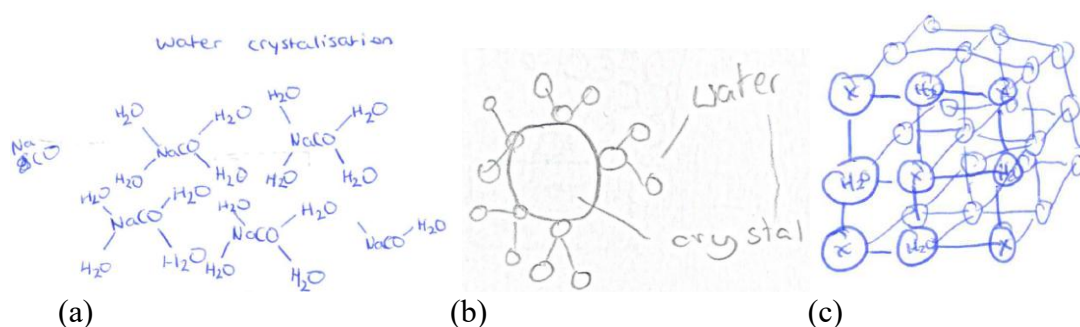


Figure 7.2 Student (a) KQN, (b) SUN and (c) DGD responses to the prompt question *‘How did you visualise the water as part of the crystals in the substance?’*

In my reflections I noted the think-aloud protocol “*as being useful in providing students the opportunity to voice how they think about chemistry, especially at the abstract submicroscopic level*” and I also reflected on how the think-aloud protocol “*provided opportunities for me to embed metacognitive prompts*”. Previous research has also argued for the enhancement of the think-aloud protocol by combining it with other strategies (Schelling, et al., 2013).

7.2.7 The Regulatory Checklist

A Regulatory Checklist (RC) was included in lesson activities to incorporate metacognition, particularly the subcomponents of metacognitive regulation (King, 1991). Based on my experience on the TY pilot studies the developed RC templates in the ‘Chemistry Metacognitive Journal’ (see Appendix B) were used by students for problem solving tasks in the fifth-year study e.g., Calculate the concentration in % w/v and moles per litre of a solution of sodium carbonate given the grams dissolved in 250cm³ of water. The RC aimed to develop student awareness of their cognitive processes and alternative cognitive processes for solving problems in chemistry.

The RC template provided prompt questions which addressed MP (*What is the nature of the task?; What is my goal?; What kind of information and strategies do I need?; How much time and resources will I need?*); MM (*Do I have a clear understanding of what I am doing?; Does the task make sense?; Am I reaching my goals?; Do I need to make changes?*); and ME (*Have I reached my goal?; What worked?; What didn't work?; Would I do things differently next time?*).

The use of this checklist was challenging for students, as evident in the lack of detail in the responses received. Despite my prompts during the use of the RC, students tended to complete the MM section of the checklist after completing the problem rather than while solving the problem. For this reason, during problem solving tasks I would ask students to stop and answer the prompt questions as part of the RC.

In a lesson reflection, I also noted that the RC, or the way I was incorporating it into lessons, led to limited responses during problem-solving tasks. For example, during a problem-solving task which involved a stoichiometry problem for the oxidation of iron, student FRK's response lacked the detail I had aimed for while the student was using it;

Question: *Do I have a clear understanding of what I am doing?*

Student FRK: *Not exactly, as they never done an equation like this before*

Question: *Does the task make sense?*

Student FRK *Probably not, I don't really understand it*

Question: *Am I reaching my goals?*

Student FRK *Halfway, not pushing myself enough.*

Question: *Do I need to make changes?*

Student FRK *Yes*

The responses by FRK require more detail to demonstrate awareness of their cognitive processes in approaching the problem, and the limited nature of FRK responses (and the responses by other students) to the prompt questions in the RC indicates the incorporation of it in senior cycle chemistry requires further development.

The RC strategy was used a relatively low number of times in lessons (See Figure 7.3) and while these have potential value, as I noted in reflections it was “*difficult to incorporate the metacognitive monitoring aspect of the RC as I had to stop students in the middle of solving the chemistry problems to ask them to complete the survey, I felt this almost led to cognitive overload for students*”. Previous research has made a similar argument regarding the process of answering questions during problem-solving tasks (Wang, 2015; Ericsson & Simon, 1993).

7.2.8 The Strategic evaluation matrix

The use of the Strategic evaluation matrix (SEM) strategy to address metacognition in chemistry in this study was adapted from its original use in language education (Schraw, 1998). A SEM template with specific prompts was used as a guide to promote metacognitive awareness while reading tasks in chemistry. The SEM was originally developed for reading large texts, such as chapters in novels etc. The SEM in the developed template (see Appendix B) had five prompt questions.

- (i) *Skim: After skimming the article for 60 seconds I think the article is about*
- (ii) *Activate prior knowledge; I already know the following about the topics in this article.*
- (iii) *Slow down; Now that I have read the article slowly, I think the article is about*
- (iv) *Mental integration; The theme of this article is*
- (v) *Diagrams: Draw the main ideas in this article and connect them.*

The SEM was incorporated in the fifth-year study as part of homework tasks in relation to sections of the textbook, or particular articles on chemistry that I chose e.g. ‘The Periodic Table turns 150’ (Warmflash, 2016).

I noted in my reflections how I thought the use of the SEM “*requires students reading a large amount of text and as such it was not suitable for my lessons*”. This may explain the relatively low number of occurrences of it in my lessons (see Figure 7.3) and I noted “*it was used as a homework task to look at particular articles*”. Further work is necessary if the SEM is to be embedded as a metacognitive strategy in senior cycle chemistry lessons.

7.2.9 Occurrence of metacognitive strategies in the fifth-year study

As discussed in Section 5.1.1.1, as part of developing my understanding of metacognition in the context of chemistry and forming the conceptual framework for this research (see Section 6.6), I developed an observational rubric to identify the occurrence of metacognitive strategies in chemistry lessons (outlined in Table 5.2 and detailed in Appendix F). Using the developed observational rubrics, the occurrence of metacognitive strategies, as identified through the analysis of 40 lessons, is presented in Figure 7.3. It should be noted, that when the generation of representations were used as part of the think-aloud protocol, metacognitive modelling, or instruction, they were categorised as occurrences of the strategy within which they were embedded, rather than as independent instances of the generation of representations. This in-depth reflection and analysis of lessons helped me assess how I embedded metacognitive strategies, while also allowing me to become more adept at being aware of metacognitive aspects of strategies. The learnings from my experience of this contributed to the design of the methodology module in the PST study (AR Cycles 4 & 5) where the PSTs were asked to reflect on metacognitive strategies incorporated in the workshops.

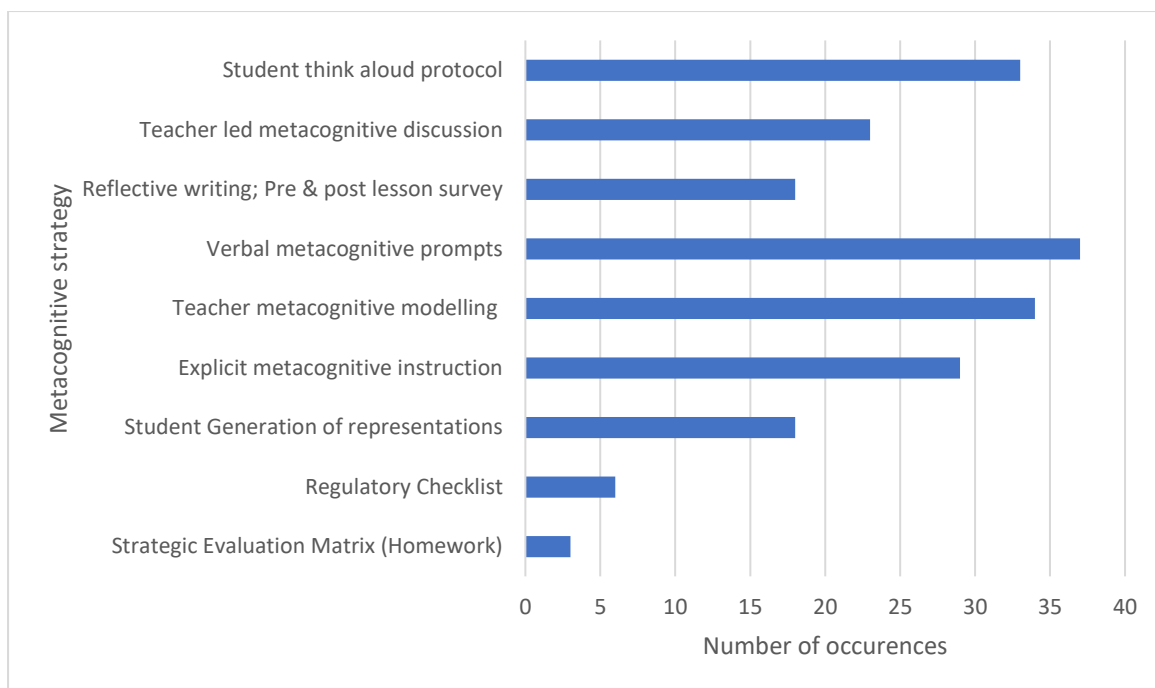


Figure 7.3 Number of occurrences of metacognitive strategies in a sample of 40 lessons in the fifth-year study

7.3 Metacognition in chemistry and the generation of representations

Building on the findings of the TY pilot studies, the generation and refinement of representations of chemical phenomena aimed to enhance students' metacognition by encouraging them to become aware of how they activate prior knowledge, articulate and explain how they visualise the submicroscopic level, and reflect on their understanding of chemical phenomena. The 'Chemistry Metacognitive Journal' section designed for students to generate representations included a large blank space accompanied by the prompt; "*The way in which I visualise the chemical phenomenon/concept that was just discussed in class looks like* (represent your thinking using sketches with notes)". My aim was fostering students' awareness of themselves as generators and refiners of representations of their own cognitive processes (e.g. thinking and visualisations) in chemistry at a point in time, rather than receivers or interpreters of representations, as described by Tytler et al. (2013).

During the initial weeks of the fifth-year study, I identified a potential issue with using representations as a metacognitive strategy. Student-generated representations often closely resembled those provided by me or the textbook, making it difficult to determine the extent of knowledge activation or cognitive processes demonstrated in these

representations. This contrasted with my aim of using representations to encourage students to become more aware of how they think about and visualise chemical phenomena at the submicroscopic level reflecting their unique cognitive processes. Instead, students appeared to replicate previously seen representations without becoming more aware of the understanding or visualisation process. For example, the representations generated by DJC and UKN, of how they visualised the Arrhenius acid and base theory and Bronsted Lowry acid and base theory are shown in Figure 7.4. Both representations were quite similar, suggesting that the students were replicating my representation rather than generating their own based on their cognitive processes and their activation of prior knowledge. This is understandable, as both students were taught in the same way, and I had generated the representation during a lesson they both attended.

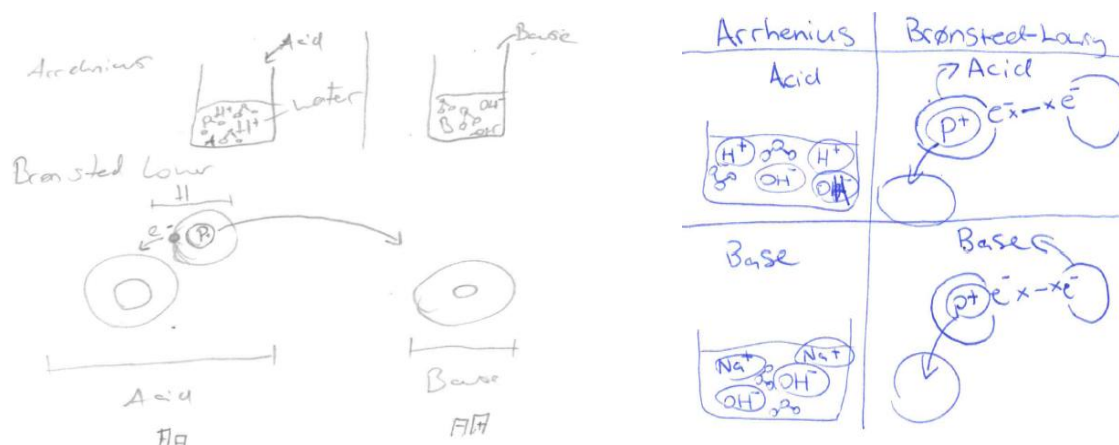


Figure 7.4 Representations of how they visualised Arrhenius acid and base theory and Bronsted Lowry acid and base theory, by (a) Student DJC, (b) Student UKN

Providing further evidence for the assumption that the representations were replicas of a representation I generated, in response to the prompt question, *Are there any additional questions you would like to know the answer to*, UKN noted they were “*confused about how to visualise Bronsted Lowry acid + base & Arrhenius base*” even though they had produced the representations in Figure 7.4 (b). This underscores the challenge of fostering metacognition through the use of representations in chemistry when students replicate previously seen examples rather than becoming aware of the cognitive processes, such as understanding or visualising the submicroscopic level as part of generating their own representations. Previous research has highlighted the challenges students face in learning *with* representations, as opposed to merely learning *from* them (Tippett, 2016).

Reflecting on the metacognitive use of generating representations, I adjusted my approach during the fifth-year study. Instead of introducing representations of how I visualise chemical phenomena or a representation from another source, I asked students to generate their own representations of new chemical phenomena based on their existing understanding, with minimal input or introduction from me. Following this adjustment, I noted in my reflections how the “*student representations demonstrated a more authentic reflection of their cognitive processes and visualisations, as evidenced by their uniqueness*”. For example, the representations generated by the students for polar and non-polar substances as a solid, liquid and gas at the submicroscopic level were considerably different to each other and include different aspects of their chemistry understanding. For example, while some students used generic circles to represent molecules e.g. UKN (Figure 7.5 (b)), others used polar and non-polar substances e.g. BGN used H₂O as the polar substance and generic diatomic molecule as a non-polar (Figure 7.5 (c)). Examples of the representations generated by students BTD, UKN and BGN are shown in Figure 7.5 and are discussed below to demonstrate how my, as the students’ chemistry teacher, awareness and interpretation of possible student cognitive processes involved in generating the representations.

Student BTD’s representation of polar substances (Figure 7.5 (a)) includes the polarity of water in the liquid state with the delta positive signs next to the hydrogens and the delta negative signs next to the oxygens. The arrangement of these partial charges next to each other can be interpreted as representing their understanding in relation to electrostatic attraction and repulsion which gives rise to intermolecular bonding. However, the arrangement under the solid for the polar substance is not clear and H₂O is represented with spheres in a lattice-like structure without reference to the orientation of the molecules. Polarity ($\delta +$ and $\delta -$ signs) is also indicated on the liquid state for the non-polar substance however the temporary nature of the polarity is not indicated in their representation of the gas state. These representations by BTD provide opportunities for questioning their cognitive processes for example ‘*why have you only indicated polarity in the liquid state for both substances*’ and ‘*what do the straight lines in the solid state for both substances represent in your thinking?*’ If these straight lines represent intermolecular bonds, then it does show a level of understanding in relation to the fixed nature of intermolecular bonds in a solid, however the distance between the molecules could then be discussed with the student.

UKN noted MDK in terms of an awareness of their cognitive processes related to their representation (Figure 7.5(b)), stating they were “*not sure how to draw a non-polar substance*”. Despite this uncertainty, they attempted to depict a solid non-polar substance, providing evidence of their effort to use their existing understanding of non-polar substances. Their representation of a non-polar substance as a solid includes indications of partial charges, whereas their representation of a polar substance as a solid does not. This discrepancy could be used as a basis for probing and increasing the student’s awareness of understanding related to partial charges and how substances exist as a solid at the submicroscopic level. The inclusion of the words “vibrating”, “rolling”, and the arrows indicated on the representation of a gas provides evidence the student was trying to indicate the motion of the molecules in each of the three states. There is no indication of the role of polarity within their representation of the polar substance.

Student BGN’s representation of how they visualise solids, liquids and gases provided evidence of their understanding in relation to polarity (Figure 7.5 (c)). The polarity (indicated with the $\delta +$ and $\delta -$ signs) on the water molecule and the orientation of the water molecules in the liquid state indicates BGN’s understanding of electrostatic attraction and its influence on the orientation of molecules. The horizontal arrows they include on the non-polar liquid molecules possibly indicates they understand the principle of temporary dipoles giving rise to a non-polar substance existing as a liquid. Supporting this assumption about their cognitive processes, when prompted to describe their thinking BGN stated, “*Polar covalent is where a permanent slightly positive and a permanent slightly negative end is formed, whereas the slightly positive and slightly negative end are not permanent in a non-polar substance*” BGN left the solid section for the non-polar substance blank, which indicates they were unclear in their understanding in relation to how non-polar substances exist as a solid, and it can be assumed this task increased their awareness of this gap in their understanding.

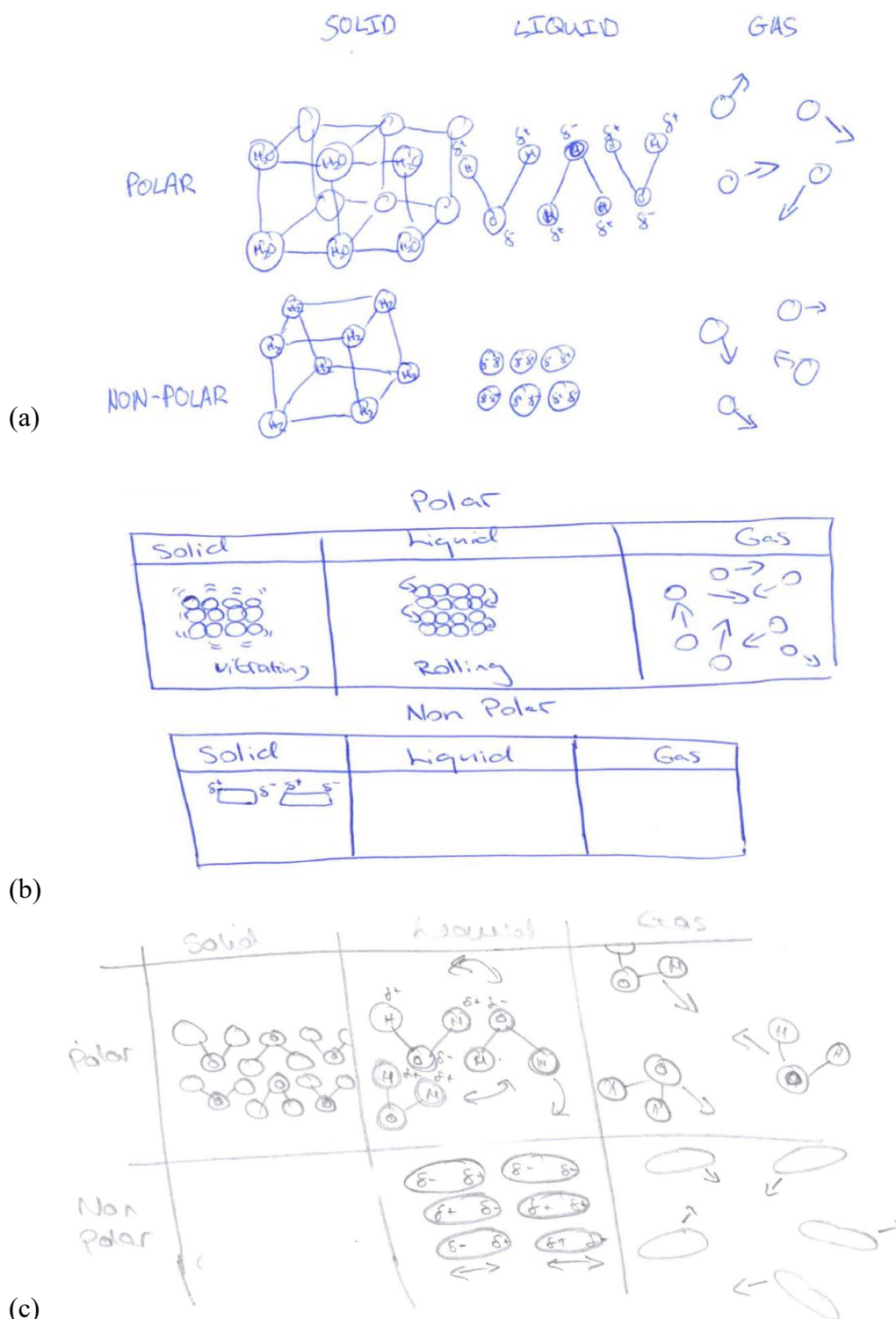


Figure 7.5 Representations of how students visualise a polar and non-polar substance as a solid, liquid and gas at the submicroscopic level. Representations by (a) BTB, (b) UKN, (c) BGN

As part of incorporating student's generated representations, I become more aware of how they can provide opportunities for metacognitive prompts and discussions around

student cognitive processes in relation to the chemical phenomenon. Analysing the student-generated representations (e.g., Figure 7.5) also increased my awareness of the rich possibilities for illuminating cognitive processes as part of generating representations in chemistry.

My reflections and analysis of the data suggest that requiring students to generate representations based on their existing knowledge, prior to being provided with a representation, challenges them to reflect on and apply their prior knowledge of related chemical phenomena and underlying concepts. For this to be true, I noted in my reflections following a lesson the importance of *“it being based on student thinking drawing on chemistry understanding and not a replication of an image they have seen and not understood”*.

7.2.2 Generation of representations – an embedded metacognitive strategy

The generation and refinement of representations were embedded in other metacognitive strategies in the fifth-year study, for example, metacognitive prompts (see Figure 7.2) the think-aloud protocol, metacognitive modelling by me and student reflective writing. The use of reflective writing as a metacognitive strategy has been well-documented in previous literature (e.g., Zohar & Barzilai, 2013; Veenman et al., 2006). In the fifth-year study, the generation of representations was integrated into reflective writing tasks. For example, in a particular task related to student understanding of chemical bonding, I prompted students *‘Can you generate representations at the submicroscopic level of what you have described here in words?’*. The responses from BGN and BTB are shown in Figure 7.6. The word description by BTB discusses the relative difference in electronegativity giving rise to polarity, and it could be assumed by the student (and their teacher) that they understand polarity and chemical bonding relatively well. The representation of the polar molecule indicates shared electrons (represented by two crosses and two dots) being distributed unevenly, resulting in the polarity of the molecule. Although the student-generated representations shown in Figure 7.6 may reveal possible misconceptions in the two students’ chemistry understanding, this highlights the strength of using representations to increase awareness of such misconceptions, which might not have been apparent through word-based responses alone. During my reflections in the fifth-year study, I noted that a student’s misconception is cognitive, while their awareness of the misconception and the cognitive processes that contributed to it, is metacognitive.

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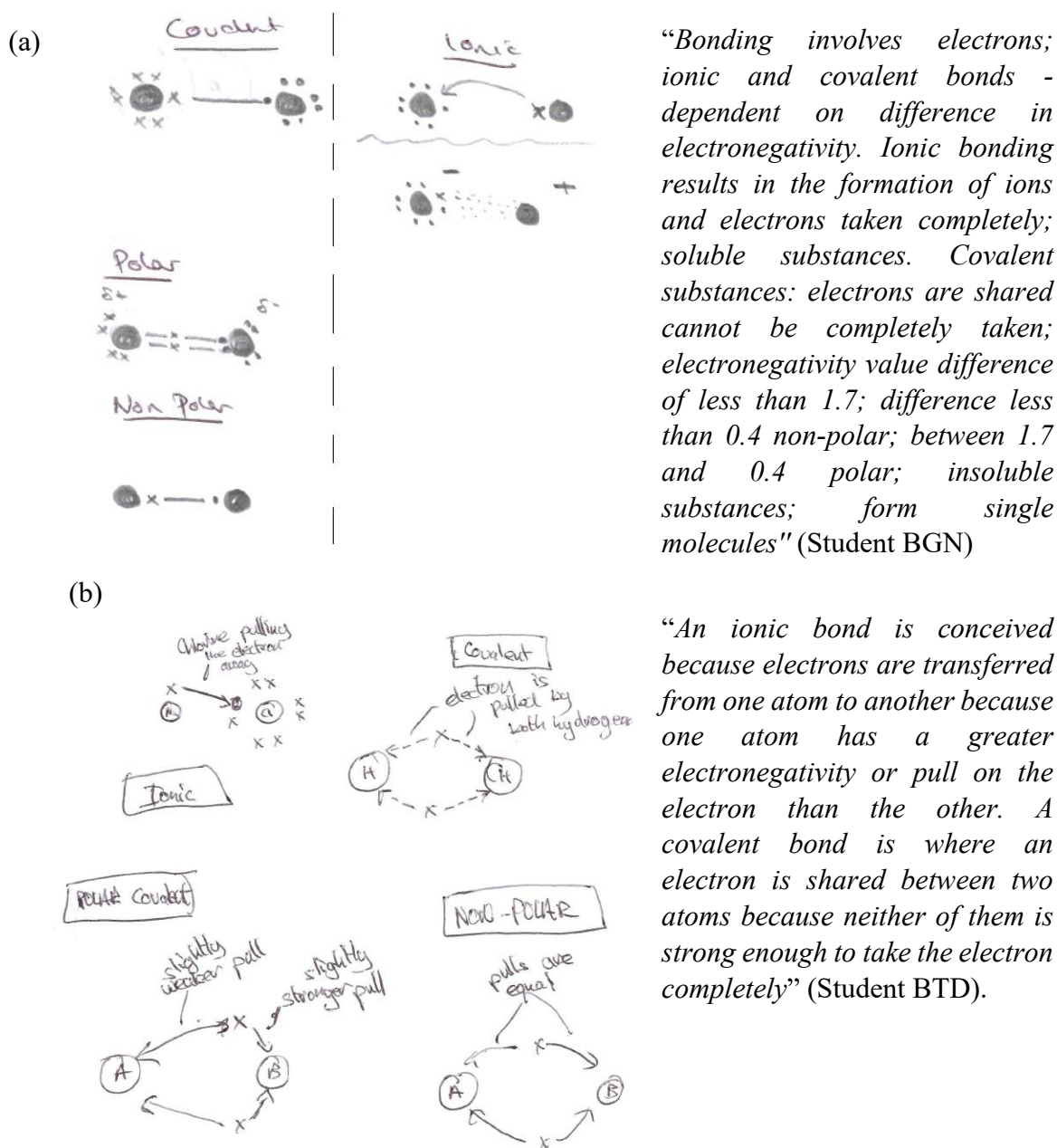


Figure 7.6 Responses to the prompt question *Can you generate representations at the submicroscopic level of what you have described here in words?* from (a) BGN Student and (b) Student BTD

I noted the benefit of embedding the generation of representation in other metacognitive strategies in a lesson reflection.

“representations produce rich responses of student understanding and provide evidence of their thinking and visualisations of what occurs at the submicroscopic level, I often see questions in textbooks or previous exam papers where students are given an molecular formula and ask to use electronegativity values to ascertain

the type of bonding in the molecule, but this type of questioning results in little indication of a student's thinking at the submicroscopic level rather rewards their ability to look up and subtract two numbers based on generic rules which student can memorise but not understand" (PR)

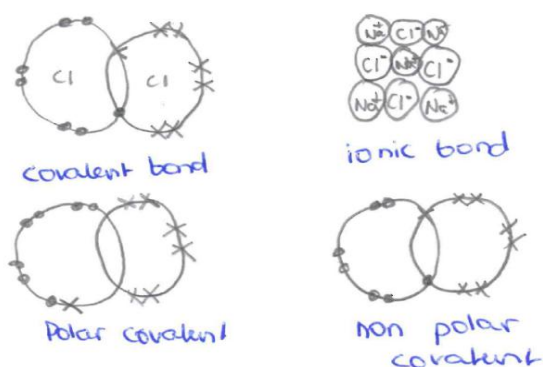
Throughout the AR cycles in the Senior Cycle study, the generation and refinement of student representations emerged as particularly relevant for providing domain-specific opportunities in chemistry. These opportunities facilitated the incorporation of metacognition alongside other domain-general metacognitive strategies, such as reflective writing as discussed in this section.

7.2.1 Generation of representations – voice, evolution, and consolidation of cognitive processes

As part of my reflection on the incorporation of the metacognitive strategies, I recognised the importance of supportive and encouraging teacher-student dialogue in promoting a metacognitive culture in the classroom, where students feel they can express their authentic voices regarding their cognitive processes. For example, when I asked students to generate a representation of their cognitive processes, I highlighted to the students the importance of not being constrained by but rather, the importance of relying on, and being aware of, their cognitive processes at that time. For example, in a lesson where I asked students to generate a representation of how they visualise the reaction between magnesium and sulphuric acid at the submicroscopic level I stated;

"About what I just said, you've never seen this before, why would I expect you to get this perfectly right. Just draw something based on your thinking at this moment, what you think it might look like, there's always a reason for what you draw when you are thinking, so you shouldn't dismiss your own work. Then describe your thinking." (PR)

I reflected on the benefits of asking students to generate representations of their cognitive processes, as it provides an opportunity for them to voice their thinking in a domain-specific manner, particularly at the submicroscopic level. For example, student DEH in response to a prompt question to represent and describe their thinking in relation to different types of chemical bonding (Figure 7.7) indicates an awareness of their own understanding at that point in time i.e., MDK *"I know covalent bonding involves the sharing of electrons between atoms and ionic bonding involves the transfer of electrons between atoms which are held together by opposite charges"*



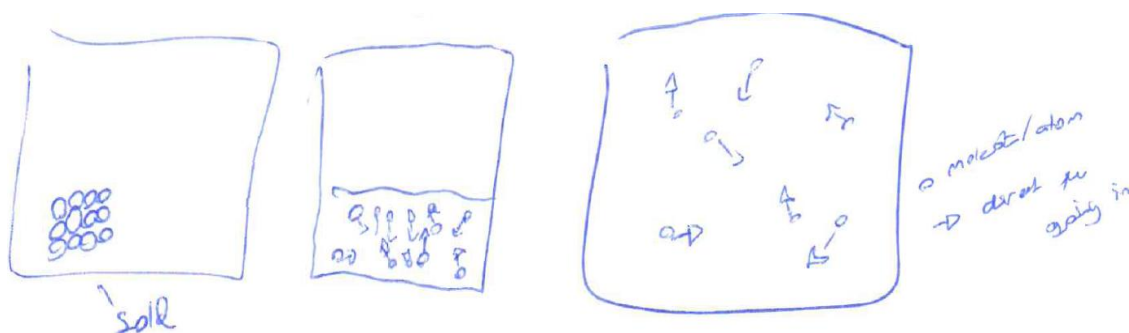
I know covalent bonding involves the sharing of electrons between atoms and ionic bonding involves the transfer of electrons between atoms which are held together by opposite charges. Polar covalent bond is when the shared electrons spend more time around one atom than the other. A non-polar covalent bond is where the shared electrons spend relatively equal time around both atoms as the electronegativity difference small (DEH).

Figure 7.7 Response by DEH to a prompt question ‘*Represent and describe your thinking in relation to different types of chemical bonding*’

Whilst the word description is relatively accurate the representation provides an opportunity for the student to address possible misconceptions and hence aid the evolution of their cognitive processes. For example, DEH has represented a polar molecule where both atoms appear to have seven valence electrons which would indicate they would not form a polar covalent bond as represented.

I used the refinement of representations to encourage students to develop an awareness of how their cognitive processes evolve, particularly from the initial introduction of a chemical phenomenon to subsequent points during their study of the phenomenon. An example of this approach involved asking students at the beginning of our study of the properties of gases, to generate a representation of how they visualise solids, liquids, and gases at the submicroscopic level. The same task was then repeated two weeks later to promote student awareness of how their thinking and understanding can evolve. For example, DJC was asked to reflect on their representations which are shown in Figure 7.8.

(a)



(b)

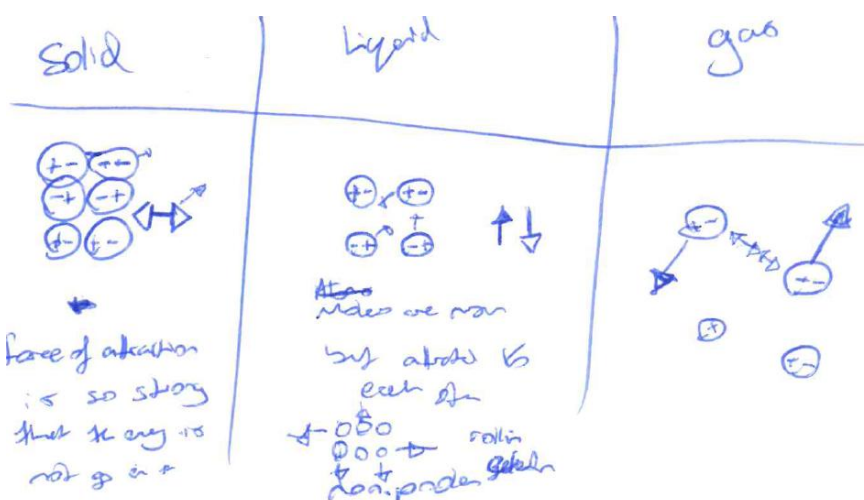


Figure 7.8 Student DJC generated representations of a solid liquid and Gas at the submicroscopic level (a) before and (b) after studying the properties of gases

When asked to describe how their thinking had changed or evolved between the generation of their first and second representations DJC indicated;

"I now think about what holds the molecules together, in water for example the oxygen is more negative because it has a higher electronegativity. To turn water to ice you have to take energy away from the molecules so that the forces of attraction become significant" (Student DJC)

Students generating representations based on their cognitive processes at a particular point in time, provides opportunities for students to voice their cognitive processes, evolve their cognitive processes through metacognitive discussions, prompts, while also providing opportunities for consolidation of their cognitive processes through reflection. This approach to generation of student representations in chemistry also provides opportunities for the teacher to become more aware of students' cognitive processes in

terms of their understanding related to chemical phenomena, as opposed to the replication of representations that were generated by the teacher or textbook, or a reliance on word-based definitions.

Through my reflection and analysis of the Senior cycle study (AR Cycles 1-3), five key characteristics emerged regarding the use of student generated representations as a metacognitive strategy.

(i) Generating representations based on their authentic cognitive processes at a point in time before a chemical phenomenon is explicitly addressed in class promotes the activation of prior knowledge and can be used to enhance students' awareness of their cognitive processes.

(ii) The importance of allowing sufficient time for students to generate representations of their cognitive processes.

(iii) Student generation and refinement of representations create opportunities to incorporate metacognitive prompts, which enhance students' awareness of their cognitive processes.

(iv) Evidence for using representations as a metacognitive strategy should include students' descriptions of their cognitive processes, verbal or written, provided through discussions, responses to prompts, and similar activities.

(v) Students need regular, supportive and encouraging reminders that the focus is on representing their cognitive processes at that point in time.

My reflections on the use of student generated representations as a means of incorporating metacognition which facilitated the voicing, evolution and consolidation of cognitive processes in chemistry was a learning from the fifth-year study which contributed to the design and implementation of the PST studies (AR cycles 4 & 5).

7.4 Metacognitive orientation of the learning environment - MOLES-S

As discussed in Chapter 2, in metacognitively-orientated learning environments, students, in addition to thinking about the material to be learned, will also think about (i) how they learn the material, (ii) their difficulties in learning such subject material, and (iii) how they could improve their learning of that material and so become better learners (Thomas, 2003). As a measure of how metacognitive orientated the environment was in

the lessons during the fifth-year study, and to triangulate my reflections, students completed the MOLES-S survey at the end of the fifth-year study in relation to their experience of the chemistry lessons. The MOLES-S subcategories were outlined in Chapter 4, Section 4.4.2.2. The overall mean score for MOLES-S and for each of the subcategories is shown in Figure 7.9, with the higher value (1-5) highlighting a greater positive response to that subcategory.

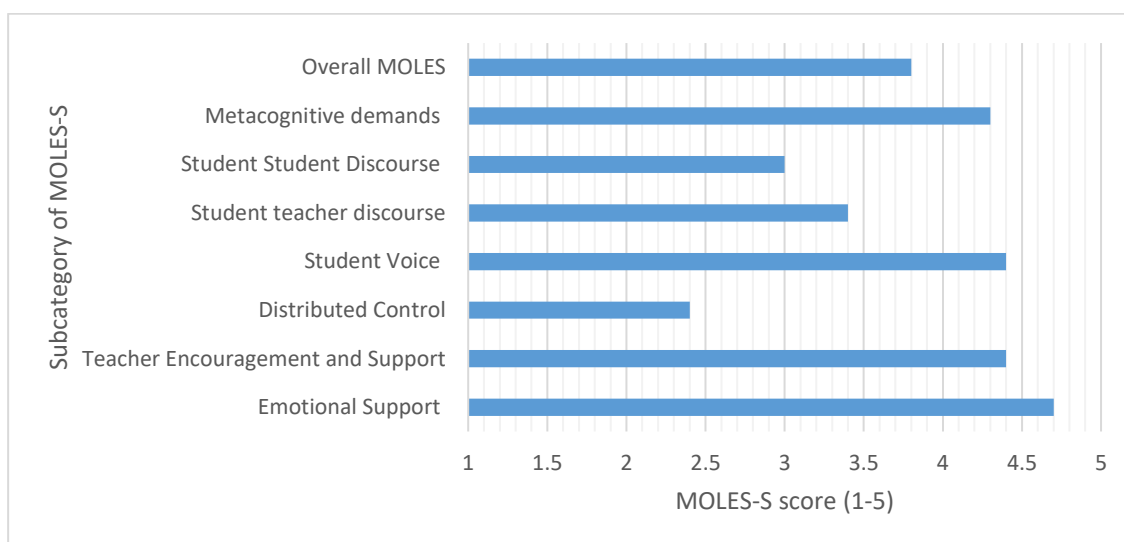


Figure 7.9 Mean scores on MOLES-S instrument in fifth-year study

Based on the MOLES-S overall score (3.8/5.0), it can be interpreted that the students' perception of the classroom environment during the fifth-year study was that it was metacognitively orientated, and it would be logical to conclude the incorporation of the metacognitive strategies contributed to this perception. The MOLES-S scores for '*Metacognitive demands*' (4.3/5.0) suggests that the students' experience of lessons in the fifth-year study was characterised by 'often' experiencing metacognitive demands which provides evidence that the metacognitive strategies had the intended effect. For example, metacognitive prompts in lessons and tasks were intended to be metacognitively demanding for students. Each of the items in the MOLES-S subcategory of *Metacognitive demands* showed a relatively large mean score (Appendix J). Each of the items deals with being asked by the teacher about various aspects of thinking in chemistry and are included as part of metacognitive strategies, especially the metacognitive prompts.

There was a relatively high mean student score (3.7/5.0) for the MOLES-S item of *Students discuss with the teacher about how they think when they learn chemistry* within

the subcategory of *Student-teacher discourse*. Metacognitive strategies in the fifth-year study which may have contributed to this perception include metacognitive discussions and metacognitive modelling.

MOLES-S subcategory scores suggest that students experienced *emotional support* (mean 4.7/5.0) and *teacher encouragement and support* (mean 4.4/5.0), reflecting a positive classroom environment conducive to voicing, evolution and consolidation of cognitive processes rather than assessing chemistry ability in a ‘high stake’s’ environment (Figure 7.9 & Appendix J). Lesson reflections underscored the importance of a supportive atmosphere in fostering metacognitive engagement, consistent with research highlighting the socially mediated nature of metacognition and the critical role of the learning environment (Thomas, 2002). Students also reported high perceptions of fairness and respect (‘Students are treated fairly’ and ‘Students’ ideas are respected’, both mean 4.9/5.0), which my reflections identified as key to enabling honest and thoughtful participation, particularly during think-aloud protocols (Appendix J).

In keeping with the level to which I planned the lessons in the fifth-year study, and I made the decisions on the direction of lessons, the mean score (2.4/5.0) for the MOLES-S subcategory of *Distributed control* suggests students felt they had little control over the choice of classroom activities. The score for this subcategory is an example of the negative case (Guba & Lincoln, 1989) and supports the use of the MOLES-S survey as part of the analysis as it indicates the students did not just give answers that they presumed I would have wanted. The students’ score for *Student voice* indicates the students often felt like it was legitimate to question my plans and methods, which is an important aspect of a metacognitively orientated environment (Figure 7.9).

The data collected using the MOLES-S survey in the fifth-year study is supported by my reflections. For example, I noted “*the atmosphere in the classroom was developing all the time, where students voice their thinking as part of the metacognitive strategies I was incorporating, and they seemed to feel free to say and represent what they think rather than what has to be correct*”. As evidenced by my reflections and the MOLES-S data, creating a metacognitively oriented environment in chemistry lessons involves focusing on student cognitive processes, rather than solely on theoretical correctness. This approach addresses students’ awareness of their voice in relation to their cognitive

processes as a foundation to promote their awareness of the evolution and consolidation of their cognitive processes in chemistry.

7.5 Student metacognition - MAI

The MAI was used to provide additional data in relation to students' metacognitive development as part of experiencing the metacognitive strategies during the fifth-year study, while it also helped me reflect on the specific metacognitive aspects of the strategies I was incorporating in lessons, as discussed in this section.

An increase in the post student mean score was noted for the overall MAI inventory and this was reflected in an increase in both of its components - MAI metacognitive awareness and MAI metacognitive regulation (see Figure 7.10)

Evidence of student development before and after the fifth-year study in MDK is reflected in a notable increase (15%) in the MAI item, "*I have control over how well I learn.*" This improvement is attributed to the use of metacognitive prompts during lessons. A similar increase (15%) was observed for "*I understand my intellectual strengths and weaknesses,*" addressed through metacognitive prompts and pre-lesson surveys. The largest gain within the MDK subcomponent (20%) was seen in "*I know what the teacher expects me to learn,*" likely influenced by metacognitive modelling and explicit metacognitive instruction.

Within the MAI subcategory of MPK, evidence of student development exists in the relatively large increase in the mean score for the items (both 17.5%) of '*I am aware of what strategies I use when I study*' and '*I try to use strategies that have worked in the past*'. An item which showed a relatively large increase (10%) linked to this awareness of the use of strategies in the subcategory of MCK was '*I know when each strategy I used will be most effective*'. The use of metacognitive strategies which addressed these items include metacognitive prompts, explicit metacognitive instruction, and metacognitive discussions.

There was also an increase in the component of metacognitive regulation and for each of its subcategories (Figure 7.10(c)). The individual scores for each of the items in the subcomponent of metacognitive regulation are shown in Appendix J. The MAI data indicates student development in the area of MP, within the subcategory of *Planning* a relatively large increase (25%) in the item "*I set specific goals before I begin a task*". Metacognitive strategies which addressed developing students' MP included

metacognitive strategies which encouraged awareness of cognitive processes related to chemical phenomenon they were about to study e.g., pre lessons surveys, metacognitive prompts, RC, etc.

Student development in their metacognitive regulation as a result of their experience with the metacognitive use of the generation of representations may have contributed to the relatively large increase (22.5 %) for the item “*I draw pictures or diagrams to help me understand while learning*” within the subcategory of *Information management* strategies. A particular emphasis in the lessons was placed on students taking time to show and analyse their cognitive processes in chemistry through the use of metacognitive prompts, think aloud protocol, and the generation of representations. Evidence of student development in this area is reflected in the subcategory of Information Management Strategies, with a relatively large increase (17.5%) in the mean score for the item *I slow down when I encounter important information*.

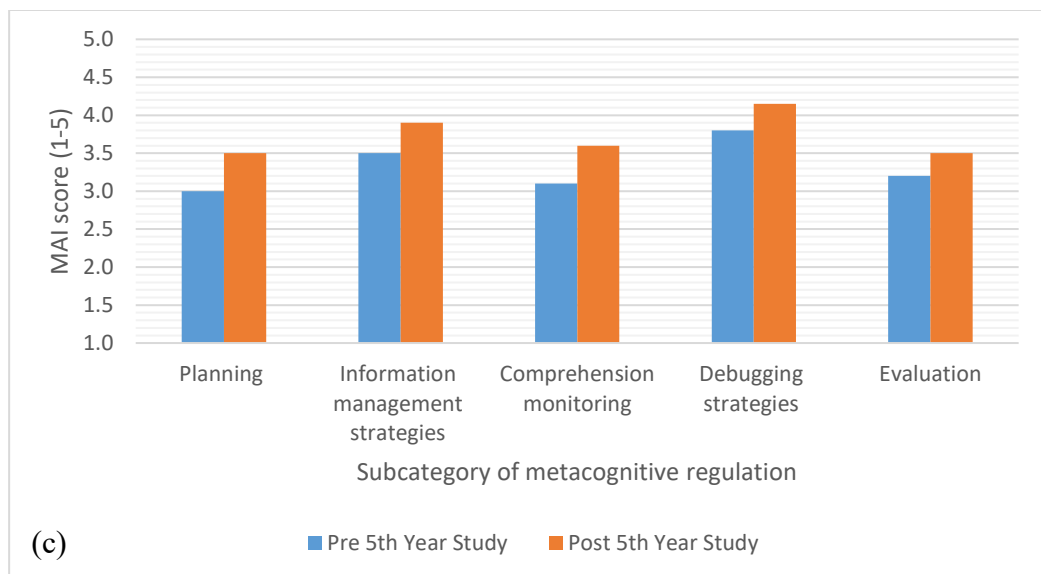
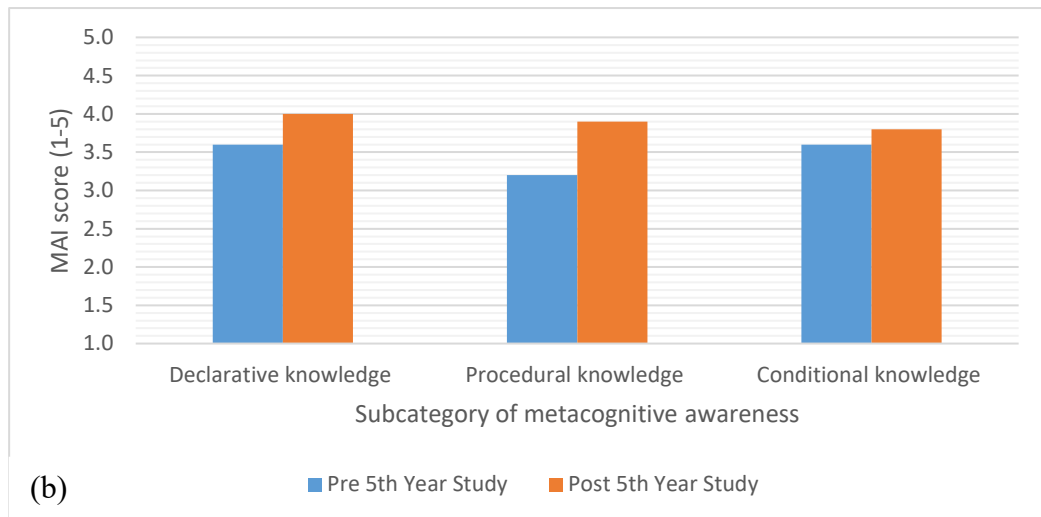
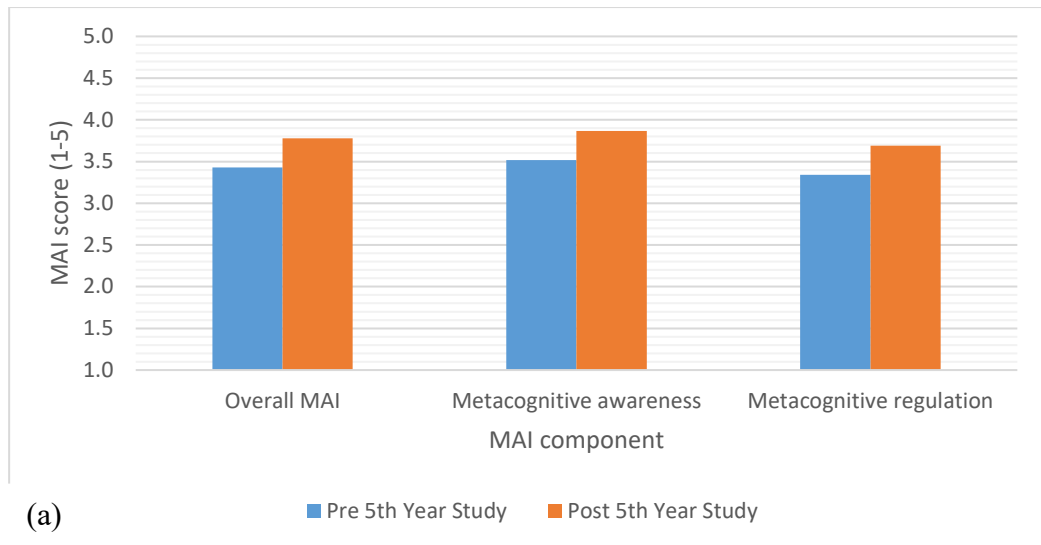


Figure 7.10 Mean scores for the MAI inventory- fifth-year study; (a) overall score and components; (b) metacognitive awareness subcategories and (c) metacognitive regulation subcategories.

There were relatively large increases in the items “*I find myself analysing the usefulness of strategies while I study*” (20%) “*I consider several alternatives to a problem before I answer*” (17.5%), “*I find myself pausing regularly to check my comprehension*” (15%), in the subcategory of *comprehension monitoring*. Metacognitive that addressed this item included student generation and refinement of representations of chemical phenomena, metacognitive prompts, the think-aloud protocol, and the RC.

The mean score for the item ‘*I ask others for help when I don’t understand something*’ showed a relatively large increase (17.5%) in the subcategory of Debugging Strategies. This reflects the culture of the lessons, where students were encouraged to discuss challenges in their cognitive processes as part of metacognitive strategies e.g. Think-aloud protocol and metacognitive discussions.

For each of the items in the subcategory of *evaluation*, there are only marginal increases. This provides evidence that there could have been a greater focus on the evaluation aspects of metacognitive strategies used, for example in the final sections of the SEM and RC.

Using the MAI data to analyse the metacognitive strategies I incorporated provided additional opportunities for me to reflect on and increase my awareness of the metacognitive aspects of the strategies and their implementation.

It is reasonable to argue that the increase in post scores across the subcomponents of the MAI provides evidence students experienced metacognitive strategies in the chemistry lessons as part of the fifth-year study. However other possible factors which may have influenced the MAI scores include an increase in understanding and confidence in chemistry and the increase in the age and experience of the students. Isolating any of these variables in a quasi-experimental investigation with a group such as the participants in the fifth-year study in the Irish context would be difficult, if not impossible to achieve, while it would also not be in keeping with the AR approach I have taken.

7.6 Student learning strategies and motivation - MSLQ

The students completed the MSLQ as a measure of the types of cognitive and metacognitive learning strategies they use. Students’ awareness of their use of learning strategies can give an insight into their metacognition helping triangulate the data from the MAI. Students completed the MSLQ at the beginning of the study (Pre) to reflect on their approach to learning in Junior Certificate Science and again at the end (Post) to

reflect on their approach following the fifth-year study. The MSLQ provided specific evidence of the student's use of cognitive and metacognitive strategies. The subcategories of the MSLQ are given in Table 4.7. The mean scores (pre and post) in each MSLQ subcategory of *Learning strategies* are shown in Figure 7.11; six subcategories out of nine subcategories showed a relatively large increase ($\geq 10\%$) in post score, namely *elaboration*, *critical thinking*, *metacognitive self-regulation*, *time and study environment* and *effort regulation* and *help seeking* (Figure 7.11).

The changes in mean scores for the individual items in each subcategory of the MSLQ *Learning strategies* are shown in Appendix J. The subcategory of *elaboration* refers to one's ability to build internal connections between different topics or concepts. The increase in score for *Elaboration strategies*, particularly the items “*I try to apply ideas from course readings in other class activities such as lessons and discussion*” (mean increase 52%) and “*I try to understand the material in this class by making connections between the readings and the concepts from the lessons*” (mean increase 14%) provides evidence that the students were more aware of the use of the cognitive process of understanding through underlying concepts. The metacognitive strategies such as pre lesson surveys, generation of representations, teacher led metacognitive discussions aimed to help increase student awareness of connecting newly introduced chemical phenomena with their existing understanding, including underlying concepts.

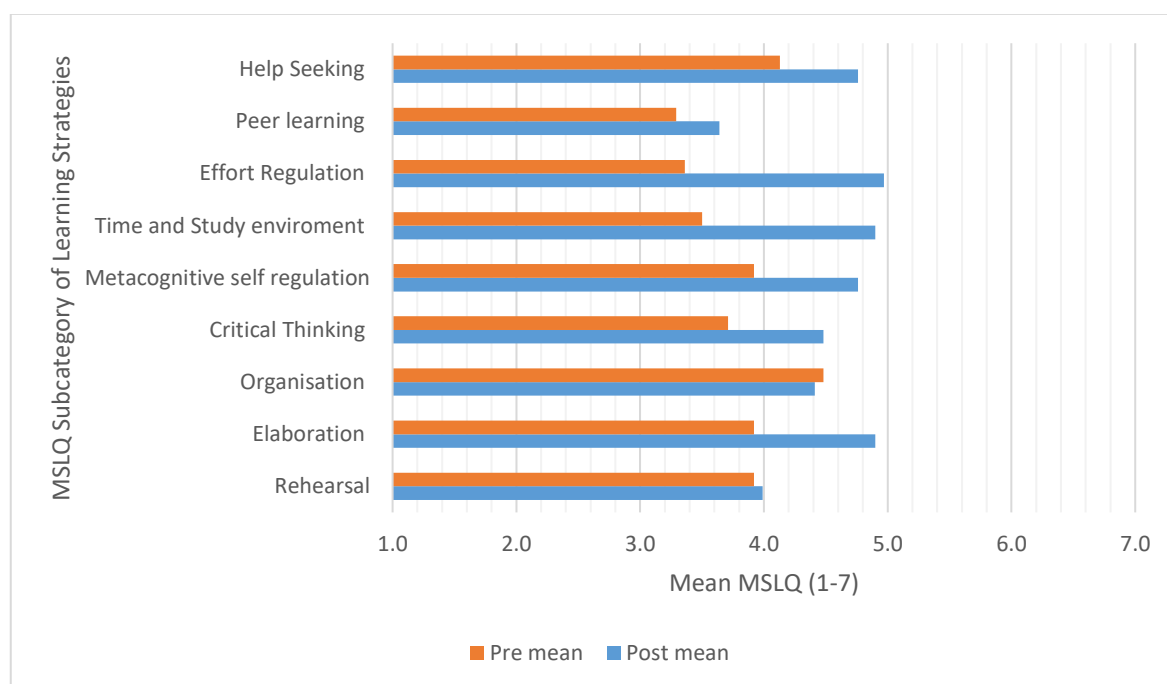


Figure 7.11 Mean scores for MSLQ - Learning Strategies

The increases indicated in the *Critical thinking* subcategory score (mean increase 14%) indicates that students developed skills in applying previous conceptual knowledge to new situations in order to solve problems and reach decisions. Within critical thinking there was a relatively large increase in the items of *'Whenever I read or hear an assertion or conclusion in this class, I think about possible alternatives'* (mean increase 33%) and *'I often find myself questioning things I hear or read in this course to decide if I find them convincing'* (mean increase 17%). As part of the metacognitive prompts, I placed an emphasis on students' awareness of alternative ways of thinking about the chemical phenomenon.

The subcategory of *Metacognitive self-regulation* refers to the fine-tuning and continuous adjustment of one's cognitive activities. Increases in this subcategory are an indication that students became more capable at the general processes that make up metacognitive self-regulatory activities. There was a relatively large increase in score for the items *'When studying for this course I try to determine which concepts I don't understand well'* (mean increase 48%). The metacognitive strategies such as the metacognitive prompts I used addressed this item. These prompts encourage students to think about their knowledge when trying to understand new chemical phenomena and were an important part of various metacognitive strategies. Metacognitive prompt questions used throughout the course in relation to MP would have addressed the item *"When I study for this class, I set goals for myself in order to direct my activities in each study period"* (mean increase 38%). This is similar to the item on the MAI of *'I set specific goals before I begin a task'* which also showed a relatively large increase (mean increase 25%) (Appendix J, under *planning*). The metacognitive strategies which addressed *metacognitive self-regulation*, included metacognitive prompts, think aloud protocol, the generation of representations and the RC.

Supporting and triangulating findings from other sources (e.g., visual and audio recordings), the MSLQ data provides additional evidence that students engaged with the metacognitive strategies during the fifth-year study.

7.7 Reflections in the fifth-year study

Similar observations were made during AR Cycles 1, 2, and 3 regarding the use of the generation of representations as a metacognitive strategy, the classroom atmosphere, and my evolving understanding of metacognition in a domain-specific context through the

implementation of the metacognitive strategies. For brevity, only observations not included in previous reflections are elaborated on here.

As part of the AR approach, and as with the other AR cycles, I engaged in daily reflection during the data collection period in the fifth-year study. I observed metacognition becoming part of the culture of the lessons through the use of metacognitive prompts during student tasks. Planning can take place for metacognitive strategies such as pre and post lesson surveys, introduction of a chemical phenomenon through student generation of representations, while other opportunities arise on a more impromptu basis in lessons. Hence, I needed to plan for the inclusion of metacognitive strategies, but I also had to be metacognitively aware to take advantage of opportunities which arose in lessons as part of a broader metacognitive approach. This is in agreement with Thomas and Anderson (2014) where they argue teachers need to incorporate events into classroom environments that promote the incorporation of metacognition.

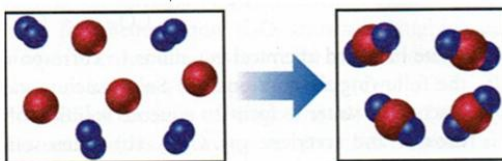
I noted that based on my experience of teaching mathematics, to effectively model my thinking in mathematics I must generate calculations on the board in front of the class (i.e., not just present the finished calculation) while verbalising my own metacognition, similarly I found this is the case for my metacognitive modelling in relation to the generation of representations of chemical phenomena. This has possible implications for the use of premade computer-generated representations which are used on PowerPoint presentations, posters etc. While examples exist in research where the teacher's modelling is followed by each student forming a representation of their understanding of the same concept (e.g. Thomas & McRobbie, 2013), other research has shown the value of students generating representations first (e.g. Tyler et al., 2013; Tippett, 2016). I noted the value of representations in

“Students' generation and refinement of representations serve as a developmental strategy to foster metacognition in a domain-specific way in chemistry by increasing awareness of their current thinking and awareness of how their thinking can evolve. Through discussions, metacognitive prompts, and written or verbal descriptions of chemical phenomena, this approach is particularly effective in promoting and providing evidence of the development of metacognitive awareness in chemistry.”

Reflecting on the cognitive processes expressed by students during discussions and think-aloud activities while generating representations, I revised my approach to class tests

which were conducted bi-weekly or tri-weekly basis in the fifth-year study. The revised tests placed greater emphasis on students generating representations and providing associated explanations of their cognitive processes, rather than relying solely on word-based or calculation-based questions from previous national examination papers. This change aimed to address a gap I had observed memorisation being elicited by the questions (text based) from state examination papers, with little need to be aware of this cognitive process. The shift in my approach to class tests can be seen when comparing the extracts from my class tests shown in Appendix K (my class test based on state exam papers) and Appendix L (my class test for inclusion of the generation of representations and associated rationale) which I used in the fifth-year study. As an example, student DEH's responses to questions in the same week are shown in Figure 7.12. It is interesting comparing the responses from DEH which indicate that they understood the principles of balanced equations and the ratio of atoms in a compound (Figure 7.12 (a)). However, when answering the calculation-based question (Figure 7.12 (b)) they seem to have used a procedural mathematical approach without providing evidence of their cognitive processes related to the submicroscopic level, which is reasonable because it was not required in the question. The key aspect I reflected on was which type of question provides evidence of an awareness of the cognitive processes of understanding and visualisation, particularly at the abstract submicroscopic level of chemistry. In my view, questions requiring the generation of representations and associated explanations offer greater opportunities to challenge students' awareness of their cognitive processes at the submicroscopic level. Aligning with my reflections, previous research argues students often do not use the submicroscopic level to explain the macroscopic properties of matter (Driver et al., 1994; Knel et al., 1998), and they find it challenging to relate mathematical symbols to coherent chemistry understanding (Lythcott, 1990; Nurrenbern & Pickering, 1987).

- (a) 5. The reaction between reactant A (blue spheres) and reactant B (red spheres) is shown below.

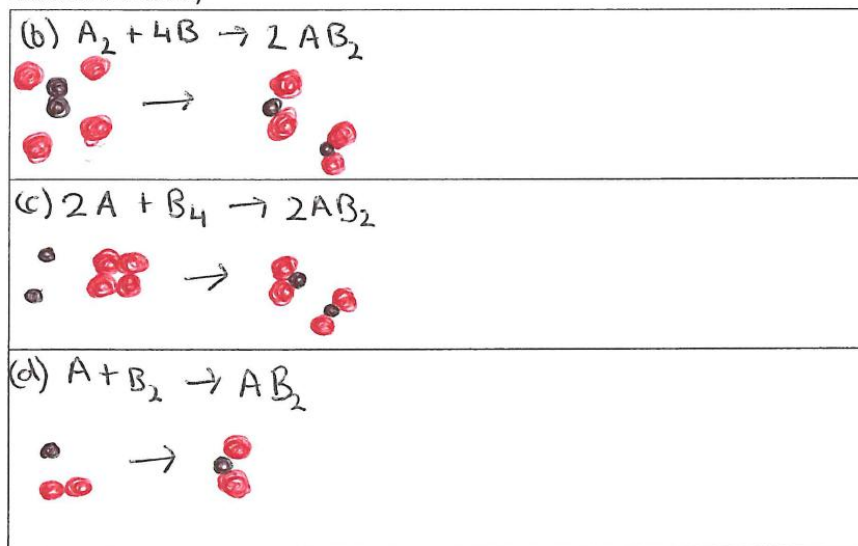


Based on this diagram, which equation best describes the reaction

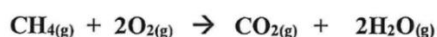
- (a) $A_2 + B \rightarrow A_2B$ ✓
 (b) $A_2 + 4B \rightarrow 2AB_2$
 (c) $2A + B_4 \rightarrow 2AB_2$
 (d) $A + B_2 \rightarrow AB_2$
6. Give a reason for each of your answer in question 5

There's two A bonded together that react with 1 B to produce 2 A's and 1 B which gives you A_2B

7. Using diagrams similar to the diagrams above, represent each of the other three reactions from Question 5. (label the diagrams with each of the reactions letters)



- (b) Methane burns in air according to the equation



If 2.5 moles of methane are reacted fully with oxygen calculate

- a) The moles of carbon dioxide formed
 b) The number of moles of water formed
 c) The number of moles of oxygen consumed

$$2.5 \text{ moles } CH_4 = 12 + 4 = 16 \times 2.5 \\ 40 \times \frac{3}{4} = 30 \text{ moles C}$$

$$2.5 \times 4 = \frac{10}{1.8} = 0.56 \quad \frac{30}{12} = 2.5 \quad 2.5 \times 2 = 5$$

(a) - 2.5 mole of CO_2 formed
~~12 + 4 = 16~~ ~~12 + 16(2) = 44~~
 (b) 2(2 + 16) = 36 moles 0.56 moles water
~~12 + 4 = 16~~ ~~12 + 16(2) = 44~~
 (c) 2(16 + 16) = 64 moles of oxygen consumed
 (c) = 2.5 + 0.56 = 3.06 moles oxygen consumed

Figure 7.12 Student DEH's responses to questions from (a) test which included the generation of representations and test (b) based on questions from the state exam papers in the same week of the fifth-year study

It could be argued that the changes I made to the tests are at odds with preparing students for a final state exam at the time of this study, which was dominated by word-based or calculation-based questions. However, my rationale for incorporating representations into the tests was that they provide a deeper indication of student awareness of cognitive processes in chemistry, which I believed was more durable and transferable throughout the two years of their senior cycle chemistry studies. The approach I took with student generating representations as described above was also because I was not focused on what Nuthall (2005) described as a negotiation to find the most expedient approach to arrive at the desired answer. The inclusion of questions which require students to generate representations and provide associated evidence of cognitive processes in chemistry, particularly at the submicroscopic level, is a possible area for development in the assessment of the new Senior Cycle Chemistry course (NCCA, 2023).

As part of a reflection, I noted that for me as a teacher to provide the conditions for fostering metacognition in chemistry lessons, I also need to understand my own metacognition in the context of chemistry, while also having an ability to implement metacognitive strategies. In my end of senior cycle study reflection, I described how I developed my understanding of metacognition in chemistry through the phases in the AR Cycles in the senior cycle study and this contributed to my understanding in terms of how to incorporate metacognitive strategies in chemistry lessons. This includes drawing on experience to avail of the impromptu opportunities to embed metacognition e.g. metacognitive prompts and metacognitive modelling. Berliner (1994) emphasises the importance of this aspect of teacher development, arguing that teachers must make on-the-spot responses to students' emerging cognitive processes. Effectiveness in such a dynamic environment, like the classroom, requires teachers to know how to act appropriately at the right time. A teacher's own awareness of this '*adaptive expertise*' could be described as metacognitive (Cocking, et al., 2000; Duffy 2006). I also noted at the end of the fifth-year study and following the analysis of the data "*there were opportunities for additional metacognitive prompts and discussions throughout the implementation of the metacognitive strategies which I did not utilise*". For example, following the analysis of the student representations, opportunities were missed to discuss students' awareness of their cognitive processes.

7.8 Conclusions from the senior cycle chemistry study (AR Cycles 1-3)

A number of interesting conclusions can be made based on the findings from the analysis of the data from the senior cycle study. In addressing the overall research question in the senior cycle study (AR Cycles 1–3), *What are the affordances and limitations of integrating metacognitive strategies in Senior Cycle chemistry lessons in the Irish context?*, the findings are presented below for each sub-research question.

RQ What metacognitive strategies are particularly appropriate for the incorporation of metacognition in senior cycle chemistry classrooms?

Through their incorporation in the senior cycle study (AR Cycles 1-3) the metacognitive strategies which were found to be particularly appropriate for the incorporation of metacognition in chemistry lessons were (i) think aloud protocol, (ii) teacher led metacognitive discussions, (iii) metacognitive modelling by the teacher, (iv) generation and refinement of representations, (v) reflective writing; pre and post lesson reflections (vi) metacognitive prompts (vii) explicit metacognitive instruction. Following an analysis of the lessons, it was noted that the inclusion of the SEM and RC in the senior cycle lessons require further development, including a more consistent incorporation in lessons. As part of the findings of the senior cycle study, it was noted that to take opportunities to incorporate metacognitive strategies, I as the teacher, would need to understand metacognition in a chemistry context such as awareness of cognitive processes (e.g. thinking, visualising, learning understanding), at the submicroscopic, macroscopic and symbolic levels and recognise opportunities to include metacognitive strategies in chemistry lessons. My analysis of audiovisual recordings of lessons for both metacognitive strategies and events that addressed the subcomponents of metacognition contributed to my understanding of metacognition in the context of chemistry lessons and the formation of the conceptual framework (see Section 6.6).

To triangulate qualitative data, several quantitative inventories were piloted during the TY studies (AR Cycles 1–2). For the fifth-year study (AR Cycle 3), the MAI and MSLQ were used to assess student metacognition, while MOLES-S evaluated the metacognitive orientation of lessons. These tools offered me valuable insights into how the metacognitive strategies aligned with specific metacognitive components and inventory items. The data collected using the MOLES-S supported my reflections and analysis, indicating that the implemented metacognitive strategies created a metacognitively

oriented chemistry classroom environment in the fifth-year study. In terms of student metacognition, there were notable increases ($\geq 10\%$) in students' scores for overall metacognitive awareness and regulation, as reported using the MAI before and after the fifth-year study. These MAI results were supported by comparable increases ($\geq 10\%$) in the cognitive and metacognitive subcomponents of elaboration, critical thinking, and metacognitive self-regulation, as reported by the MSLQ. While acknowledging other potential contributing factors, such as students' involvement in other subjects, the interpretation of MSLQ and MAI responses supports the assertion that students did engage with metacognitive strategies in the fifth-year study. This finding is further supported by triangulation with qualitative data sources, such as the audiovisual analysis of the lessons and my reflections (Section 7.7).

RQ What are the affordances of metacognitive strategies and a metacognitive environment for senior cycle chemistry lessons?

I noted the importance of teachers' own metacognition in recognising and leveraging opportunities to incorporate metacognition into teaching and learning strategies and this is an important aspect of effectively implementing metacognitive strategies. I deepened my understanding of metacognition in chemistry by (i) continually reviewing literature on metacognition, (ii) planning, implementing, and reflecting on metacognitive strategies and (iii) developing a domain-specific conceptual framework (see Section 6.6). This process was supported by categorising events in my lessons that addressed the subcomponents of metacognition (See Section 7.1) and metacognitive strategies (see Section 7.3).

Explicit metacognitive instruction, teacher-led metacognitive discussions, and metacognitive modelling formed an important part of lesson discourse, and I found that it was important for these to be contextualised within chemistry and presented using accessible language. Examples of these occurred by design following my own development in terms of my theoretical knowledge of metacognition and my pedagogical knowledge in the context of incorporating metacognition in chemistry. Examples of teacher metacognitive modelling in relation to chemical phenomena provided opportunities for students to relate to my cognitive processes in chemistry, rather than there being an assumption on the student's part that I had an unattainable ability to understand chemistry. I also noted a belief in my lesson reflections that to avail of domain

specific opportunities for metacognitive modelling, metacognitive prompts or explicit metacognitive instruction, teachers must have experience of, and understanding of, metacognition as it applies to chemistry.

A central aspect of a metacognitively orientated environment in chemistry lessons in the senior cycle study was found to be the incorporation of metacognitive strategies in a supportive atmosphere where the importance was on student cognitive processes at a particular time and not necessarily generating responses that had to be theoretically correct. In this way, awareness of student cognition at a particular time is interpreted as a ‘stop’ on the ‘journey’ to theoretical correctness, rather than the theoretical correctness being a ‘stop’ on the ‘journey’ to student cognition. Once awareness of cognition in relation to a chemical phenomenon is addressed, it can be used to address misconceptions or difficulties based on the students' cognitive processes at that point in time. This provides opportunities to increase awareness of their cognitive processes, how their cognitive processes can evolve, and how they can be consolidated. I believe these are questions for both the student and the teacher to be aware of as part of embedding metacognition in chemistry lessons.

RQ What are the affordances of representations for the incorporation of metacognition in senior cycle chemistry lessons?

A metacognitive strategy which gained domain specific prominence through (AR cycles 1-3) was the ‘generation of representations’, and how they provide opportunities for the incorporation of metacognition as part of other metacognitive strategies e.g., metacognitive discussions, the think aloud protocol and metacognitive prompts, teacher metacognitive modelling and explicit instruction on metacognition in chemistry. An important aspect of this strategy was found to be ensuring the representations generated by students were based on their own cognitive processes and knowledge at a point in time, rather than a simple replication of a diagram they observed previously. It was found that opportunities for metacognitive engagement increased when students were not initially provided with a representation of the chemical phenomena. Instead, they were provided with a supportive environment and specific instructions to create a representation based on their cognitive processes at that time. This approach to representations provided students the freedom to voice their cognitive processes, thereby promoting opportunities to incorporate metacognition through prompts, discussion and

descriptions. Subsequent discussions and prompts and refinement of representations, students and I gained insights into the evolution and consolidation of their cognitive processes. I reflected on how this process was especially valuable in relation to abstract chemistry at the submicroscopic level. This insight informed the generation and refinement of representations in the design and implementation of the PST study (AR Cycles 4 and 5).

Chapter 8 Pilot PST methodology module (AR Cycle 4)

Following the second-level study (AR Cycles 1-3), my role as a teacher educator in PST education presented an exciting opportunity to implement the insights gained from AR cycles 1-3 into the design of a PST methodology module. For context, the overarching aim for the methodology module was preparing PSTs for teaching and assessing senior cycle chemistry in the Irish education system. The challenge for me in transitioning from the second-level study to the PST study lay in incorporating what I had learned as a teacher, through the phases in the AR cycles in the senior cycle study, into the design of a methodology module. One of my aims for the module was to integrate metacognition to prepare PSTs for teaching chemistry as part of the reformed Senior Cycle, which places an emphasis on cognitive and metacognitive skills (NCCA 2023a). This chapter presents the planning, action and observation, and reflection phases in the *pilot methodology module* (AR Cycle 4), which was used to inform the *methodology module* (AR Cycle 5) which is discussed in Chapters 9, 10 and 11. As part of the planning for the pilot methodology module (AR Cycle 4), I distilled the key findings from AR Cycles 1-3 and integrated relevant literature on teacher education and metacognition (see Section 2.6). The action and observation phase of this cycle took place in workshops with the PSTs. As with the previous AR cycles, my reflections were embedded throughout the action and observation phases, with an overall reflection and analysis conducted at the end of the AR cycle. The overview for the PST study is shown in Figure 8.1.

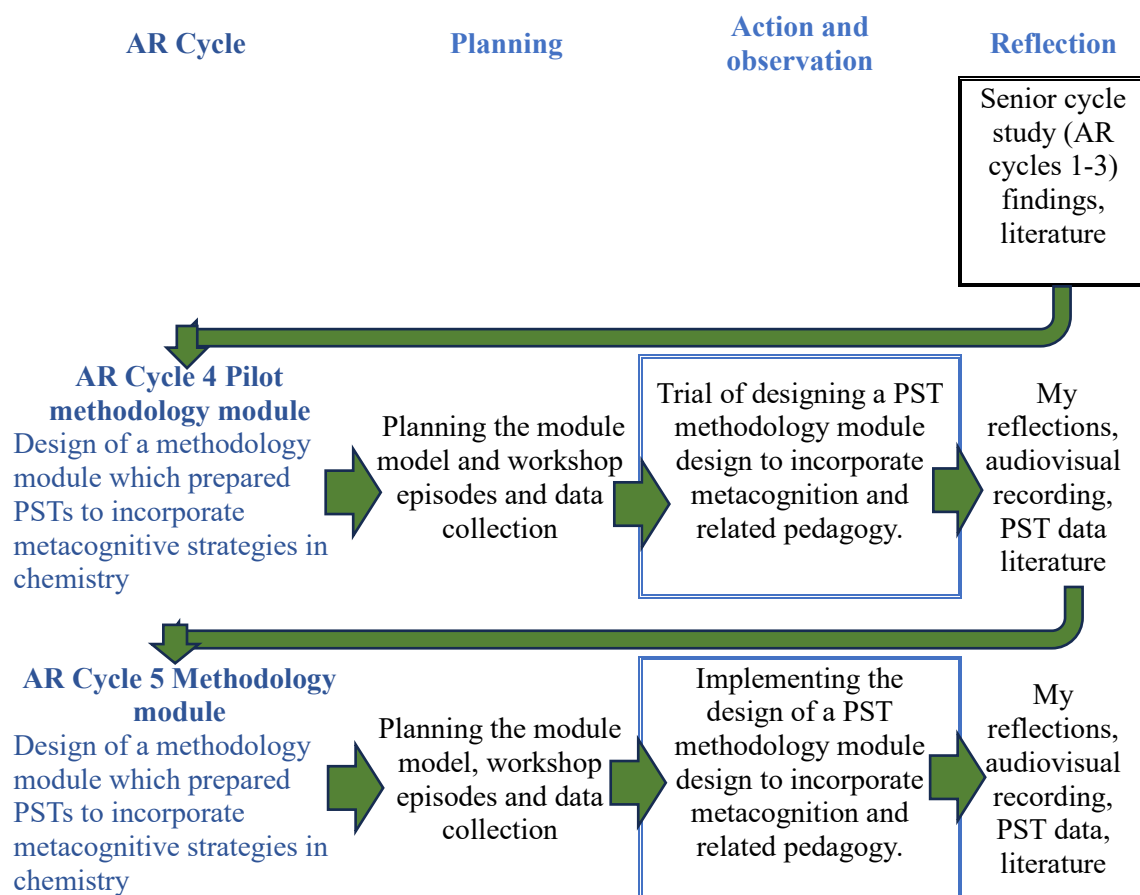


Figure 8.1 An overview of the phases in the PST education study

8.1 Introduction to pilot methodology module

As discussed in Chapter 2, researchers have argued that if metacognition is to find its way into routine instruction, metacognition needs to be part of teacher education and it needs to be reflected in teacher educators' practices (Georghiades, 2004; Thomas, 2012; Kallio et al., 2021). Literature has argued that teachers require a sound understanding of metacognition, and they need to incorporate events into classroom environments that provoke metacognition in students (Thomas & Anderson 2014; Ryan, 2014; Flavell 1979). As discussed in Section 2.4.1, Zohar and Barzilai (2013) argue that in order for teachers to have a sound knowledge of metacognition, they need to have a general theoretical knowledge about metacognition and its various components. Ryan (2014) argues that in order to facilitate the transfer of students' thinking to other areas of learning, teachers must first be aware of the thinking the students engage in, and that this requires a sound understanding of metacognition. In line with this literature and the findings from the senior cycle study, as part of the pilot methodology module, a focus

was placed on the PSTs' theoretical understanding of metacognition. My experience of studying metacognition from a theoretical point of view also supported my rationale for incorporating metacognition in the module through a theoretical exploration of metacognition. This theoretical approach was embedded in workshop tasks, assignments, and explicit instruction on metacognition throughout the pilot methodology module.

8.2 Implementation of the pilot methodology module

A number of chemistry topics were included in both iterations of the methodology module in this research (AR Cycles 4 & 5) and are summarised in Table 8.1. I selected these topics based on insights gained from the senior cycle study. These topics are central to the Leaving Certificate chemistry curriculum (DES, 2002) and I found they provide opportunities to explore awareness of cognitive processes in chemistry through underlying concepts, such as electronegativity, electrostatic charge, and collision theory.

Table 8.1 Chemistry topics included in the methodology module (AR Cycles 4 & 5)

Chemistry topic
Electronegativity- States of matter, Kinetic molecular theory.
Knowledge of electronegativity through oxidation and reduction
Electronegativity through Acids and bases.
Redox reactions
Chemical equilibrium
Le Chatelier's principle
Reactions in Organic Chemistry– Mechanisms for substitution and addition reactions
Qualitative tests for the anions, SO_4^{2-} , SO_3^{2-} , Cl^- , and NO_3^- in aqueous solution
Redox reactions of the halogens and Displacement reactions of metals

In conjunction with other components of pedagogy, the metacognitive components of the pilot methodology module were focused on developing the PSTs' theoretical understanding of metacognition and their use of metacognitive strategies in chemistry teaching. The metacognitive aspect addressed in each workshop is shown in Table 8.2 and are summarised in Appendix M.

Table 8.2 Metacognitive aspect addressed each workshop in the pilot methodology module

Workshop	Metacognitive aspect	Metacognitive strategy
1	Levels of representation and cognitive processes in chemistry	MAI inventory
2	Introduction to the principle of metacognition	Theoretical aspects of metacognition- Teacher explicit instruction of metacognition
3	Generating representations of chemical phenomena to display cognitive processes, to introduce PSTs to metacognitive awareness and its subcomponents	Think-aloud protocol- Teacher metacognitive modelling
4	Cognition in chemistry- through the chemistry triplet	Generation of representations. Strategic evaluation matrix (SEM)
5	Developing student metacognitive regulation in chemistry	Metacognitive prompts. Metacognitive Awareness Inventory for Teacher (MAIT)
6	Metacognition in the generation of representations in chemistry	Reflective writing, Pre and post surveys in chemistry
7	Problem solving and teaching & learning strategies which promote metacognitive regulation in chemistry	Regulatory checklists Metacognitive prompts, metacognitive modelling.
8	Developing metacognitive regulation through the refinement of representations	Think aloud protocol relating to the generation of representations
9	Identification of techniques for assessing metacognition in chemistry	Metacognitive discussions
10	Revise the metacognitive teaching & learning strategies as they apply to a chemical phenomenon	Theoretical aspects of metacognition

8.2.1 PST assessment in the pilot methodology module

The assignments in the pilot methodology module included parts on the PSTs' own understanding of metacognition in chemistry and their planning for the use of metacognitive strategies. The metacognitive aspects of the assignments in the pilot methodology module are summarised in Table 8.3.

Table 8.3 Metacognitive aspects of the assignments in the pilot methodology module

Module Assignment	Description
<i>Weekly Reflections on Articles from the literature</i>	Guidelines given to PSTs with prompt questions for reflective writing. e.g. <i>Preview the text and make predictions; Make connections to personal experience or other texts; Ask clarifying questions of the text; Identify difficult sentences or passages.; Restate in your own words; Reactions to the text.</i>
<i>Compendium</i>	Teaching Strategies for improving the student's cognition and metacognition through a chemistry experiment. (i) Stimulus to engage students (ii) Links to underlying concepts (iii) assessment techniques (iv) Description of the experiment from a teacher's perspective.
<i>Final Assignment Part 1</i>	Assessment of their own cognitive processes on an assigned topic in Senior Cycle chemistry This assignment is in relation to their description of their awareness of (a) their cognitive processes and (b) themselves as a thinker and learner, in relation to a concept as it applies to a topic in Leaving Certificate Chemistry. It was to be completed under the heading's declarative knowledge, procedural knowledge, conditional knowledge, representations of their visualisations.
<i>Final Assignment Part 2</i>	This part of the assignment was based on teaching strategies which develop student metacognition in chemistry. This assignment aimed to encourage the PSTs to think about metacognition as part of their teaching of chemistry. It was to be completed under the headings of teaching strategies to promote student awareness of their metacognition, declarative knowledge, procedural knowledge, conditional knowledge, and representations of their visualisations.
<i>Final Assignment Part 2</i>	Audiovisual recording of incorporating metacognitive teaching strategies in relation to their assigned topic based on the material covered throughout the semester, using the final assignments Part 1 and Part 2 in particular. How would they promote student metacognition in relation to your concept within the topic? The aim of this part of the assignment was to determine how the PSTs would incorporate metacognitive strategies in their teaching.

8.3 Summary analysis of the pilot methodology module

In order to analyse the data relevant to the PST study research questions (see Table 3.1), the following sources were used in the pilot methodology module (AR Cycle 4); (i) PST assignments (ii) PST interviews (iii) results of the MAI and MOLES-S and (iv) my reflections.

8.3.1 PST assignments

The final module assignments had three parts (See Table 8.3). Part 1 included questions on the PSTs understanding of metacognition and the subcomponents of metacognitive awareness. Many of the responses from the PSTs in the Part 1 assignment appear to be word-for-word definitional accuracy instead of expressing their understanding in their

own words in the context of chemistry. For example, PS1 defined conditional knowledge as *“referring to knowledge when and why to use declarative knowledge and procedural knowledge”*, while PS2 defines it as *“thinking about how one thinks”*. PS4 describes metacognition as *“thinking about one’s own thinking”* and *“that it involves identifying ways in which a person can learn best from and use this information to then effectively learn”*.

As described in Chapter 4, it is important that PSTs and students can see the value of metacognition in terms of understanding in chemistry in a domain specific way. While explicit instruction in metacognition is one of the metacognitive strategies, an important element of the PSTs’ understanding is the domain specific incorporation of metacognition in the teaching and learning of chemistry. However, the PSTs’ focus on the theoretical description of metacognition in a domain general way was evident at the end of the pilot methodology module. For example, when asked in the Final Assignment Part 2 (Table 8.3) how they would introduce metacognition in chemistry lessons, PS7 indicated they would introduce metacognition to students by firstly putting *“Metacognition”* on the whiteboard and ask students to *“discuss in their pairs what they think metacognition might mean”*. PS7 goes on to describe how to break the term into two components *“meta”* and *“cognition”* and ask students to think *“about those two terms independently of one another and then try to bring them together to come up with what they believe metacognition to be”*. PS5 describes that when they are introducing metacognition to a senior cycle chemistry class, they would initially ask students *“to write down anything they know about metacognition”* as they believe that would be a *“good starting point to get the students who have experienced it to explain their own thoughts on it”*. PS5 indicates they would describe metacognition as *“thinking about thinking”* and they would *“explain to them [their students] that this process involves thinking about how they interpret new material.”* In another example where a PSTs description of metacognition lacked sufficient domain specific detail was by PS1 at the end of the module where they indicate they *“think that metacognition is the key to getting students to understand a topic/concept and in doing so makes chemistry more accessible to everyone. It is a skill that should be used in every subject that students do and then it would become second nature to them”*. The PSTs descriptions of metacognition and how they would introduce it into their teaching provide evidence of the PSTs ability to define metacognition theoretically. However, their descriptions are focused on the theoretical, domain-general

aspects of metacognition rather than its use in the teaching and learning of chemical phenomena. The implication of this finding for the design of the next iteration of the methodology module (AR Cycle 5) is that the importance must shift to an understanding of metacognition through PSTs experience of discussing and using metacognition in the domain specific context of chemistry, or what Zohar and Barzilai (2013) describe as the personal ability to practise metacognitive thinking with respect to classroom activities.

The PSTs descriptions of their visualisations in the pilot methodology module failed to include examples of representations in many cases, which would have supported their word-based descriptions. Seraphin et al. (2012) argue that teachers need to be taught about metacognitive strategies, but they also need sufficient time and support to practise these strategies before they are asked to teach them to their students. During the pilot methodology module, representations and visualisations grounded in metacognitive strategies for chemistry were discussed and modelled by me, but evidently not enough time was given for PSTs to generate representations of their own. For example, PS1 described their visualisations of the chemistry concept of electrostatic attraction and repulsion as it applies to the *valence shell electron pair repulsion* (VSEPR) theory in the following way.

“When I visualise the concept of electrostatic repulsion and attraction I think about magnets, the lone pair having a greater magnetic effect than a bond pair. The electrons are negatively charged and so act like the negative pole of a magnet. When two lone pairs are on the shell, I think about two opposing magnets pushing each-other away from each-other and thus pushing the bond pairs closer together. The lone pairs have the strongest magnetic push as they have a very dense region of electrons, very negative. When thinking about the bond pair, due to the unequal sharing of electrons (“tug of war” of electronegativity as described above) the electron cloud is not as dense at any one time and so the magnetic effect is weakened” (PS1)

While this account by PS1 uses an analogy to describe how they visualise the chemistry, they appear to conflate magnetic and electrostatic forces in their description, and it is missing the richness that would have been achieved through the inclusion of representations. The use of representations of one's cognitive processes was identified by the PSTs in the pilot methodology module. For example, PS3 describes in their final assignment that there are “*two ways that we can visualise concepts, firstly, by seeing an image in our head and secondly, transferring that image to paper*”. PS3's approach of

first describing generating a mental image and then an external visual on a page, requires more awareness of their own cognitive processes when compared with observing an image then mentally integrating the image. To model this approach PS3 gave examples of how they would describe their visualisations before drawing a representation e.g. *“When I think of a molecule of methane, I imagine a central carbon with four single bonds of hydrogen attached, I will draw this on the whiteboard to aid my explanation”*. PS3 also describes their awareness of their understanding linked to their visualisations *“When I am applying my idea of a molecule of methane to polarity, I know that I need to include the electrons in the image in my head”*. This is evidence of MDK linked to their visualisations while PS3 also addressed their own MPK in relation to their representations:

“I will then redraw my molecule with dot and cross electrons included. I can see in my diagram that the electrons are shared equally between the atoms within the molecule. Therefore, I can say that it is a non-polar molecule. This is an example of adaptation of an internal visualisation using my metacognitive skills. I have used my initial image of a molecule to relate it to a more detailed concept, by using my prior knowledge of the molecule itself” (PS3)

PS3 used this example to demonstrate their use of language and how it ties into both metacognitive awareness through the description of their visualisations as it would be presented in a representation. Methods of assessment that PS3 would use in relation to visualisation include asking students to give examples of visualisations in chemistry, selecting students and asking them to draw what they imagine on the board in front of the class, and encouraging students to *“talk through their process of drawing and what they may have to adapt in order to transfer the image in their mind to an image on the whiteboard”*. The above example provides opportunities for students to talk through the process of drawing and illustrating representations of their visualisations of chemical phenomena and how visualisations are generated by the PST, which addresses both visualisation and metacognition. The descriptions by PS3 provide evidence they have understood the value of metacognitive strategies linked to generating representations in chemistry.

8.3.2 PST Interviews Pilot methodology module

Following the insights gained from the senior cycle study related to the data collected, I conducted interviews with the PSTs involved in the pilot methodology, which took place

at the end of their teaching placement (a semester after they attended the module). The PSTs indicated in the interviews that they had not previously heard of or been taught about metacognition as part of their teacher training or otherwise before this module. They acknowledged the potential benefit of introducing it earlier and in domain specific contexts in their PST education. For example, PS1 stated:

“Yeah, well this module is the only place where I would have heard about it [metacognition] before. I think metacognition is something that is important to the whole of teaching and I think I have heard about the type of strategies. But when explaining those types of strategies, I think the link needs to be made, that ok this is metacognition and metacognitive development. Make it more explicit. Like I suppose in first year when you do microteaching, it could be linked in there, we have done assessing Junior Cycle science, Junior cycle mathematics and it hasn’t come up before. So, I think it could be introduced into quite a lot of different modules, and it would be more developed” (PS1 Post placement interview).

In agreement with the data from their final assignments, when I asked the PSTs in the interviews what their understanding of metacognition was following the module, their responses indicated they had a general theoretical understanding rather than a domain-specific one. For example, PS1 noted:

“I think the easy way to explain it [metacognition] would be to say it’s Thinking about your thinking, but in terms of the classroom it allows students to become more self-directed learners. So, when they are doing problem solving or when they are going through a solution, they are able to recognise what they are thinking about when they are doing it and what’s the right way and what’s maybe not the right way of thinking about it.” (PS1 Post placement interview).

Interestingly, the PSTs suggested that metacognition must be introduced gradually to students, which aligns with my own experience of introducing this abstract concept. For example, PS5 suggested a gradual approach in an interview:

“Yeah, I would gradually bring in what metacognition is, just to make it easier for them [students], it might even get them thinking better about the things for themselves. You know actually their thought process behind something, they might actually, rather than just diving into it if they were aware of what metacognition was and the thought processes involved” (PS5 Post placement interview).

In line with the approach developed for incorporating metacognitive strategies in the senior cycle study and the design of the pilot methodology module, the PSTs indicated in the interviews that having time to think and the use of visualisation and representations

were valuable in incorporating metacognition. Additionally, the PSTs responses in relation to the reflective assignments (see Table 8.3) provide evidence of how they provide opportunities for the time to think about metacognition as a concept. For example, PS1 described:

“Like I think I said it in my reflective assignments already, like I used the visualisation, representations and metacognition. I did them before, but I was never aware of doing them. When you were doing the literature on metacognition assignments each week you were able to reflect on it a bit more, that was a strategy I was missing. Reflecting, I didn’t have time to reflect, but these reflective assignments gave me time to reflect as you had to do them.” (PS1 Post placement interview)

Regarding their own students, PS1 described a similar approach to the value of ensuring time for students to visualise chemical phenomenon:

“Giving them the time to do thinking, giving them the time to think about how they think about this, and I think sharing, share among the class everyone else’s ways of doing it then that would help students with their own internal visualisation, and I think that would then also link in with the metavisualisation and if you discuss a range of different visualisations. Then you could see what best suits you” (PS1 Post placement interview).

In addition to emphasising the importance of an encouraging and supportive environment, the PSTs described how, following their experience in the module, they adopted strategies to address student metacognition including the use of pre- and post-lesson surveys and metacognitive modelling, by themselves and their students when on teaching placement. For example, PS5 explained these ideas in their post-placement interview:

“Definitely the post class surveys and the pre too, at the very start of a topic and they would not be afraid to get something wrong at that stage. Then the one, as a teacher when I talk through how I think about my thinking, because that would definitely help make it more accessible and increase awareness as I explain my thought processes. And then definitely getting the students up to the board, to explain their thinking, I would be a big fan of it. Getting the students to talk through how they had done the question, because if they are able to explain their thoughts, you can see fairly well they actually know what they are doing and it helps other students become more aware of thinking and then metacognition” (PS5 Post placement interview).

The responses from the PSTs indicated that they had gained experience with metacognition through participating in the methodology module. However, the interviews contributed to my belief that while they had developed a theoretical

understanding of metacognition, it was still difficult to determine the domain-specific applicability of their understanding of metacognition in their teaching of chemistry.

8.3.3 Senior cycle and pilot methodology module experiences - MOLES-S

Analysis of the MOLES-S data for the PSTs prior experience of chemistry in their senior cycle (shown in Figure 8.2) indicated that the PSTs perception of their experience in senior cycle chemistry was not particularly metacognitively-orientated. In particular, the mean score for the subcategory of ‘metacognitive demands’ was notably low (Mean = 1.9/5.0) (Figure 8.2), highlighting the importance and relevance of incorporating metacognitive strategies into the PST methodology module. This low score suggests to me that PSTs perceive they did not often encounter metacognitive demanding strategies during their own senior cycle chemistry experience. Consistent with this data, during the PST interviews, PS1 indicated a lack of metacognitive demands in their own second-level chemistry experience when asked about different ways they learned chemistry.

“My teacher, I had a fantastic teacher, but the reason I think I thought they were a fantastic teacher was because her methods were good for me. The majority of the time she would just put a blanket of notes on the board, and you take them down. That was what she did, so I don’t think she varied from that much from what I remember, obviously she did the experiment, but it was always copying it from the book, it was never think about it, or why are you doing this or what hypothesis do you have or what conclusion can you draw from the experiment. It was always we are going to do this experiment because it’s a mandatory experiment, that was kind of what she did. She was quite old fashioned, as I said it worked for me, and it worked for a lot of students. We would just go home and do it, and we would get the results then.” (PS1 post placement interview)

In the above extract, PS1 demonstrates an awareness of their own cognitive processes by demonstrating awareness of the parts (memorisation) of the teaching strategies that worked for them to achieve results, but that the strategies did not encourage them to think. This rewarding of passive and rote learning was described by Stone (1998), as presenting challenges in fostering metacognition in teaching and learning. However, I can see how it can also present opportunities, as metacognition can illuminate an individual’s cognitive processes in chemistry, thereby providing a contrast to the passive, rote learning approach they may have previously experienced.

It is interesting to note the high scores for the subcategory of *emotional support* in their senior cycle experience but somewhat lower score for *teacher encouragement and support*. This suggests that while they felt emotionally supported, they

experienced less encouragement and support in relation to reflecting on their learning in chemistry. It is important to note that the PSTs were completing MOLES-S inventory relying on their memory of their senior cycle chemistry experience, at least three years previously.

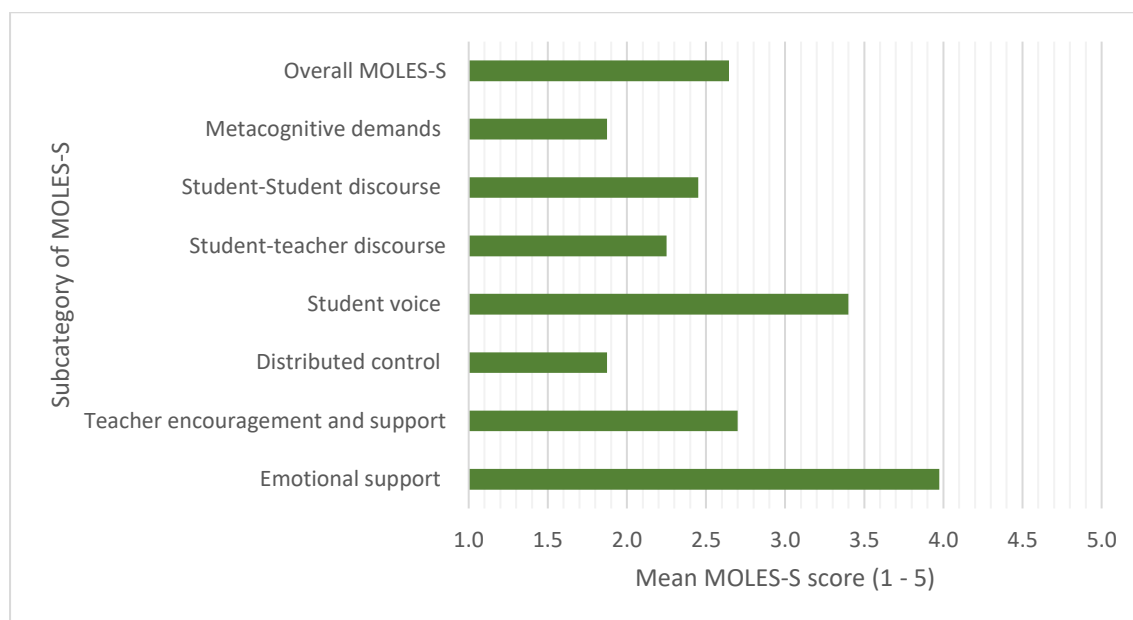


Figure 8.2 Mean score MOLES-S for the PSTs senior cycle chemistry experience

The MOLES-S data from the PSTs experience at the end of the pilot methodology module (see Figure 8.3) suggests that the PSTs perceived the environment in the module to be metacognitively orientated (overall, MOLES-S score 4.2/5.0). The PSTs' scores for each subcategory were approximately 4 out of 5, with the exception of distributed control. Notably, the subcategory of '*metacognitive demands*' received a mean score of 4.5/5.0, indicating that the PSTs found the workshops to be metacognitively demanding, consistent with the intended design of the workshops in the pilot methodology module. Aligning with this finding, PS5 described in their post placement interview how they were encouraged to become more aware of their cognitive processes during the pilot methodology module, while also demonstrating metacognitive awareness of how they visualise and think after completing the module.

"I suppose we were, definitely, reflecting on different parts of the material and how we think about it in the module. Try and recognise what state you are thinking about; how you are thinking about things you are dealing with. I think analogies help people think about their thinking. For example, when I think of the collision

theory, I imagine the screen saver which has the balls bouncing off each other. I don't know why it always comes into my head. But that sped up would be one to show increased collisions. Another one I think of is people on the ice rink ice skating, the faster people move, the greater chance of collisions, if there were two people moving really slowly, if they do collide there won't be a lot of damage. And that ties in with the collision theory, if molecules don't have sufficient energy” (PS5, post-placement interview).

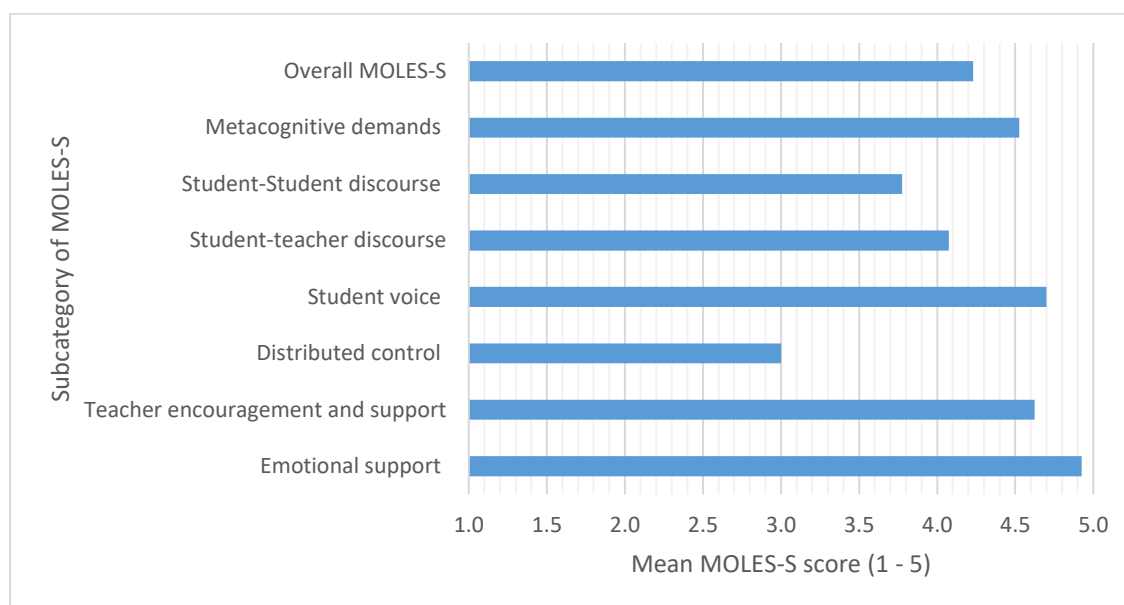


Figure 8.3 Mean score MOLES-S for the PSTs experience in the pilot methodology module

8.3.4 PST metacognition - MAI

The MAI was completed by the PSTs at the beginning (pre) and end (post) of the pilot methodology module and the results are shown in Figure 8.4. There was little change in the overall score at the end of the pilot module; however, there was a small increase in the subcomponents of metacognitive awareness i.e., MDK, MPK and MCK. In terms of the subcomponents of metacognitive regulation, there were only marginal changes noted (Figure 8.4).

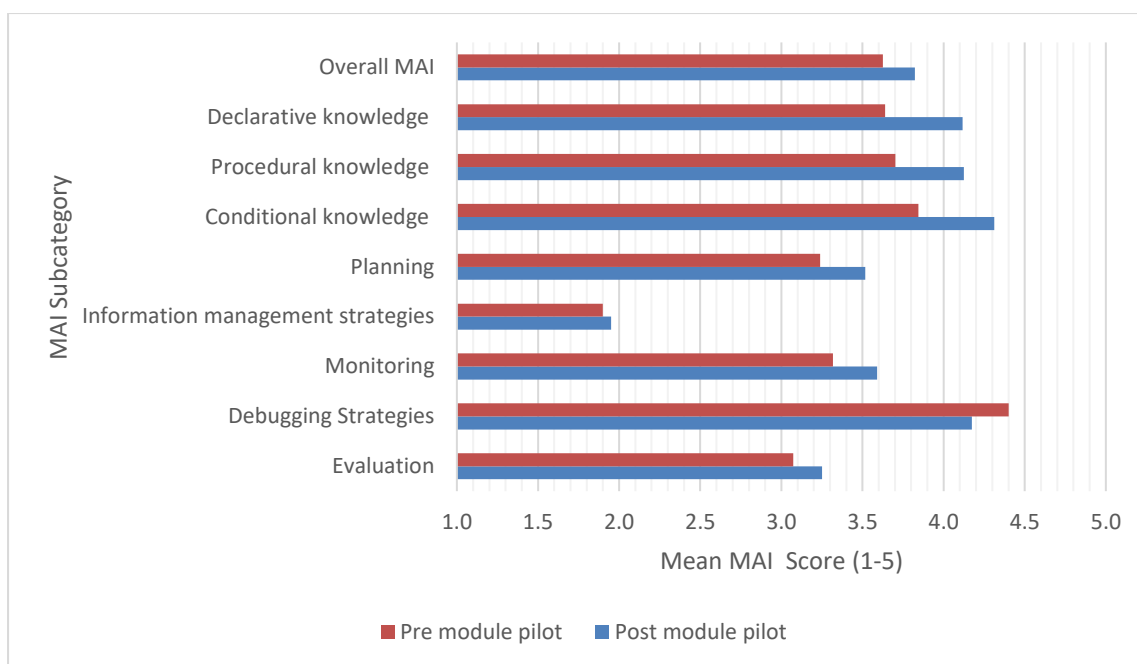


Figure 8.4 PSTs pre and post mean MAI in the pilot methodology module

The lack of change in the metacognitive awareness and regulation as determined by the MAI may be attributed to the focus within the module on increasing the PSTs' theoretical understanding of metacognition. This is in agreement with the PSTs responses in their post placement interviews (see Section 8.3.2). Additionally, in the workshops, there was insufficient emphasis on developing the PSTs' metacognition by having them experience metacognitive strategies firsthand as learners. I aimed to address this in the redevelopment of the design of this module (AR cycle 5) by allowing the PSTs to experience metacognitive strategies as learners before they considered their implementation as teachers.

8.3.4 Reflections on the pilot methodology module

A number of recurring themes emerged in my reflections during the pilot methodology module.

I noted in a post workshop reflection the PSTs “*appreciated opportunities to discuss what would be relatively basic chemistry phenomena*” and how they “*engaged with the idea of thinking about chemical phenomenon through underlying concepts*” which was part of the type of cognitive process I wanted to increase awareness of, where PSTs see the value and building awareness of understanding through revisiting underlying concepts as they apply to chemical phenomena. However, a central issue that was evident in my reflections was the lack of emphasis on the domain specificity of how the PSTs interpreted

metacognition. For example, I noted following the submission of the PST chemistry compendium assignment (See Table 8.3) *“how it didn’t demonstrate student conceptual knowledge or incorporation of metacognition in the way I had intended”* and how *“PSTs mostly included the methods of the experiments as the central aspect of the compendiums they submitted”*. I noted how *“the compendium as an assignment needs to be revised as it’s not generating conceptual rich or metacognitively rich evidence from the PSTs”*.

I also noted as part of a reflection on the assignments the *“domain general descriptions of metacognition that the PSTs used in their final assignments”*. I noted an observation of the passive nature of the PSTs in relation to the metacognitive strategies after workshop seven that I *“was mostly demonstrating the metacognitive strategies, while they would probably see more value in experiencing the metacognitive strategies for specific chemical phenomenon”*. Following the completion of the module I identified *“the need to address the domain specificity of the inclusion of metacognition through the PSTs experiencing, discussing, practicing, and planning implementing metacognitive strategies with each other”*. This change in the design of the methodology module meant going from a focus on the PSTs having a general theoretical knowledge as described by Zohar and Barzilai (2013), to a greater domain specific pedagogical knowledge of metacognition in the context of chemistry. Based on my reflections there was an identified need to have a greater emphasis in the implementation of the module on what Seraphin et al. (2012) describe as the need for teachers to have time to practise metacognitive strategies before they implement them with students. For example, in line with the findings of the senior cycle study, I noted the need to provide more *“opportunities to experience the premise of generating representations where the focus is voicing their cognitive processes at that time rather than the pressure of having to be being absolutely correct”*, while *“then emphasising to the PSTs that these can be used as a path to reach theoretical correctness and increase their own awareness of the evolution and consolidation of their own cognitive processes and that of their students”*. The key point here is the need to create opportunities in the design of the methodology module for PSTs to generate, discuss, and refine representations of their cognitive processes in chemistry. This approach emphasises a shift from them being observers or interpreters of representations to becoming active generators and refiners of representations, fostering learning *with* representations rather *than* merely learning from them. Although this use of representations has been discussed in the literature (Taber, 2018; Tippet, 2016), the

design of the methodology module (AR Cycle 5) should also emphasise opportunities for incorporating metacognition as part of generating and refining representations of cognitive processes.

8.4 Summary findings from the pilot methodology module and implications for AR cycle 5

The findings from the pilot methodology module (AR Cycle 4), which informed key implications for the methodology module (AR Cycle 5), are summarised in this section.

As the PSTs in the pilot methodology module displayed a theoretical definition-based description of metacognition rather than a domain specific understanding of metacognition in chemistry, this needed to be addressed in the design of the module.

My findings indicate that the pilot methodology module focus on this approach may not be effective, particularly where the aim was for domain specific use of metacognition and metacognitive strategies. The final design of the methodology module also needed to address the PSTs' domain-general incorporation of metacognition in the planning of their teaching, as indicated in their assignments from the pilot methodology module. In the pilot methodology module, the PSTs planning of their teaching was more focused on teaching metacognition as a domain general concept rather than incorporating it in a domain specific way or embedded in strategies in their teaching of chemistry. The PSTs were able to define '*metacognition*'; however, they missed the chemistry specific aspects which would indicate a robust understanding of metacognition in the context of chemistry which is necessary for incorporating metacognition in chemistry lessons.

The data from the PSTs indicates they valued visualisations and representations and would incorporate them into their teaching and learning strategies when teaching senior cycle chemistry. However, this was demonstrated through word descriptions rather than through the inclusion of examples which demonstrate their use. A valuable modification informed by the pilot methodology module was the need to increase emphasis on the use of associated descriptions, discussions, and metacognitive prompts in relation to how the PSTs generated and refined their own representations.

The pilot methodology module included the PSTs implementing metacognitive strategies. However, it was identified that in the revised module there was a need to adjust the design of the module to ensure the PSTs develop their own awareness of cognitive processes through experiencing the metacognitive teaching and learning strategies first

before planning or practicing their implementation. The revised module design and assessment requires a greater focus on addressing a richer demonstration of PSTs' understanding of metacognition in the context of chemistry, both in terms of their own metacognition and the metacognitive strategies.

8.5 Conclusion

This chapter summarised and discussed the data from the planning, action, observation and reflection phases of the pilot methodology module (AR Cycle 4). The insights gained from the findings of the pilot methodology module informed the last iteration of the methodology module (AR Cycle 5). The design of the methodology module (AR Cycle 5) is outlined in Chapter 9, with the findings discussed in Chapters 10. Chapter 10 also presents the overall findings of the PST study (AR Cycles 4 & 5) through relevant research questions.

Chapter 9 Design of PST methodology module (AR Cycle 5)

The planning and design of the second iteration of the methodology module was adjusted based on the insights and findings from the previous AR cycles, particularly those from the pilot methodology module (AR Cycle 4). In the *planning phase* of this AR cycle, I shifted from a general to a more domain-specific approach to incorporating metacognition into the module design. The *action and observation phase* occurred throughout the methodology module workshops and assignments, while reflection was both embedded throughout the AR cycle while summative reflection took place at the conclusion of this AR cycle, which is discussed in Chapter 10. This chapter discusses the key aspects which influenced the design of the methodology module, how the metacognitive aspects of the workshops were implemented, and the module PST assessment is also discussed.

9.1 Design for incorporating metacognition into the methodology module (AR Cycle 5)

The design of the second iteration of the methodology module (AR Cycle 5) shifted from a focus on PSTs theoretical understanding of metacognition, as emphasised in the pilot methodology module (AR Cycle 4), to a more practical domain specific incorporation of metacognition. This iteration prioritised PSTs' own metacognition in chemistry by providing opportunities to experience and plan metacognitive strategies. This approach aimed to encourage the PSTs to value the metacognitive strategies and enhance the likelihood of PSTs incorporating them into their future teaching of chemistry. This approach has been used in other contexts (Shukla & Dungsungnoen, 2016; Wilson & Bai, 2010). The design of the methodology module (AR Cycle 5) included the following key aspects:

(a) addressing the development of the PST's own metacognition, before gradually moving the balance toward their use of teaching and learning strategies which incorporated metacognition in chemistry. The importance of the methodology module providing time for the PSTs to experience, practice and discuss metacognitive strategies as part of teacher education was recommended by Seraphin et al. (2012). The importance in the methodology module design is placed on the incorporation of metacognition embedded in the teaching and learning of chemistry, and not as a standalone concept;

(b) continually emphasising the importance of activating knowledge and representing and discussing cognitive processes related to chemical phenomena to support the metacognitive orientation of a chemistry classroom e.g. creating an environment where PSTs discuss awareness of their own cognitive processes in relation to chemical phenomena through underlying concepts. An important metacognitive aspect of the design of methodology module is the PSTs can reflect on the evolution and consolidation of their cognitive processes, e.g., through discussions and descriptions related to the generation and refinement of representations of how they visualise and understand chemical phenomenon;

(c) challenging PSTs to think about the degree to which their representations (or the representations of their future students) are a manifestation of their own cognitive processes versus simply a replication of a diagram which was previously presented to them, for example in a textbook. This was to ensure the use of representations in development of the subcomponents of metacognition as described in the conceptual framework (see Section 6.6) and where the focus is on cognitive processes related to the generation of representations rather than as instruments to provide knowledge to a ‘receiver or interpreter’ (Tytler, et al., 2013);

(d) building and modelling a supportive and encouraging environment; for the module to be effective, PSTs require reassurance that their knowledge at any point in time will be built upon, such that they are confident to voice their own difficulties in their cognitive processes related to chemistry, even basic chemistry, and not enter into a ‘group think’ or simply give answers which they believe I want them to say. Thomas (2003) argues this trust dynamic is an important part of a metacognitively orientated classroom, where an emphasis is on PSTs efforts being valued, ideas respected, and the PSTs and I trusting each other. The importance of PSTs feeling they can voice their cognitive processes regarding chemical phenomenon is a fundamental part of the metacognitively orientated environment I aimed to incorporate in the methodology module.

9.2 Methodology module overview and implementation (AR Cycle 5)

The metacognitive focus of the first four workshops and their associated reflective assignments in the methodology module was on the PSTs' own metacognition in chemistry. The design of the workshops incorporated opportunities for PSTs to

experience and discuss metacognitive strategies developed over the previous AR cycles, as well as to engage in discussions on metacognition within the context of chemistry.

The focus of the metacognitive component of the methodology module shifted in Workshop 5 to the PSTs practicing and planning for the implementation of metacognitive strategies. Details of the implementation of the metacognitive aspects included in the methodology module are discussed in the following section.

9.2.1 Methodology module implementation

The chemistry topics covered in the workshops (see Table 8.1) were the same as those in the first iteration, with a similar aim: to use underlying concepts to enhance both conceptual understanding and PSTs' understanding of metacognition by increasing awareness of cognitive processes in relation to understanding chemical phenomena using underlying concepts. This includes awareness of reducing cognitive overload through chunking of information using underlying concepts (Miller, 1956). The metacognitive aspects incorporated into each workshop of the methodology module are shown in Table 9.1 and are described in this section. The metacognitive aspects of module assessment tasks are discussed in Section 9.4.

Table 9.1 Metacognitive aspects incorporated in the methodology module

Workshop	Metacognitive aspect
1	PSTs cognitive processes in chemistry
2	PSTs' metacognition in chemistry
3	PSTs' metacognitive knowledge in chemistry
4	PSTs' metacognitive regulation in chemistry
5	PSTs' identification of metacognitive teaching and strategies
6	Implementation of metacognitive teaching and strategies
7	Representations of cognitive processes through metacognitive modelling and metacognitive prompts
8	Metacognitive strategies in experimentation.
9	Metacognition, cognitive processes related to linking the macroscopic to the submicroscopic levels
10	Assessment of metacognition in chemistry

As part of designing the module, workshops were planned in detail and divided into episodes (see extract in Appendix I). The summary of each workshop in the action and observation phase of the PST methodology module (AR Cycle 5) are detailed in Appendix N.

9.3 Metacognitive strategies in the methodology module

Metacognitive strategies incorporated into the methodology module are described in detail in Appendix O. These strategies were planned based on my experience in previous AR cycles, and analysed through various sources, including audio transcriptions of the workshops, PST-generated work and responses in tasks, my reflections, etc.

9.4 Methodology module PST assignments

The PSTs completed a series of assignments that addressed various aspects of the module content, including their own metacognition in the context of chemistry and the integration of metacognitive strategies within the context of chemistry teaching and learning.

Workshop reflection tasks, aimed to support the PSTs development related to the aims of the workshop. Two examples of reflection tasks are shown in Table 9.2.

Table 9.2 Examples of workshop reflection tasks in the methodology module

Reflection task Workshop 2 <i>Given the paper by Rickey and Stacy (2000), there are two problems given on the 2nd page. (i) Answer these two problems yourself (note that torr is a unit of pressure; you can change it to Pa if you wish, but it doesn't impact on the nature of the problem) (ii) Note your thinking as you went through the problem. (iii) Read the first three pages of the paper and comment on the strategies used by the undergraduate student vs the graduate student in solving these problems.</i>
Reflection task Workshop 4 <i>(i) Based on the further clarification of metacognition this week, describe metacognition in chemistry. In your description, use your assigned topic this week to articulate your understanding of metacognition. (ii) After reading this week's reading, "Students' ideas about open system chemical events", list student misconceptions identified in the article. (iii) Represent the reaction between butane and oxygen at the sub-microscopic, symbolic and macroscopic levels, in your representations include evidence of key concepts which apply to this reaction.</i>

Based on the findings from the pilot methodology module (see Chapter 8), the 'Chemistry Compendium Assignment' was replaced by a 'Chemistry Concept Assignment'. The 'Chemistry Concept Assignment' was completed by the PSTs in pairs, where they were assigned a chemical phenomenon and they were asked to investigate that chemical phenomenon by describing (i) the activation of their knowledge for the chemical phenomenon, (ii) the relevant and underlying concepts within the topic and how to address awareness of thinking about underlying concepts in chemistry with students, (iii) how they would teach the chemical phenomenon to promote student awareness of their

thinking in chemistry and (iv) at the end of the assignment how their thinking had changed in relation to the chemical phenomenon (see Table 9.3).

The final assignment was modified from the pilot methodology module (AR Cycle 4), where the first part focused on PSTs description of their cognitive processes related to an assigned chemical phenomenon, the second part of the assignment involved PSTs' describing how they would teach that chemical phenomenon to a class of senior cycle students, while the third part involved the PSTs recording an audiovisual of how they would teach the chemical phenomenon to senior cycle students, essentially modelling the implementation Part 2 of the assignment (see Table 9.3).

Table 9.3 Metacognitive aspects of the assignments in the methodology module

Assignment	Details of assignment instructions
Weekly Reflections on Articles from the literature	Guidelines given to pre-service teachers with prompt questions for the reflective writing
Chemistry Concept Assignment	<i>This is an assignment which you will complete in pairs for assigned topics.</i> <i>1. Relevance of topic the activation of their knowledge for the chemical phenomenon.</i> <i>2. Core ideas within this topic the relevant and underlying concepts within the topic and how to address awareness of thinking about underlying concepts in chemistry with students</i> <i>3. Teaching of topic. how you would teach the chemical phenomenon to promote student awareness of their thinking in chemistry</i> <i>4. Your own confidence/knowledge about the concept and how your thinking has changed during your study of the topic in this assignment.</i>
Final assignment	Final assignment (three parts) For all three sections please consider the following prompts to support you in your tasks: strategies which address student awareness of metacognition; strategies which encourage student visualisations and representations; strategies which encourage students to make links to other relevant/ underlying concepts; appropriate experimental work; appropriate student activities. Part 1: Demonstration of your understanding and thinking of your given sub-topic. Part 2: Description of how you would teach your given sub-topic. Part 3: Audiovisual recording demonstrating an element of your teaching on your given sub-topic.

9.5 Conclusion

This chapter outlined aspects of the action and observation phase of the methodology module (AR Cycle 5), including the rationale for changes based on the findings of the pilot methodology module (AR Cycle 4). The data analysis of this iteration of the methodology module is discussed in Chapter 10, while the overall reflections and findings from the PST study (AR Cycles 4 & 5) are also presented in Chapter 10.

Chapter 10 PST experience in the methodology module (AR Cycle 5)

The initial sections of this chapter discuss the PSTs experience of metacognition in chemistry, more specifically their experience in lessons in senior cycle chemistry and in the methodology module (AR Cycle 5). The later sections in the chapter discuss data related to the PSTs' awareness of metacognition in a chemistry context, followed by an analysis of how they plan to incorporate metacognitive strategies into their teaching of chemistry.

10.1 Evaluation of PSTs experience of metacognition in senior cycle chemistry: MOLES-S and related discussion

At the start of the methodology module, as part of a workshop discussion following the PSTs' completion of the MOLES-S survey reflecting on their experiences in senior cycle chemistry lessons (See Figure 10.1), I asked the PSTs to reflect on their senior cycle chemistry experiences using metacognitive prompt questions as part of a workshop discussion. The low MOLES-S scores for the subcategory *metacognitive demands* (2.3/5.0 where the possible range is 1.0-5.0) are supported by the PSTs comments during the workshop discussion: “*learnt chemistry based on memorisation*” (S12), “*was a very traditional classroom, the teacher read off the textbook, the only variation we would get was that the students would be asked to read from the textbook*” (S10), while S9 indicated their senior cycle experience was dominated by “*memorisation of knowledge and methods, repetition*”(S9). S7’s ‘*metacognitive demands*’ score indicated they experienced metacognitive demanding environment *less than sometimes* (see Appendix P). Aligning with this, during the workshop discussion, S7 indicated examples of activities they experienced which would not be considered to be metacognitively demanding while also demonstrating MDK in relation to their cognitive processes (e.g. understanding and learning) in chemistry which was part of my rationale for the discussion;

“a lot of learning off answers, using exam papers as reference but resulted in just learning how to answer certain questions. Not much inquiry in the experiments, just following steps. Difficulty to understand experiments, why we were carrying out certain steps; Organic chemistry reactions/ thermochemistry, I didn't understand why? Struggling with any inquiry questions or new questions I was unfamiliar with” (S7).

However, S7's responses of *Almost always* for the items in the MOLES-S subcategory of *Emotional Support* would indicate the supportive role of the teacher in S7's experience.

Reflecting on their senior cycle chemistry experience, S4 indicated how they learnt chemistry through strategies such as “*memory, note taking, textbook reading, videos, repetition. And where the teacher called out individual students to read*” (S4), while in relation to their difficulties in senior cycle chemistry S4 indicated “*organic chemistry was very long and complicated, a lot of memorisations required. Class could be boring as the main focus was the textbook. I found it difficult to concentrate*”. These comments are in agreement with the scores given by S4 (see Appendix P) where they responded sometimes, seldom or almost never for the items for *Metacognitive Demands, Student Teacher Discourse, Student Voice and Distributed Control*. S4 who indicated the highest PST mean score for *Student-student discourse* explained that in their senior cycle they were “*asked to read the textbook with other students and discussed it ourselves*”.

S1 demonstrated metacognitive awareness in terms of their understanding in chemistry when they characterised their senior cycle experience in the classroom discussion as;

“Learning off information, started doing exam papers in fifth year and learnt off answers. Done calculations all the time but never understood what they meant. Done all the experiments and calculations. Learning stuff off by heart, repetition, as well being asked to do exam papers over and over and over again but never fully comprehending the answers just learn it off and that's it” (S1).

S1 also indicated that they “*never really understood the why of the chemistry we were studying. For example, Bonding-no clue*” (S1.). Scores on MOLES-S for S1 in general between overall *Sometimes* and *Seldom*, while only the subcategory of *Student Voice* gave a response which were *often*. This would suggest that while they felt it was OK for students to ask the teacher why they have to do a certain activity, the majority of their experience in senior cycle chemistry was not particularly metacognitively orientated.

The PSTs expressed an awareness of difficulties they had related to the cognitive process of learning in senior cycle, for example S10 indicated “*The reasoning behind the experiments was never explained, I would only learn the steps of stoichiometry/oxidation reduction etc. I never understood what the calculations meant*”. Reflecting on their senior cycle experience the PSTs indicated an awareness of better approaches to learning (MDK), which aligns with their course of study. They provided examples such as,

“should have aimed to understand topics rather than focusing on memorisation or recall” (S3), and *“tried to understand the topics instead of just learning them off”* (S12). However, the PSTs' descriptions of their experiences in senior cycle chemistry lessons contrast with these approaches.

The reflection workshop episode using the MOLES-S survey and the associated discussion of the PSTs experience in senior cycle chemistry achieved two objectives; firstly, it established the experience that the group of PSTs had in their senior cycle chemistry, and secondly, it provided opportunities for the PSTs to reflect on, describe and analyse their own cognitive processes when in senior cycle chemistry before they become teachers of the subject. The two common themes, (i) memorisation and (ii) lack of focus on understanding chemistry, emerged from the responses. While rote learning, memorisation, lack of understanding are aspects of cognition, my aim in discussing the PSTs experience in their second-level chemistry was to increase their awareness of the cognitive processes they engaged in when in second level chemistry. This reflection was also intended to increase the PSTs' awareness of the type of cognitive processes that their teaching strategies will promote in their own students. As discussed in Chapter 2, while much knowledge can be acquired by the type of rote learning the PSTs described and this is often reflected by efficient recall in examination questions, real understanding demands the bringing together of conceptual understandings in a meaningful way (Sirhan, 2007). Research indicates that a focus on rote learning in chemistry often leads to persistent misconceptions and a lack of understanding of fundamental concepts, which are still not understood even in undergraduate level chemistry (Vladušić, et al., 2016; Goodney, 2006; Johnstone, 2006; Hinton & Nakhleh, 1999; Bodner, 2003).

The PSTs MOLES-S data on their second level chemistry experience, analysed as outlined in Section 5.3.2, is presented in Figure 10.1, showing the mean PST score for the survey and for each of its subcategories. It is important to note that the possible range of mean values for the MOLES-S scores is from 1 (minimum) to 5 (maximum).

The mean MOLES-S scores reported for the overall group of PSTs (Mean = 2.7) suggests that the PSTs in this study perceived that their chemistry lessons in senior cycle were not particularly oriented to the development of metacognition. The survey also indicates that in their senior cycle chemistry lessons the PSTs (i) felt like it was legitimate to *‘sometimes’* question the teacher's pedagogical plans and methods (*Student Voice*, mean

score = 3.1), (ii) were ‘*sometimes*’ encouraged by their teacher to improve how they learn chemistry (*Teacher encouragement and support*, mean score = 3.1), and (iii) they sometimes/often were emotionally supported (*Emotional Support*, mean score = 3.6). The subcategories relating to *Student-student discourse* and *Student-teacher discourse* have relatively low scores and the particularly low scores for the responses to the items (mean scores less than 1.9) (i) *Students discuss with each other about how they think when they learn chemistry*, (ii) *Students discuss with each other about different ways of learning chemistry*, and (iii) *Students discuss with the teacher about how they think when they learn chemistry*. These results suggest that the PSTs perception is that discussions on cognitive processes did not occur often in their own experience in senior cycle chemistry.

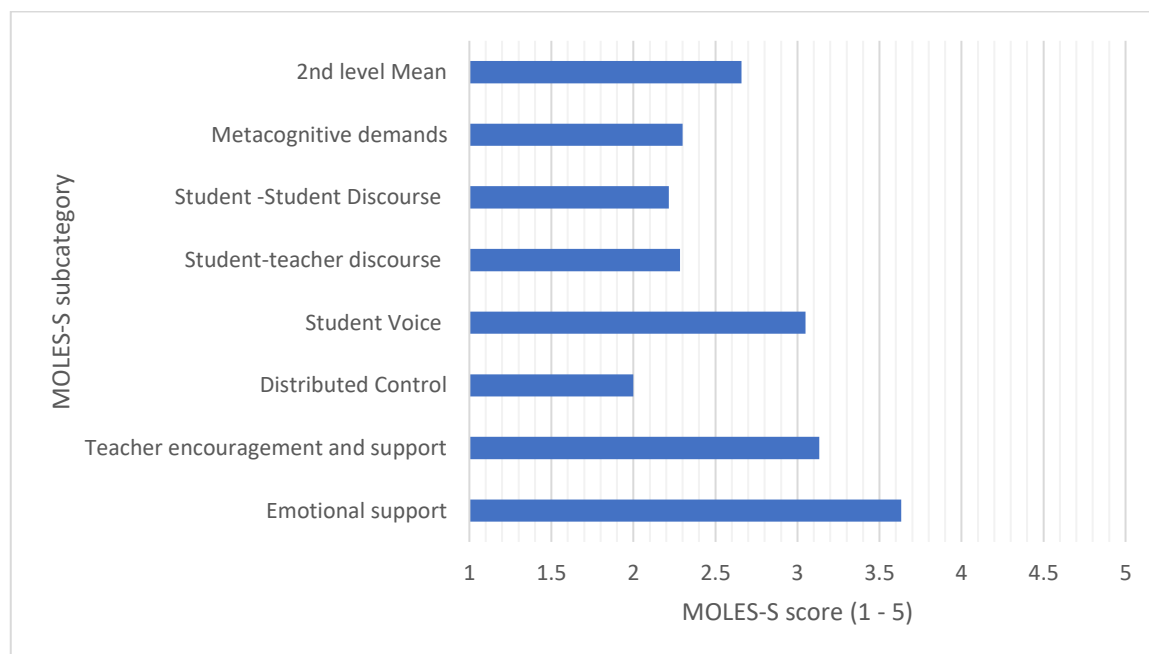


Figure 10.1 MOLES-S scores for PST experience in senior cycle chemistry

The PSTs low scores for MOLES-S subcategory of *metacognitive demands* agrees with literature, where while the value of a metacognitive approach for the teaching of chemistry is recognised, the inclusion of teaching and learning strategies which address developing metacognition in chemistry and other subjects are rare (Georghiades, 2004; Thomas, 2012; Zohar & Barzilai 2013; Lavi, et al., 2019; Kallio et al., 2021). Within this subcategory, the mean scores for the individual items are shown in Figure 10.2. The item with the lowest score was *Students are asked by the teacher to try new ways of learning chemistry*. Failing to address this item misses possible opportunities for student development of metacognitive awareness in terms of MDK and MPK but also

metacognitive regulation MM and ME. The item ‘*Students are asked by the teacher to explain how they solve chemistry problems*’ had a higher mean value when compared with the other items in the subcategory, which provides evidence that their experience involved having to think about how they arrived at solutions during their use of problem-solving techniques, however on average it is still was experienced less than ‘*sometimes*’ (Figure 10.2).

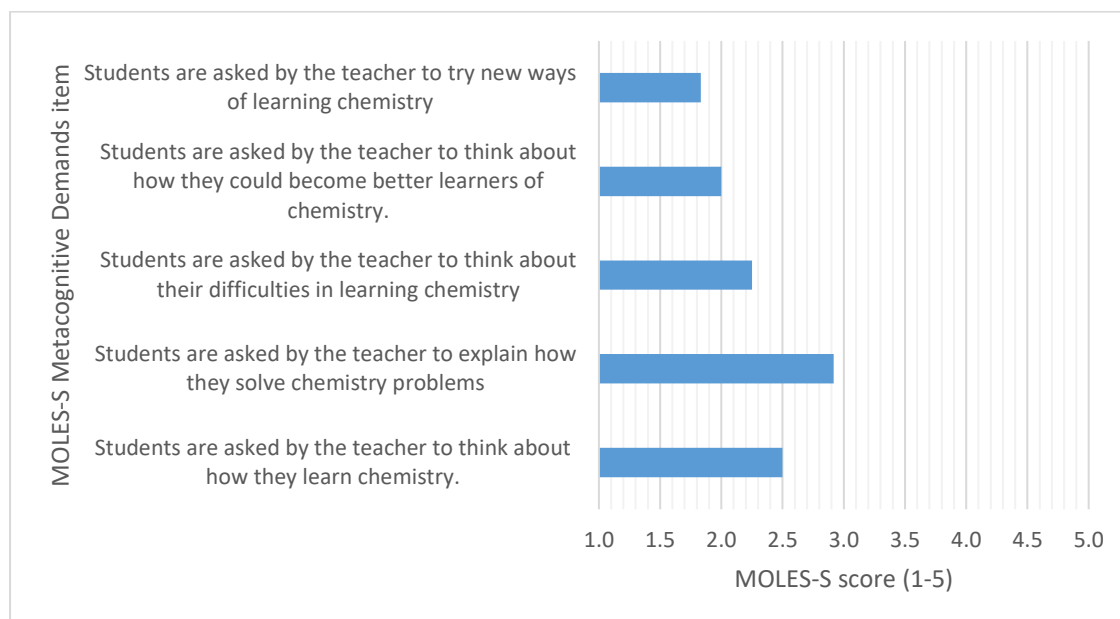


Figure 10.2 MOLES-S scores subcategory *Metacognitive demands* - PST experience in senior cycle chemistry

The PSTs' perception of their senior cycle chemistry experience aligns with those of PSTs in the pilot methodology module (AR Cycle 4) and with literature indicating that, despite evidence highlighting the importance of metacognition for high-quality learning in science classrooms, their chemistry lessons were often characterized by a lack of focus on enhancing students' metacognition (e.g., Schraw, 1998; Thomas & McRobbie, 2001; Thomas & Mee, 2005; Zohar & Barzilai 2013;). Instead, these lessons tended to overemphasise memorisation. Hence as the experience of the PSTs in senior cycle chemistry was not particularly metacognitively orientated (based on their perception), it is appropriate that the PSTs experience and demonstrate metacognitive strategies in workshops as part of a methodology module. Particularly in light of the importance of metacognition in chemistry as discussed in Chapter 2, and its place in the context in current Irish second level education reform as discussed in Chapter 1.

It is important to note that the data above is based on the perception of their experience of their senior cycle chemistry and may be influenced by a number of factors, such as the time since their senior cycle experience, an unawareness of their teachers' learning objectives, how happy they were with their final results in senior cycle chemistry etc.

10.2 PSTs experience of metacognition in the methodology module

As discussed in Chapter 2, an important aspect for incorporating metacognition is the teachers 'adaptive metacognition' which involves both the adaptation of self and the environment in response to classroom variability and metacognition in the context of their subject (Duffy et al., 2009; Lin, et al., 2005; Manasia, 2015; Kallio et al., 2021).

10.2.1 The PSTs understanding of metacognition

The PSTs awareness of metacognition as adapted in the context of chemistry teaching and learning was part of the rationale for the design of the methodology module. For example, the PSTs were asked to verbalise their understanding of metacognition in chemistry throughout the module. In Workshop 3 of the module, the PSTs were asked to describe what metacognition in chemistry meant following its introduction in the initial workshops. This was to increase awareness of the PSTs own understanding of metacognition in chemistry by asking the PSTs to "think aloud" in relation to what they understand metacognition to be. Examples of their responses are given below.

"Assessing your thinking and your thought process. You take a step back in your own knowledge, and how can I use my knowledge to solve a problem? For example, if I don't know how, and then I use some of my knowledge to start the question, and then maybe start it off with thinking, 'Oh, yeah, I actually do,' and know how to answer it" (S1, Workshop 3)

"It is about thinking about how exactly you understand a certain topic in chemistry and almost having debates with yourself about what you think you really know. It is about asking yourself; do I really believe that this is what happens in intermolecular bonding?" (S5, Workshop 3)

"Just think deeper about your own thinking related to underlying chemistry concepts. If something doesn't make sense, that you think about what's really going on, at the subatomic level, and then from that, use your understanding there to grasp what you got stuck with" (S12, Workshop 3)

These examples provide some evidence of the PSTs understanding of metacognition following their participation in the initial workshops, rather than a purely theoretical or definition-based description of metacognition. For example S1 provides an example of

MDK (*You take a step back in your own knowledge, and how can I use my knowledge to solve a problem*), MP (*if I don't know how and I use some of my knowledge to start the question, and then maybe start it off with thinking, 'Oh, yeah, I actually do,' and know how to answer it*) and ME (*Assessing your thinking and your thought process*) through their examination of their own thinking. S5 provides evidence of MDK (*It is about thinking about how exactly you understand a certain topic in chemistry*), MM (*having debates with yourself about what you think you really know It is about asking yourself; do I really believe that this is what happens in intermolecular bonding?*). The example from S12 shows their awareness of their cognitive processes in chemistry and looking beyond individual chemical phenomena to underlying concepts and the subatomic level in an example of MDK in displaying an understanding of one's cognitive resources.

These examples provide evidence for the approach taken in this module where the focus was on the domain specific interpretation of metacognition through experiencing and discussing metacognition in a chemistry context, rather than the theoretical approach taken in the pilot methodology module. This approach addresses PSTs' personal ability to understand metacognition in the context of chemistry (Zohar & Barzilai, 2013).

In the end-of-module assignment (see Table 9.3), S2 reflected on how their initial encounter with the term 'metacognition' was during the methodology module. As their understanding of the concept deepened, they became increasingly aware of how they had already been metacognitive in other areas of their life:

"through having developed my understanding of metacognition over the course of this module, I now realise had been using it in other areas of my life such as maths and even in my own personal life during sport when I assess my thinking and how I can improve my thinking in the future, what about my preparation was good or bad and what I should do before the next game" (S2)

S2 displayed MDK and MP when they described difficulties with their understanding of metacognition in the first weeks of the module, but that they found *"it helpful to think of metacognition in stages, before, during and after learning"*. S2 highlights how the descriptions of metacognition which use the terms *"plan, monitor and evaluate were not enough to fully appreciate what metacognition is"* (S2, Assignment P1). S2 indicated how metacognition prompts in assessments allowed them to *"better understand what [metacognition] means"* by challenging them to analyse their cognitive processes. S2

goes on to argue that “*By seeing [metacognition] used in assignment questions and labs [workshops] it was much more beneficial to its use than just definitions*”. The comments by S2 are in agreement with literature which describes metacognition as being difficult to comprehensively define (e.g., Veenman, et al, 2006; Rhodes, 2019), but the experiential approach to incorporating in the methodology appears to have scaffolded S4’s understanding of metacognition.

S10 describes metacognition at the end of the module in a way which addresses the awareness of cognitive processes (e.g. thinking, understanding) and the monitoring and control aspects of metacognitive regulation:

“Metacognition includes being aware of your own thoughts, having certain perceptions of yourself, understanding the reason for your thinking as well as the adaptability and willingness to modify your thoughts to new conditions” (S10).

S4 supports the inclusion of metacognition as part of teaching senior cycle chemistry and demonstrates an understanding of metacognition in terms of the ME, MM and MDK related to the cognitive process of visualising in chemistry:

“It [metacognition] encourages having a dialogue, questioning one’s thoughts, trialling different methods, getting incorrect answers, recognising this, collecting and regulating thoughts and building conceptual images. Metacognition allows for a broader understanding of the underlying chemistry” (S4, end of module assignment).

The PSTs also described metacognition in terms of how it benefits the cognitive process of learning for students in chemistry. For example, S8 indicates they believe that metacognition will help a student be aware of how and when “*to visualise problems, conceptualise topics and use problem solving*” and how it can “*support learning and thinking in chemistry as it can increase motivation within a student due to them being more in control and aware of their own learning*”. This aspect of motivation is linked to one’s control and awareness of one’s learning and is reflective of MM (Driver, et al., 1994; Thomas, 2002). Similar to other PSTs, S8 describes reconstruction of thinking as being an important aspect of metacognition “*Reconstruction is important in terms of metacognition as the students must adapt their knowledge to answer the problem. This is where the students really implement their awareness of their own thinking.*” S1 describes how MDK and MP are beneficial to students.

“When students are aware of their learning it allows them to take a step back from anything new they may encounter, and think about how they are going to approach it and how they will learn this new concept” (S1)

In line with the interpretation of MCK by Schraw et al., (2006), S4 argues that metacognitive awareness aids students by connecting formulas through underlying concepts.

“Underlying concepts allows students to create a conceptual image of a chemistry formula and allows students to make cognitive connections within the chemistry course for a more well-rounded understanding of the subject, as students can organise what they already know in their thinking and relate it to the new content” (S4, end of module assignment).

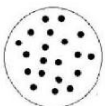
This extract addresses aspects of their awareness of reducing cognitive overload through chunking of information using underlying concepts (Miller, 1956). The examples above illustrate the value PSTs place on student metacognition in chemistry by the end of the module. It is reasonable to argue that the approach of incorporating metacognition through the PSTs' direct experience of metacognitive strategies and associated discussions, rather than a purely theoretical approach, led to a more domain-specific understanding of metacognition. This approach aimed to avoid a reliance on the memorisation of definitions and fostered deeper, practical engagement with metacognition in a chemistry context. Evidence for this includes the PSTs unique descriptions and interpretations of metacognition as discussed in this section. This approach addresses an issue highlighted by Seraphin et al. (2012) regarding in-service teachers' lack of understanding of metacognition.

10.2.2 PSTs awareness of cognitive processes related to representations in chemistry

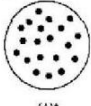
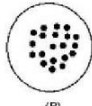
As part of incorporating metacognition into the module, PSTs were challenged to examine the cognitive processes elicited by problem solving tasks to enhance their awareness of these processes. This included the use of representations in chemistry, which was informed by findings from previous AR cycles. I designed tasks that encouraged PSTs to develop their awareness of the different cognitive processes elicited by various tasks before I discussed my own thinking. I intentionally adopted this scaffolding approach to metacognition, which was informed by the findings from previous AR cycles. For example, the PSTs completed a workshop reflection task (see

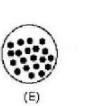
Table 9.2) where they reflected on what cognitive processes they thought were required in problems which incorporate representations (Problems I and IV in the assignment) and compared these with calculation/word-based problems (Problems II and III). To provide context, the problems are shown in Figure 10.3.

Problem I.
The following diagram represents a cross-sectional area of a rigid sealed steel tank filled with hydrogen gas at 20 °C and 3 atm pressure. The dots represent the distribution of all the hydrogen molecules in the tank.



Which of the following diagrams illustrate the most probable distribution of molecules of hydrogen gas in the sealed steel tank if the temperature is lowered to -5 °C? The boiling point of hydrogen is -252.8 °C.

(A)* (B) (C) (D) (E)
Correct answer: (A)

Problem II.
Calculate the maximum weight of SO₃ that could be produced from 1.9 moles of oxygen and excess sulfur.
 $2S + 3O_2 \rightarrow 2SO_3$

Problem IV.
The equation for a reaction is $2S + 3O_2 \rightarrow 2SO_3$. Consider the mixture of S (□) and O₂ (oo) in a closed container as illustrated below:



Which of the following represents the product mixture?







(A) (B) (C) (D) (E)
Correct answer: (E)

Problem III.
0.100 mole of hydrogen gas occupies 600 mL at 25 °C and 4.08 atm. If the volume is held constant, what will be the pressure of the sample of gas at -5 °C?
(a) 4.54 atm (b) 3.67 atm (c) 6.00 atm (d) 2.98 atm
(e) 4.08 atm

Correct answer: (b)

Figure 10.3 An extract used in a workshop reflection task from the article ‘*Concept learning versus problem solving: There is a difference*’ (Nakhleh, M.B. & Mitchell, 1993).

The PSTs demonstrated an awareness of their perception of the different cognitive processes required by the two types of problems. S4 describes how they believe Problem I is “*visualisation based, as students are provided with an image and are required to imagine the motion of the particles of hydrogen gas. It is the more conceptual of the two – bringing both the behaviour of particles and the factors which affect this behaviour into the minds of students*”. This extract presents S4’s MDK in relation to how they would interpret the cognitive processes of students including the visualisation of chemistry at the submicroscopic level. Interestingly S4 specifically indicates they think the two problems (I and IV) which use representations as “*more conceptual*”. While S4 points out for the calculation-based Problem (III) they believe that it “*focuses on the algorithmic approach to problem solving. It requires the use of the ideal gas equation: $PV = nRT$. This is more of a routine for students than a thinking exercise*” and they describe problem (II) as “*more of an exercise than a problem for students. They are presented with a*

balanced chemical equation and the aim is to use stoichiometric equations to deduce the mass of the sulphur trioxide produced". This interpretation, that calculation-based problems are perceived as more memory-driven and procedural, requiring less understanding, suggests that S4's sees a hierarchy of cognitive processes involved in problem-solving. They appear to perceive problems that demand genuine understanding as requiring the integration of conceptual understanding in a meaningful way, rather than merely following a series of memorised steps typical of rote learning. This viewpoint aligns with the findings of Sirhan (2007).

S10 describes Problem I *"as a question that tests conceptual understanding of the topic"*, while they describe Question III as *"a question that tests the students' ability to use algorithmic means to find the answer"*. S10 goes on to describe MDK in relation to the cognitive processes which are promoted by Problem I;

"Problem I asks the students to visualise the gas in the tank and give them information that they could use to predict the behaviour of the gas. To find the answer, it is not necessary for the students to use any equations or algorithmic means, only their knowledge and understanding of the topic. This can show a lot about a student's confidence in the topic, if they can solve the problem, it shows that they understand the behaviour of gas" (S10)

S10 appears to argue that problems which require only *"algorithmic means"* require less understanding than those which are based on representations at the submicroscopic level.

Providing further evidence of their view, when describing Problem IV, they indicate;

"Problem IV requires the student to use the ideal gas law. In this way, they need to convert the figures given into the appropriate units and then sub them into an equation to find the unknown pressure. This can be efficient at assessing the student's ability to recognise the correct figures to plug into the right equation but does not confirm that they understand the theory behind the equation".

It is interesting that S10 describes the problem as not confirming student understanding, while it provides evidence of their MPK.

In a further example of the PSTs perceptions of the cognitive processes required by representations, S12 argues Problem I *"relies on visualisation and thinking about the problem whereas the third problem requires the student to complete a calculation type question"*. They go on to describe MM required in Problem I;

“good for assessment when it comes to a visual analysis of the topic. It requires a deeper sense of thought as one would have to ask themselves, what are the molecules doing? One would have to think about the submicroscopic level in order to answer this question.” (S12)

This is in contrast to how they described Problem III, *“It is less conceptual and more algebraic. It doesn’t assess one’s understanding of the gas laws but rather their ability to memorise and manipulate a formula”*.

The examples above demonstrate the PSTs' awareness of the value of representations in engaging and requiring the cognitive processes of understanding or visualisation in chemistry. This is an interesting insight by the PSTs, particularly when considered alongside literature suggesting that chemistry has traditionally often been taught as a mathematically oriented course, often over emphasising the algorithmic problem-solving approach (Williamson, 2015). The data from the PSTs also suggests they perceive word or calculation-based questions as requiring less understanding or visualisation and instead rely on the cognitive process of memorisation. This aligns with previous research suggesting that chemistry students are often proficient in calculations and procedural tasks but may struggle with understanding at the abstract or submicroscopic level (e.g., Harrison & Treagust, 2002).

It can be argued that discussing and challenging the PSTs to reflect on the type of cognitive processes that may be induced by representation-based problems and calculation-based problems both increases their awareness of their own cognitive processes in chemistry and how these types of problems may be used to promote different cognitive processes in their future students. This has implications for the type of questions used in the tests by both teachers and examination bodies such as the NCCA. My own identification of this in the senior cycle study resulted in the creation of tests which incorporate the generation and analysis of representations as discussed in Chapter 7, Section 7.7.

10.2.3 PSTs metacognitive use of the generation of representations

Hartman (2001) argued that the method to maximise instructional effectiveness was ‘teaching with metacognition’ while Zohar and Barzilai, (2013) argue teachers need the personal ability to practise metacognitive thinking with respect to classroom activities. Addressing these arguments, the domain specific use of representations and associated

discussions/prompts was identified in findings across AR cycles 1-4 and was incorporated in the design of methodology module (AR cycle 5). Also, drawing from the findings of previous AR cycles, I did not generate representations of my cognitive processes when discussing chemical phenomena initially (see Chapter 7, Section 7.3). For example, at the start of the methodology module as part of a strategy which would span three workshops to address the use of representations to increase awareness and regulation of cognitive processes in chemistry, the PSTs were asked to draw how they visualise H_2O as a gas, a liquid, and a solid in any representation they wished, showing any intramolecular and intermolecular bonding (Task W1). The representation generated by S1 for Task W1 is shown in Figure 10.4.

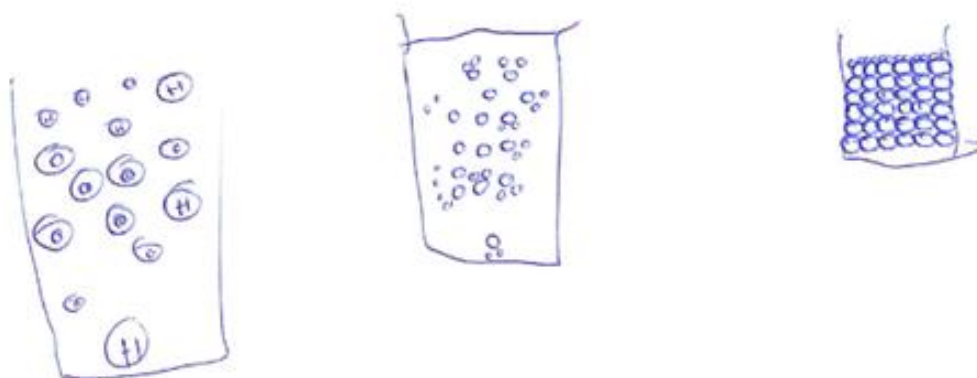


Figure 10.4 Response by S1 to Task W1 in the first workshop. *Draw how you visualise H_2O as a gas, a liquid, and a solid in any representation you wish, showing any intramolecular and intermolecular bonding?*

S1's representation appears to show a structured array of particles as a solid, a liquid with a surface layer consisting of two different particles 'suspended', and then a gas showing two different particles, labelled as H and O. While these representations display possible misconceptions, they provide opportunities for S1 to voice, evolve and consolidate their cognitive processes through discussion and prompts as part of the workshops; for example, the representations give rise to questions related to their conceptual understanding in relation to this phenomenon at the submicroscopic level. Representations generated by S4 for the Task W1 are shown in Figure 10.5. In this case, the particles are all of similar size, are shown close together in the solid, some small distance apart in the liquid and far apart from each other in the gas. Each of the particles appear to comprise three atoms, two of which are shaded in and one of which is not. The

relative positions of the shaded and unshaded circles are important opportunities for discussion, in terms of the cognitive processes presented in the representations.

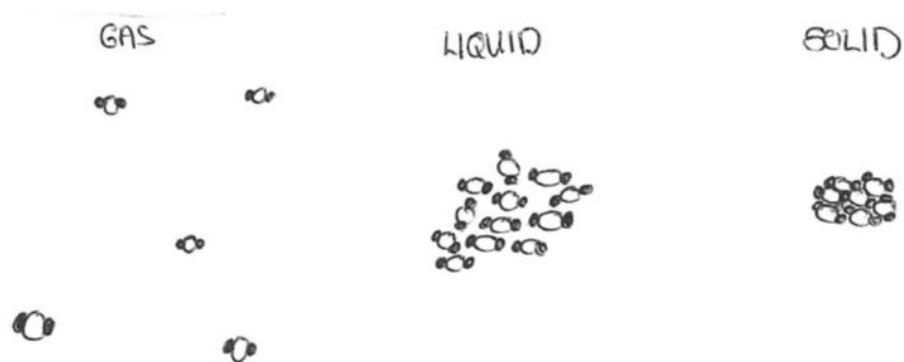


Figure 10.5 Response by S4 to Task W1 in the first workshop. *Draw how you visualise H_2O as a gas, a liquid, and a solid in any representation you wish, showing any intramolecular and intermolecular bonding?*

The representation generated for Task W1 by S7 is shown in Figure 10.6. In this case the representations are very similar to those of S4 above, however, all the particles shown are oriented in the same way, particularly so for the liquid representation. The depiction of particles in the liquid state as having significant distance between them may indicate a lack of understanding, which is an aspect of cognition. However, awareness of this lack of understanding behind the misconception, provides opportunities to address metacognition through evolution of their cognitive processes as part of associated discussions and descriptions.

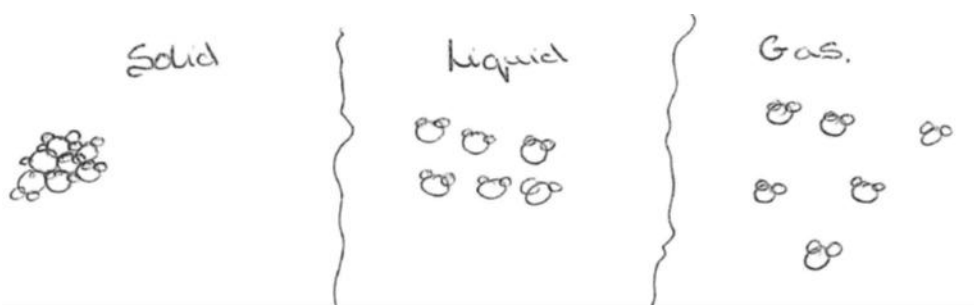


Figure 10.6 Response by S7 to Task W1 in the first workshop. *Draw how you visualise H_2O as a gas, a liquid, and a solid in any representation you wish, showing any intramolecular and intermolecular bonding?*

In none of the above examples have the representations shown the interactions between the particles as the question prompted - the inter and intramolecular bonding. Aspects of the representations are inaccurate and it is also possible that the PSTs may not have understood the role of submicroscopic representations in the module task or as a learning

strategy, this was highlighted in a study by Treagust et al. (2003) where they argue students do not always understand the role of the representation that is assumed by the teacher. Analysing this metacognitively as a teacher educator, it's possible that the PSTs made assumptions about the interpretation of their drawings and omitted details they believed to be obvious.

As part of a workshop discussion following the completion of Task W1, I asked the PSTs what cognitive processes they used to generate their representations with the aim of increasing awareness of their cognitive processes. Some of the PSTs indicated their representations were based on memorisation of images rather than generated based on other cognitive processes such as visualisations and understanding of the chemistry. For example, S1 responded "*Memory. From A mixture of, memorising from books and learning it off in lectures.*" Hence, there is a need to address with PSTs what Madden et al. (2011) describes as explicitly attending to how understanding can be developed through the use of representations.

To promote metacognitive awareness and highlight the value of generating representations of one's cognitive processes in chemistry, the second workshop involved PSTs discussing the cognitive processes behind the representations generated by their peers for Task W1. The representations were shared using a data projector and PSTs were asked for their feedback. The purpose of this activity was to provide the PSTs with an opportunity to enhance their awareness of the cognitive processes evidenced in their representations and to explore how using representations can activate and increase awareness of cognitive processes (e.g., visualisation, understanding) in chemistry. For example, the PSTs were shown S1's representation (Figure 10.4), their feedback included "*you don't want separate atoms on the left of the picture, they should be part of a molecule of water*" (S3) and there should be intermolecular "*bonds between molecules*" (S2). I discussed the importance of clarity within their representations in relation to their cognitive processes in chemistry.

Aligned with findings of previous AR Cycles, I aimed to use the refinement of representations to incorporate metacognition in the methodology module, through increasing awareness of the evolution and consolidation of cognitive processes in chemistry. For example, the PSTs were asked in the third workshop to again generate

representations of how they visualise H_2O as a gas, a liquid, and a solid in any way they wish, showing any intramolecular and intermolecular bonding (Task W3). The representation by S1 from workshop three is shown in Figure 10.7.

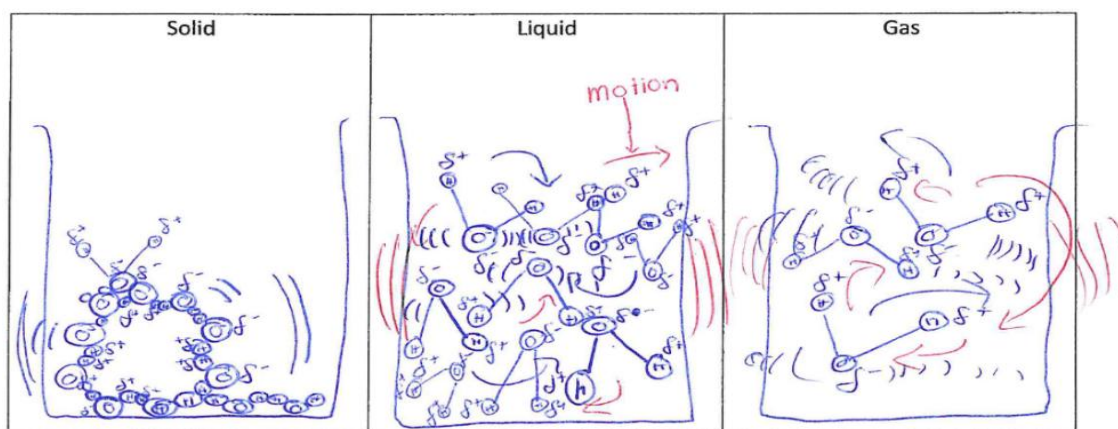


Figure 10.7 Response by S1 to Task W3 in the third workshop. *Draw how you visualise H_2O as a gas, a liquid, and a solid in any representation you wish, showing any intramolecular and intermolecular bonding?*

Evidence for the power of representations as part of incorporating metacognition in chemistry is found in the PSTs descriptions on how their cognitive processes had evolved between Task W1 and Task W3. For example, S1 described how their representations and cognitive processes evolved;

“In the first week my representations were very simple and basic but now they are much more detailed, and they show a bigger picture of what I think is going on. I now understand what intermolecular and intramolecular bonds mean. I now think about why atoms within molecules attract electrons. I can explain bonding to someone else. I now understand the underlying concepts more and see how they link in the bonds” (S1).

The above response by S1 describes ME related to the evolution and consolidation of their cognitive processes, MDK in terms of what they now think they understand related to intermolecular bonds and electron density in a molecule. S1 also demonstrates MCK in relation to when they would draw on underlying concepts, while they could have been explicit in relation to the underlying concepts they mean.

S4’s representation generated for Task W3 is shown in Figure 10.8. Additional words in the representation describe the movement of the particles in each phase, indicating a limitation of a representation to capture how one visualises movement. S4’s representation for Task W3 has more detail than S4’s representation in Task W1, for

example each state has labelled H and O atoms, indications of vibrations in the solid phase and movement of the particles in the liquid and gaseous phases; however, further points arise e.g., the varying H-O bond length, the vibrations and movement of the particles are unclear, and what does the curved arrow mean?

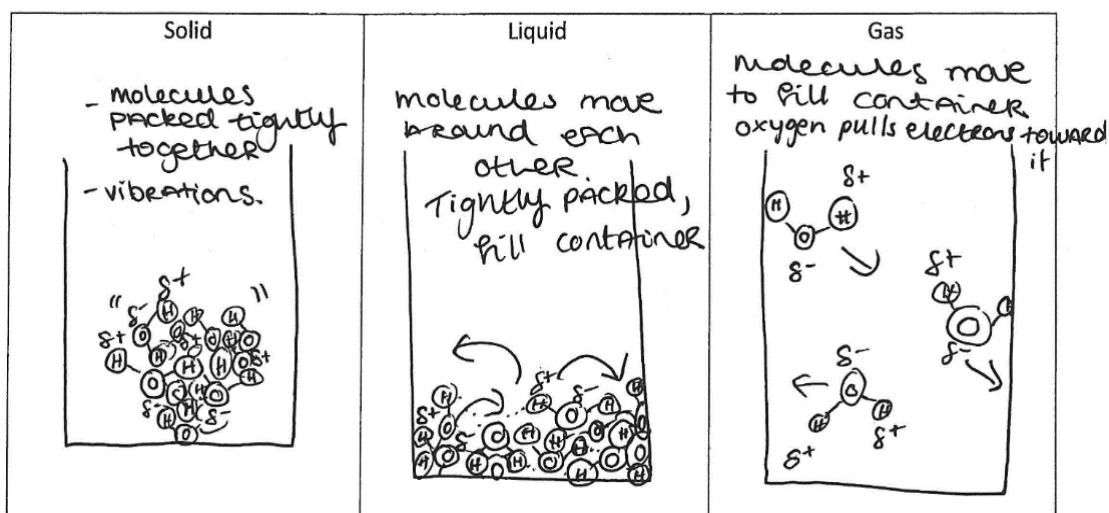


Figure 10.8 Response by S4 to Task W3 in the third workshop. *Draw how you visualise H_2O as a gas, a liquid, and a solid in any representation you wish, showing any intramolecular and intermolecular bonding?*

When asked to explain how their cognitive processes had changed, S4's response was:

"I know now to show relative charge on the atoms in the molecules and the motion of the water molecules using arrows. Oxygen has more electronegativity, so it has more of a pulling effect on electrons than hydrogen does. This gain in electrons makes oxygen partially negative and the hydrogens are partially positive, hence there is an attraction, opposite attraction, the hydrogen bonds are very strong. I now think of the shape of the water molecules in a solid as arranging in a hexagonal in shape, visualisation of this changes my view on how atoms arrange themselves in chemical bonding" (S4).

S4's response indicates MDK in terms of awareness of underlying concepts and behaviour of submicroscopic particles. S4 demonstrates MCK in terms of why and when to use electronegativity as a concept to make sense of a chemical phenomenon, while also indicating MPK in relation to how they use their understanding of electronegativity and for what purpose. In addition, S4's response indicates their ME in terms of the evolution of their cognitive processes, including awareness of their thinking at a point in time and how their thinking has changed.

The representations generated by S7 for Task W3 are shown in Figure 10.9. It is interesting to note in these representations that there is no structure associated with the

solid state, and that it seems to indicate that the whole solid is vibrating as one block. The arrows shown in the gas phase are confusing as one seems to link between the two 'O' shown. The polarity of the H-O bond is shown for solids and liquids but not for the representation of the solid.

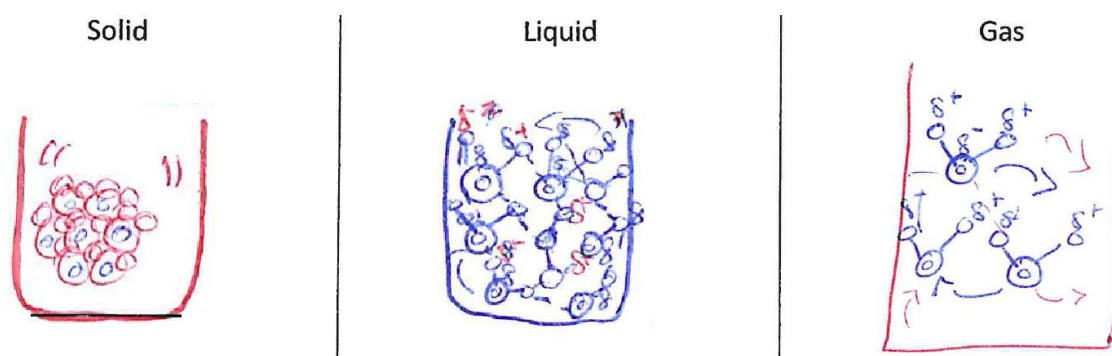


Figure 10.9 Response by S7 to Task W3 in the third workshop. *Draw how you visualise H_2O as a gas, a liquid, and a solid in any representation you wish, showing any intramolecular and intermolecular bonding?*

A value of providing PSTs the opportunity to voice their cognitive processes through reflections lies in creating opportunities to explore and demonstrate their own metacognition. For example, in a similar way to that of S1 and S4, S7 demonstration of metacognition in relation to and awareness of the evolution and consolidation of their cognitive processes between generating a representation for Task W1 and Task W3, stating that:

“Instead of visualising H_2O as a V-shaped molecule, I now know to consider the charge and the movement of electrons. Before this module my conceptual image in my head did not involve charge or bonds in the molecules particularly for liquids and gases. I now think about how the charge on the hydrogen and oxygen in water helps explain the intermolecular bonding in water and how the movement of the molecules explains intramolecular bonds. I have a better conceptual image of how charges contribute towards intermolecular bonding. I am better able to visualise the bonds between partial positive and partial negative charges. I also can visualise how the molecules in my structures move and come together or are fixed for a solid, liquid and gas.” (S7)

The above quote demonstrates S7’s metacognition in terms of evaluating how they visualised water molecules, they indicate how their cognitive processes have changed which indicates MDK, e.g. *“I know to consider charge and the movement of electrons”*. They describe MDK in relation to visualising chemistry at the submicroscopic level e.g. *“I have a better conceptual image of how charges contribute towards intermolecular*

bonding. I am better able to visualise the bonds between partial positive and partial negative charges. I also can visualise how the molecules in my structures move and come together or are fixed for a solid, liquid and gas.”. S7’s demonstration of how their cognitive processes evolved including their awareness of how they have a better understanding and ability to visualise the chemistry demonstrates their ME. Their description of how they would use electrostatic charge also reflects their MP.

The above examples include the PSTs conscious, reflective awareness of cognitive processes (Thomas, 2012; Zohar & Ben-David, 2009) related to their generation and refinement of representations of a chemical phenomenon, demonstrating how it can be used as a metacognitive strategy in the design of a PST methodology module. While the PSTs’ cognitive processes in their representations is cognition, the metacognitive aspects include being aware of our own cognitive processes and the cognitive processes of others’ when generating and interpreting representations in chemistry

The generation of PST’s representations provide opportunities to become more aware of the voice of their cognitive processes in chemistry through prompting PSTs to discuss and support their representations with descriptions of their cognitive processes. The PSTs associated descriptions of their cognitive processes related to their representations in Task W1 and Task W3 also promoted opportunities for increasing an awareness of the evolution and consolidation of their cognitive processes. Consistent with the findings of previous AR Cycles, the above examples further support the use of generating representations, along with associated descriptions and discussions, as a domain-specific approach for incorporating metacognition in chemistry.

10.2.5 Metacognitive orientation of the environment – MOLES-S

The findings of previous AR cycles emphasise the importance of the environment, particularly a supportive and encouraging one, as a key factor in providing affordances for metacognition in Senior Cycle lessons and PST workshops. In the methodology module, I aimed to model the conditions of this metacognitive environment in the workshops. To triangulate my own reflections with the PSTs’ perceptions of the environment, the PSTs completed the MOLES-S survey at the end of the module to assess their views on the environment in the workshops. The mean scores for MOLES-S and its subcategories are shown in Figure 10.10.

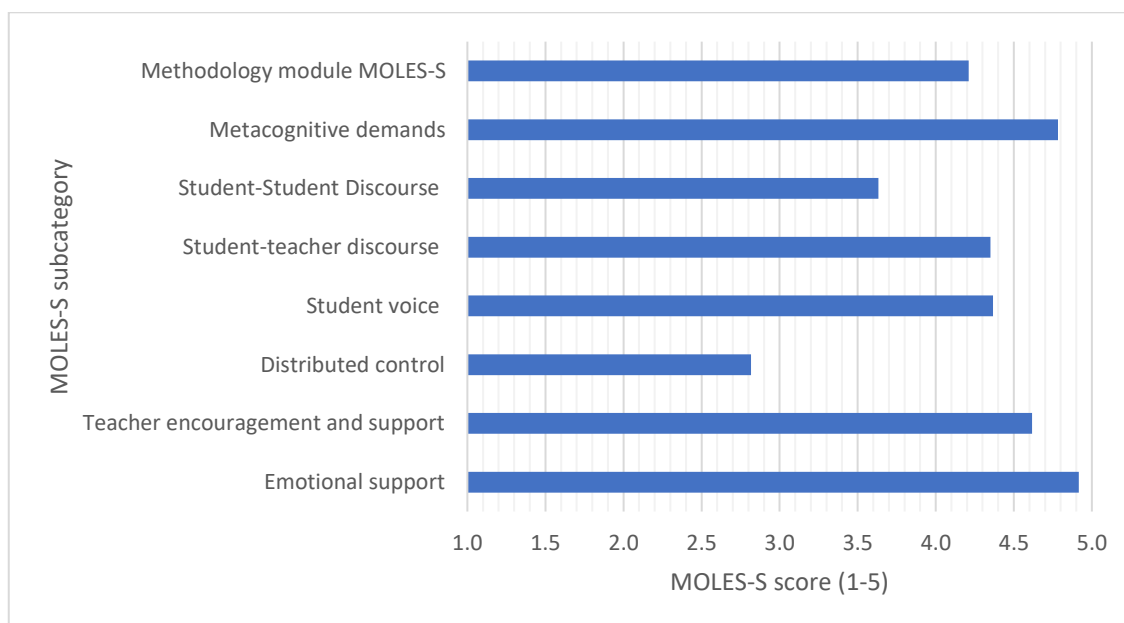


Figure 10.10 MOLES-S scores for PST experience in the methodology module

The overall mean score for MOLES-S related to the PSTs experience in the methodology module was 4.2/5.0, indicating that the PSTs perceived that the environment in the methodology module was ‘often’ or ‘almost always’ metacognitively orientated. Of particular note is the score for the MOLES-S subcategory of ‘metacognitive demands’, with high mean scores (greater than 4.7/5) recorded for each item in this subcategory as shown in Figure 10.11. The discourse promoted in the module workshops focused on the PSTs becoming more aware of their cognitive processes, including discussing their cognitive processes in relation to workshop assignments or tasks. PSTs recognition of this as part of the module is evident for the item *Students are asked by the teacher to explain how they solve chemistry problems* to which every participant's response was *Almost Always* (Figure 10.11).

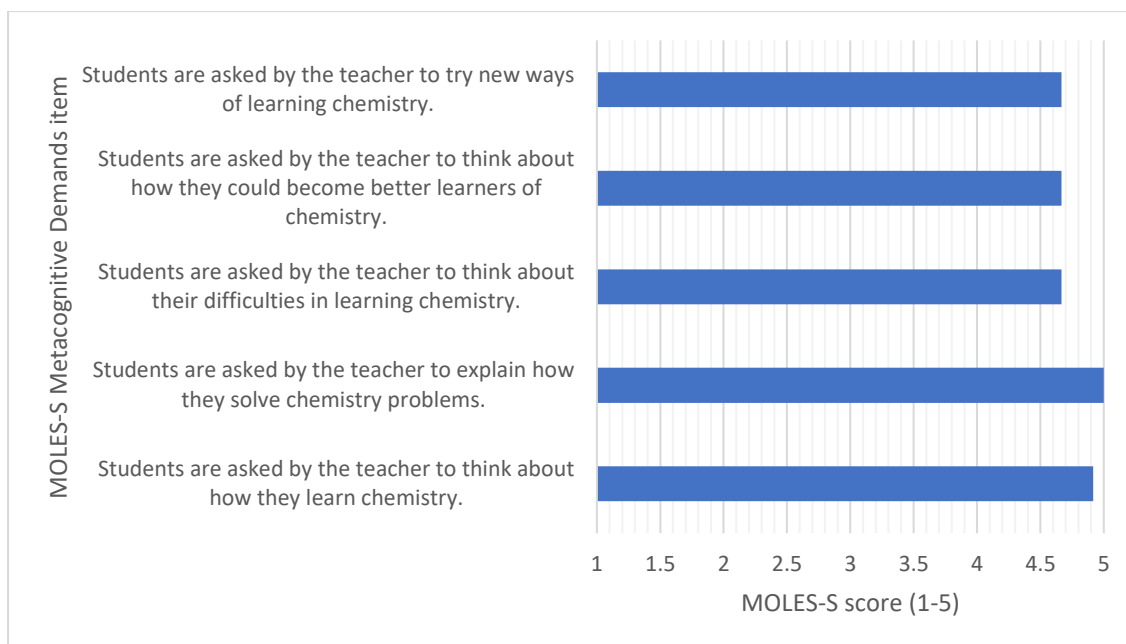


Figure 10.11 MOLES-S scores subcategory *Metacognitive demands* - PST experience in the methodology module

MOLES-S subcategories of ‘*Student- teacher discourse*’ and ‘*Student Voice*’ were scored by the PSTs in the MOLES-S as occurring at least ‘often’ during the module (Figure 10.10). The metacognitive strategies used in the workshops focused on discussing the PSTs cognitive processes related to chemical phenomena. This is reflected in the particularly high score for the item “*Students discuss with the teacher about how they think when they learn chemistry (mean score 4.8/5)*”, in the subcategory of *student-teacher discourse*. The frequent use of whole group discussions which I facilitated in the workshops could explain the lower mean score for the MOLES-S subcategory of ‘*Student-Student discourse*’ when compared with the ‘*Teacher student discourse*’ subcategory. Throughout the module, I repeatedly highlighted the importance of individuals having the freedom to indicate their cognitive processes at that point in time including when they do not understand the chemistry or are having difficulties as part of modelling a metacognitively orientated classroom. For example, in the second workshop, I stated “*This is confession for chemistry; please don’t feel like you have to hide any difficulties with the chemistry here; ask any questions; don’t think of it as too basic*”. Evidence for the PSTs perception of this is in the particularly high score for the item ‘*It is OK for students to tell the teacher when they don’t understand chemistry*’ (Mean score 4.8/5.0) (see Appendix P, *Student voice*).

Aligning with the findings of previous AR cycles, evidence for the supportive approach taken in the module is in the high scores for the subcategories of *Emotional support* and *Teacher encouragement and support* (Figure 10.10), and the narrow range of responses for the items within these subcategories, many of which were *Almost always* (see Appendix P). I emphasised to the PSTs the need for them to be aware of their cognitive processes while carrying out tasks or in response to prompt questions. Evidence for the PSTs perception of this is included in the particularly high scores for the items *The teacher encourages students to try different ways to learn chemistry* (mean score 4.7/5), and *the teacher encourages students to try to improve how they learn chemistry* (mean score 4.7/5) in the subcategory of *Teacher encouragement and support* (see Appendix P). The lowest subcategory score on the MOLES-S survey was for ‘*Distributed Control*’ (Figure 10.10), and this is understandable as I planned the module workshops in detail and divided them into episodes, and while flexibility in terms of timing of episodes was displayed, I still made the final decisions in relation to timing. The PSTs were aware of this element of the workshops as evident in the relatively low score for the subcategory of *distributed control*, and in particular the item *Students help decide when it is time to begin a new topic* (mean score 2.5/5) (Appendix P). Reflecting on the items in this subcategory, I note the possibility of the students and having more control than is evident to them. For example, the students/PSTs do influence when a new topic is started, but it is based on my interpretation of their understanding to date. The responses related to this subcategory is also an example of the negative case (Guba & Lincoln, 1989) and supports the value of the quantitative data in this work and the way it was gathered in the surveys, as the data indicates the PSTs did not just answer positively on items to appease me.

In agreement with the MOLES-S data, it is interesting to note the responses from the PSTs in the final workshop when they were asked to reflect on what they believed were the key takeaway messages from the module. Excerpts from their responses indicate the emphasis on awareness of cognitive strategies in chemistry as part of the takeaway messages the PSTs took from the module, for example: “*write down what you are thinking and say why, and do not assume people visualise chemistry the same way you do*” (S5) and “*being able to talk about your ideas helps you think of multiple representations of ideas*” (S5). S7 indicated they saw a takeaway message being the value of prompting students to increase awareness of cognitive strategies such as understanding in chemistry “*Question students on their understanding, make them think about the*

chemistry involved in statements they make". S8 noted how they see the value of generation of representations as part of a metacognitively orientated environment "*don't tell students what to write or what they will see, allow them to try themselves first and then discuss to help develop metacognition*". This comment aligns with the findings of the second level study (See Chapter 7, Section 7.8).

This section provides evidence that PSTs perceived the methodology module as fostering a metacognitive-oriented environment, triangulating the analysis of the PSTs experience in the methodology module (Case studies -Appendix R) and my reflections (see Section 10.5). This contrasts with their perception that they did not experience a metacognitively oriented environment during their senior cycle chemistry education.

10.2.6 PST metacognition - as determined by MAI

The PSTs' completed the MAI (Schraw & Dennison, 1994) at the start (pre) and end (post) of the methodology module. I used it as part of the triangulation of data with the implementation of the methodology module design, my reflections and the materials the PSTs generated. The MAI also served as a discussion tool on metacognition during the second workshop (see Section 9.2.1). The data gathered using the MAI will now be discussed under its subcomponents of metacognitive awareness and metacognitive regulation.

10.2.6.1 PSTs Metacognitive awareness

The mean MAI scores for the PST group for metacognitive awareness and its subcomponents are shown in Figure 10.12. There was an increase in the overall MAI mean score for PSTs metacognitive awareness when compared to the start of the module, with increases in each of the subcomponents of MDK, MPK, and MCK. The mean scores for the items that comprise these subcategories are given in Appendix Q.

The most significant change in MAI metacognitive awareness subcategories is observed in the PSTs' MPK (Figure 10.12); looking at the change in the mean score for the items that contribute to this subcategory, it is clear that the items *I have a specific purpose for each strategy I use*, (mean increase 25%) and *I find myself using helpful learning strategies automatically* (mean increase 20%) are driving this change.

Under MDK, the item *I understand my intellectual strengths and weaknesses* (mean increase 15%) showed the largest change, while there were also relatively large increases in scores for the items '*I am a good judge of how well I understand something*' (mean

increase 13%) and *'I know what the teacher expects me to learn'* (mean increase 13%). The items *'I know when each strategy I use will be most effective'* (mean increase 18%) and *'I use different learning strategies depending on the situation'* (mean increase 33%). showed the largest increase under MCK using the MAI. The MAI data suggests that the PSTs' metacognitive awareness increased over the course of the methodology module, aligning with the aims of its design and supported by my reflections.

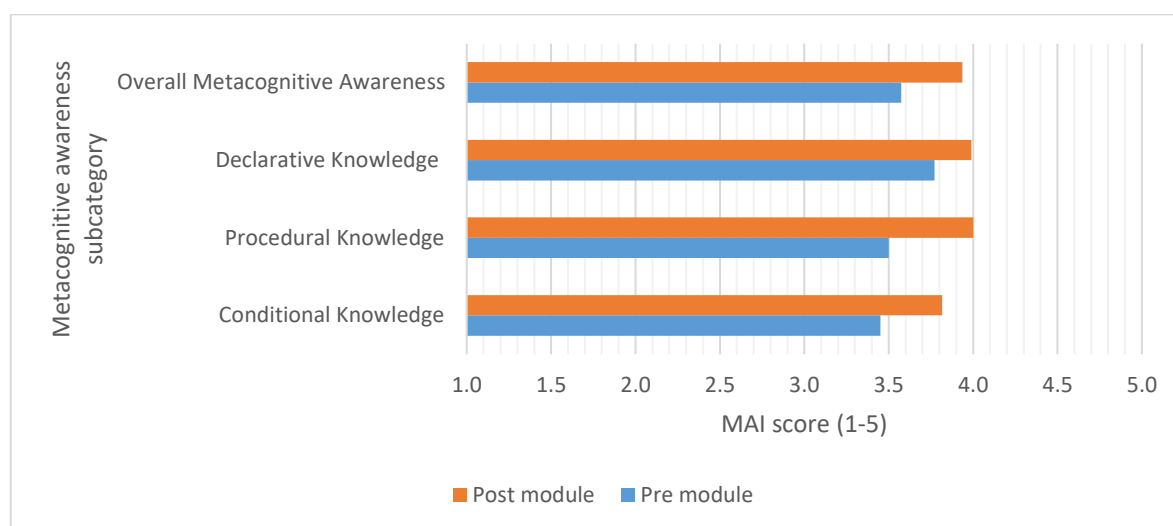


Figure 10.12 MAI - metacognitive awareness and subcategories - mean PST scores in the methodology module

10.2.6.2 PSTs Metacognitive regulation

The PST mean scores for the MAI metacognitive regulation component and its subcategories are shown in Figure 10.13. There were relatively large PST mean increases in overall MAI metacognitive regulation, and for each of the subcategories of, *planning*, *information management strategies*, *comprehension monitoring*, and *evaluation* (Figure 10.13). The mean scores for the items that comprise these subcategories are given in Appendix Q.

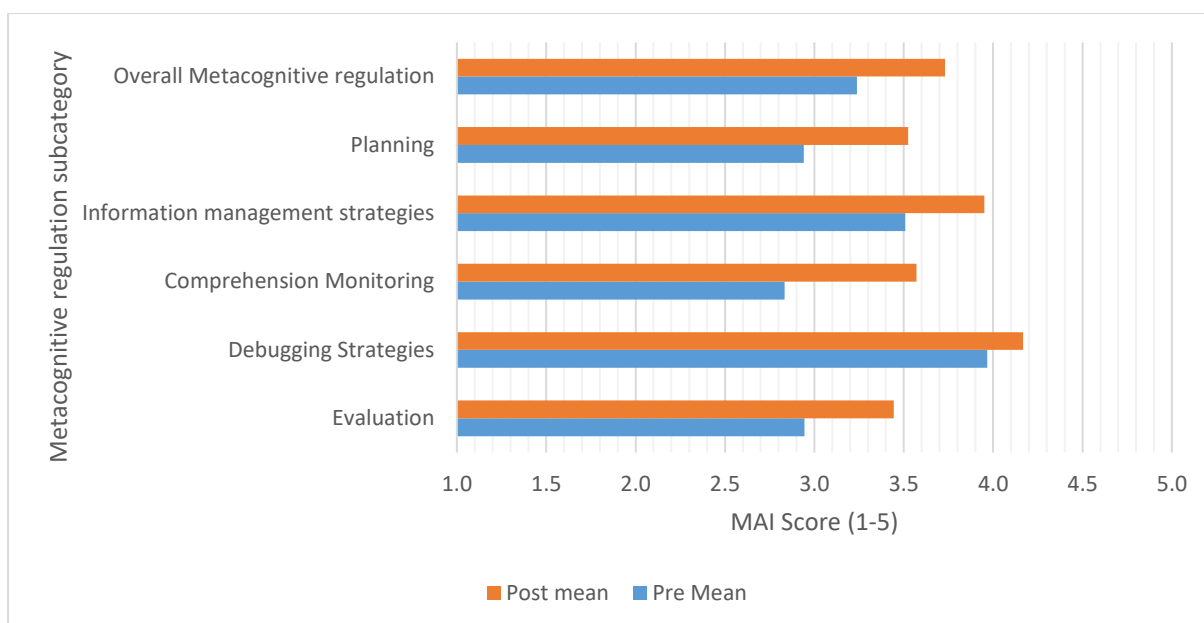


Figure 10.13 MAI - metacognitive regulation and subcategories - mean PST scores in the methodology module

Evidence for the PSTs development in aspects of planning are particularly apparent in the relatively large increases for the items:

I think about what I really need to learn before I begin a task (mean increase 20%).

I ask myself questions about the material before I begin (mean increase 20%).

I think of several ways to solve a problem and choose the best one (mean increase 25%)

The metacognitive strategies in the module which addressed planning and may have contributed to the MAI increases included metacognitive prompt questions as part of workshop tasks and planning elements of workshop assignments.

The PSTs' MAI scores for the subcategory of '*comprehension monitoring*' showed notable increases, with mean scores for all items rising by more than 15%. with the exception of the item, '*I find myself pausing regularly to check my comprehension*' (Appendix Q). Addressing the concurrent nature of this item in chemistry is a difficult skill to embed in one's thinking, as monitoring tends to arise when one reaches a point of cognitive conflict rather than self-induced pauses. I noted similar difficulties with the incorporation of the RC in the senior cycle study (see Chapter 7, Section 7.2.7). The relatively large mean increase for the item '*I periodically review to help me understand important relationships*' (mean increase 25%) supports other PST data indicating that

PSTs became more aware of using underlying concepts to connect chemical phenomena following their experience in the module (e.g. See section 10.2.1). This aligns with the module's design to enhance PSTs' awareness of the cognitive processes of visualising and thinking about chemical phenomena using underlying concepts (see Section 9.2.1). This is also supported by mean increases in the MAI subcategory of '*information management strategies*', in particular the items:

- I consciously focus my attention on important information* (mean increase 23%),
- I focus on the meaning and significance of new information* (mean increase 20%),
- I create my own examples to make information more meaningful* (mean increase 18%)
- I draw pictures or diagrams to help me understand while learning* (mean increase 13%)
- I focus on overall meaning rather than specifics* (mean increase 20%).

The absence of the PSTs mean score change for the item '*I use the organisational structure of the text to help me learn*' can be attributed to a lack of focus on reading large amounts of texts in the design of the module. This is also an example of the negative case (Guba & Lincoln, 1989) supporting the value of the MAI data in this research and as discussed in Section 10.2.5.

Interestingly there were only small changes in the items relating to '*debugging strategies*' (Appendix Q), however the mean pre-score was already relatively high for this subcategory when compared with other subcategories. In terms of the MAI '*evaluation*' subcategory, the items with the largest increases were:

- I ask myself if there was an easier way to do things after I finish a task* (mean increase 23%).
- I ask myself if I have considered all options after I solve a problem* (mean increase 25%).
- I ask myself if I learnt as much as I could have once, I finish a task* (mean increase 15%).

As learners, these aspects are particularly important and while they increased, it is notable the mean value for this subcategory was still somewhat below that of the other subcategories (Figure 10.13). Metacognitive evaluation was promoted throughout the

module, including discussion of the evolution and consolidation of the PSTs cognitive processes (e.g. See section 10.2.3).

While acknowledging other potential factors and the limitations of the MAI (outlined in Chapter 4, Section 4.2.5), my reflections (see Sections 10.4.1 and 10.5), data generated by the PSTs (see Section 10.2), and the PST MAI data discussed in this section, all suggest that the methodology module design encouraged the PSTs' metacognitive awareness and regulation in chemistry in this AR Cycle.

10.3 PSTs incorporation of metacognition in planning chemistry teaching

The metacognitive aspect of the workshops in the second half of the methodology module aimed to address the PSTs personal ability to practise metacognitive thinking with respect to classroom activities and pedagogical knowledge in the context of incorporating metacognition in the teaching of chemistry. The need for and value of research in embedding metacognitive strategies in teacher education has been described in previous research (e.g. Sulaiman et al., 2021; Mohammad et al., 2020; Seraphin et al., 2012).

10.3.1 PSTs planning to incorporate metacognitive instruction in chemistry

When teaching to promote student awareness of their cognitive processes, teachers' need to have the required metacognitive knowledge while also being capable of verbalising or voicing that knowledge using adequate 'language of thinking' (Tishman & Perkins, 1997). At the end of the module, the PSTs were asked how they would incorporate metacognition into their chemistry lessons. In response S2 describes how they would explicitly teach their own classes about "*metacognition itself and its stages*" but not "*go into a lot of detail*", rather "*just an overview*" as they think it would be "*important for their learning*" and that students should be "*trusted to be aware of the metacognitive process and not just have it cloaked in tasks and assessments*". These comments suggest that S2 is reflecting on the approach used in the methodology module, where PSTs were encouraged to reflect on their experiences and explicitly articulate how the tasks they engaged with incorporated metacognition. S2 indicated that they believe that students in their chemistry class should "*see for themselves the different stages and the reason they are being asked to predict or illustrate or plan or evaluate*". S2 acknowledges that "*some students may not see the benefit of learning about metacognition*". However, S2 goes on to describe that similar to themselves "*students will see the benefit as they encounter it*

themselves and are aware that they are engaging in the metacognitive process". This comment S2 demonstrates MDK embedded in their discourse.

As discussed in Chapter 2, the existence of both domain specific and domain general aspects of metacognition has been described in literature (Kuhn et al., 1995; Schraw et al., 1995; Van der Stel & Veenman, 2014; Veenman, 2012). The PSTs demonstrated an awareness of the domain general aspects of metacognition in teaching. For example, S6 describes an awareness of the domain general nature of metacognition where they indicate *"students may even use metacognition themselves in other classrooms, subjects or even in their lives outside of school"* or how like S6 themselves *"they may have been using some form of it [metacognition] already and find it liberating that they now have a name to the process"*. Again, this comment is an example of a PST demonstrating MDK as part of their discourse.

S1 also outlines the need to include metacognition as part of lessons, and they describe how it should be incorporated through a reflective writing task.

"Metacognition does not come naturally to most students and this needs to be encouraged in lessons. Metacognition can be brought into a lesson by the teacher in a way that aids students to work on their metacognition without giving away what they are doing. For example, students could be starting a new topic and the teacher could get the students to write down anything they think is associated with that topic and what they think would be the most beneficial way to learn that topic based on their learning so far" (S1)

S6 provided examples of questions which they believe would promote metacognition.

"Questions along the lines of "what am I doing right now", "why did I choose this particular approach", "is there a better way of thinking about this?" really improves a student's awareness of their thoughts and thought processes and a student's ability to understand why they possess these thinking patterns" (S6)

These questions suggested by S6 show a level of understanding of the MM and ME aspects of metacognition as part of planning their teaching.

S4 suggests a number of strategies they would use to incorporate metacognition as part of planning a lesson on quantifying matter.

Classroom discussion underlying concepts (core, peripheral, pre-concepts) - specific conceptual discussions. Brainstorm students' contributions to the

discussion so students can link the concepts to increase awareness of this type of thinking.

Group work (so students can think out loud) - this allows students to creatively collaborate and bounce their thinking off each other.

S10 indicated that they would incorporate metacognition by having both students and themselves voice their cognitive processes;

“The students are first asked to represent the reaction between baking soda and vinegar at a macroscopic, submicroscopic and symbolic level. To help them with this task, they can react with the baking soda with the vinegar. While they are doing this, I will go around the room looking at the visual representations and asking the students to vocalise their thinking. I will constantly ask the students “Why? The students are then asked who feels comfortable with coming up to the board and representing their visualisations for the class while using their metacognitive skills to explain their thinking. After this, I will do the same, representing the reaction at a macroscopic, submicroscopic and symbolic level while vocalising my thoughts for the class.” (S10)

S2 discussed in a post-placement interview how they applied underlying concepts during their teaching when on placement in the months following the methodology module.

“Well, electronegativity, particularly, a good understanding of that helped me get students thinking in different topics. What I've seen, the electron density images of atoms help visualise it as well. If you can visibly see how an oxygen is when it is double bonded to a carbon atom and visualising it, showing it's highly dense in electrons. I think I planned to bring the stick and ball [representation], but that doesn't really show the whole picture, especially when you're looking at the electrons. But I will definitely use underlying concepts, like the electronegativity concept and then build their [students] understanding of their thinking in chemistry from there.” (S2, Post placement interview)

The above comments indicate S2's awareness of using electronegativity in their teaching as an underlying concept for the cognitive processes of thinking, understanding, and visualising chemical phenomena.

In the above descriptions, the PSTs have demonstrated aspects of incorporating metacognition in their chemistry teaching, which includes an understanding of the metacognitive strategies used or what Zohar and Barzilai, (2013) described as pedagogical knowledge of metacognition.

10.3.2 PST and the metacognitive use of representations in teaching chemistry

The PSTs demonstrated an awareness of using the generation of representations as a domain-specific metacognitive strategy in chemistry. For example, S10 highlighted promoting metacognition and asking students to represent their thinking as part of assessing student understanding. S10 indicates that in chemistry *“Representations are also a key element of optimising metacognitive skills. When a student can show me their thinking in a drawing and can then explain why they thought like that”*. The use of representations as a means of describing cognitive processes in chemistry is highlighted by S2, who indicated that it is better to ask senior cycle students to *“illustrate what they think rather than just rely on words”* because senior cycle students won’t have the *“vocabulary to describe what they think, and this lack of vocabulary can lead to confusion or frustration”*. S2 further elaborates on this point by indicating that *“by encouraging visualisation of chemistry and then illustrations, this will give students a valuable tool for the metacognitive process in chemistry”*. S2 indicates that incorporating representations of cognitive processes in chemistry should begin with the teacher where they *“draw and illustrate what their thoughts are for their students”* and as the students see this as a tool *“they are more likely to use it themselves”* and S2 goes on to argue *“the metacognitive vocabulary will then follow as the teacher can build this by using the correct terminology while drawing representations for students”*. This comment aligns with the findings of previous AR cycles, where the use of representations offers a scaffolding approach to incorporating metacognition in chemistry. The comments by S2 and S10 above also demonstrate modelling cognitive processes in chemistry while generating representations, aligning with the design of the methodology module and previous literature on metacognitive strategies (Zohar & Barzilai, 2013; Veenman et al., 2006).

Similar to S2, S4 emphasises the use of representations to demonstrate cognitive processes in chemistry, highlighting how teachers can voice their own cognitive processes to students to enhance metacognitive awareness. S4 indicates that when they, as the teacher, generate a representation and describe their cognitive processes (understanding), it can help students become aware of the teacher's cognitive processes including how the link multiple chemical phenomena;

“Atoms can be seen to be tightly packed to form the solid. This links atomic theory to quantifying matter. All matter is made up of atoms and stoichiometry is the

means by which this can be quantified. Atomic theory is used to explain why bonding occurs and determines the ratios of atoms of different elements in molecules. The atomic mass of different elements is often used in order to determine the number of moles of a particular element. The students will metacognitively deduce this information through their own thinking as they listen to my thinking aloud” (S4, Assignment P2)

S4’s description of their chemistry understanding behind their generated representations aligns with Gilbert and Treagust (2009) who argue that for students to interpret specific aspects of a representation in chemistry at the submicroscopic level the conventions of representation should be described by the generator i.e., teacher or student. S4 argues that by asking students to “*draw out experiments on the macroscopic level, submicroscopic and the symbolic level*” is a “*highly metacognitive activity because students are given minimal instruction and must devise their own plan of action and thinking between these levels*”, and that the students should “*rely less on their teacher as a source of information, but rather, look to themselves to find the solution*”. In this example, S4 seems to have primarily described cognitive processes. However, the metacognitive aspects that may be implied or further developed include awareness of one’s cognitive processes across the submicroscopic, symbolic, and macroscopic levels during experimental work.

S6 discusses awareness of, and ability to change, one's cognitive processes and how this is fundamental to solving problems in chemistry:

“to visualise as well as conceptualise the problem based questions they are posed with in the senior cycle chemistry syllabus. Through the use of representations of one’s visualisations, it can allow for deeper understanding of the concepts in question. One must plan, implement, proceed and refine when approaching questions. Metacognition is at its peak during the refining process as students are forced to adapt their thinking in order to solve the problem. At this stage students’ thinking is heightened, and the awareness of their own thinking becomes evident” (S6 Assignment P2).

The idea of using the generation and refinement of representations has been described in previous literature, where Wu and Shah (2004) argue further opportunities for thinking and visualising of chemistry at the submicroscopic level could be achieved through explaining, revisiting and manipulating representations generated by the student. While S6 has described an awareness of the possible metacognitive use of the generation and refinement of representations, which is in agreement with the findings of successive implementations of the AR cycles in this research.

As another example, S6 describes the chemical phenomenon of *mechanisms following the electrons in substitution reactions in organic chemistry*, they indicate that teachers should not teach in a step-by-step manner, or “*give each step a term for example initiation, propagation and termination*”. S6 indicates they believe in teaching students by giving students the starting compounds and asking them to formulate the products they believe would be formed and allowing students to change and adapt their suggestions through reflection on their own cognitive processes:

“give the students the compounds in question and ask them to represent what products they think will be formed in the vessel. In this way they have to really think about their own thoughts on a deeper level and identify if they think their thought process is correct. If they have doubts about their suggestion, they must actively adapt the way in which they think about the substitution of compounds in an organic reaction” (S6, final assignment part 2).

S6 identifies the metacognitive regulation and the importance of time in the above task:

“By approaching it in this manner students regulate their thinking, in order to keep on task students must manage their timing and effort in the planning process, this allows for the correct monitoring and then they can evaluate their process” (S6, final assignment)

The above strategy outlined by S6 could be enhanced through the use of student think-aloud protocol, student descriptions of their thinking and metacognitive prompts during the task e.g. “*what do you already understand about electron orbitals which would indicate why these react?*” and “*Has your thinking changed in relation to how a mechanism explains the chemistry occurring?*”

In a post teaching placement interview, which took place three months after participation in the methodology module, S2 demonstrated their own metacognition in relation to the cognitive processes of thinking, visualising and understanding as applied to their experience while teaching chemistry. When I asked about aspects of the module which impacted on their teaching practice while on placement S2 indicated

“Students being aware of using visualisations, I would say. That really stuck with me. Thinking at the levels of Johnstone triangle. But most importantly, the visualisation and trying to bring that in any time I can. I said, what's actually happened there? Let's try and draw how we imagine it out. I did the burning magnesium experiment. In the mixture left over, we drew the atoms that worked

and bonded and then we drew the ones that didn't work. I think trying to think of how I was thinking about the chemistry topic, trying to think about it at a visualisation level, at a submicroscopic level. There was that as well, but I think mainly from the visualisation and being aware of thinking about chemistry at a deeper level, what actually happening and we discussed. But I thought that was really good because it was something that I hadn't realised, I didn't understand before. I have a deeper understanding of my own use of visualisations now.” (S2, post placement interview)

The above extract provides evidence which indicates S2's ability to transfer and apply metacognitive strategies, such as visualisation, to real-world teaching and learning scenarios.

In addition to other data including my reflections (see section 10.5), descriptions of their own thinking (see Section 10.2.2), the above examples provide evidence that the PSTs can plan for the metacognitive use of representations in chemistry, and it can be argued that through their experience in the module they see value and have an authentic understanding of representations as a metacognitive strategy in teaching chemistry.

10.4 PST Case studies

Two case studies of PSTs who participated in the module are presented in Appendix R, which provide additional triangulation of evidence for the findings on the methodology module design, the PSTs' experiences with metacognition, and their understanding of metacognitive strategies in chemistry.

Case studies are included in this thesis as they allow for an in-depth, flexible, and context-rich exploration of two PSTs experience related to the methodology module I designed and implemented. In line with my beliefs as a pragmatic action researcher, these are theory-guided interpretive case studies that aim to explain and/or interpret a single historical episode rather than generalise beyond the data (Levy, 2008). Following an analysis of individual data in relation to their experience in senior cycle chemistry and the MAI scores, two PSTs were selected for the case studies, namely S12 and S3.

S12 was selected as their perception of their senior cycle chemistry experience was one which was not particularly metacognitively orientated, due to the very low score in MOLES-S survey for their senior cycle chemistry experience and the statements they made to that effect during workshops. S12 showed development in their own metacognition over the course of the methodology module.

S3 was selected because their perception of their senior cycle chemistry experience was sometimes metacognitively orientated, as evidenced through their score in the MOLES-S survey and comments made during workshops. S3's metacognition developed over the course of the methodology module, as evidenced by the level of awareness of their cognitive processes in workshops, tasks, assignments, and relatively large increase in their MAI score.

10.4.1 Reflecting on the PST cases studies

The detailed data from both PSTs indicate general agreement with other PSTs in both AR Cycle 4 and AR Cycle 5, where they noted that their senior cycle chemistry experience was not particularly metacognitively oriented. This finding supports the methodology module design developed in AR Cycle 5, which provides opportunities for PSTs to both experience and implement metacognitive strategies. Following the module, S3 and S12 indicated that they believe a more beneficial way would be to promote students' cognitive processes in chemistry related to the submicroscopic level and to ask students to represent their cognitive processes in chemistry as part of lesson tasks which would also increase student metacognition in chemistry. The MOLES-S data in both case studies indicates their perception of the methodology module was aligned with my aim to create and model a culture of metacognition as part of teaching chemistry.

The data from both S3 and S12 also indicates they developed in terms of their awareness of metacognition. It is interesting that based on MAI scores at the start and end of the methodology module, S12 shows development in terms of metacognitive regulation, while they started with a relatively high score for metacognitive awareness, while S3 showed development in the metacognitive awareness while they began with relatively high score in regulation. This provides additional evidence which supports the design of the module in AR cycle 5. The generation and refinement of representations by the PSTs helped establish their cognitive processes in relation to chemical phenomenon, while the metacognitive element was displayed as they indicate awareness and regulation of their cognitive processes as part of associated discussions or descriptions.

Both S12's and S3's data suggest development in terms of their pedagogical knowledge in the context of teaching metacognition in chemistry. S12 and S3 embedded the use of generating representations to establish student cognitive processes in both the description of their lessons and in the audiovisual recording of their lessons at the end of the module.

However, in the design and audiovisual recording of their lesson, opportunities were missed for metacognitive discussions and metacognitive prompts in relation to the inclusion of the representations of student cognitive processes. Following the teaching placement, S3 described an awareness of the metacognitive aspects of the strategies they used in their teaching and while they also described their own metacognitive awareness in chemistry (note that S12 was not available to participate in a post placement interview).

10.5 Reflections on the Methodology Module (AR Cycle 5)

As part of my initial reflections on the design of the methodology module, I noted how *“The first weeks of the module required an adjustment for the PSTs each week as they required a lot of encouragement and support in relation to generating their representations and confidence voicing their cognitive processes openly in the workshops”*. This is in agreement with previous research (e.g. Georgiades, 2004; King, 1998; Lin, 2001) and the findings of AR cycles 1-4, which have consistently identified the importance of a supportive environment when the focus is on voicing cognitive processes at a point in time rather than an environment where participants feel anything they say or represent must be theoretically correct. In line with Thomas (2002), I noted metacognition is socially mediated, and that the importance should be placed on what the PSTs cognitive processes at that time, and that the nature of the learning environment is an important factor influencing the development of PSTs’ metacognition. I also noted that this was something that continually needed to be addressed, for example following the fifth workshop of the module I noted *“The use of representation what they [PSTs] think and visualise in chemistry rather than using text or replication of an image they have seen was an issue for parts of the workshops, I am constantly encouraging the principles of authentic representations and authentic voice related to thinking, understanding and visualisations of chemical phenomenon”*.

I noted in a workshop reflection at the end of the module that the PSTs indicated *“they had not studied the metacognitive aspects teaching and learning strategies previously”* and how this was in keeping with the responses from the PSTs in the pilot methodology module (AR Cycle 4). It should be noted that my reflections and the PSTs responses may be due to the PSTs not recalling being introduced to metacognition in previous modules they studied. However, it provides evidence that PST education should revisit

incorporating metacognition into domain-specific methodology modules, as recommended by previous research (Georghiades, 2004; Lavi et al., 2019).

As part of embedding the metacognitive use of representations I noted in a post workshop reflection the development in terms of the evolution of the PSTs representations and how they described their cognitive processes;

“The PSTs demonstrated an awareness of how their thinking evolved in their representations. The task in weeks 1-3, where they were encouraged to revisit their representations of intermolecular and intramolecular bonding in water, served as a model for how the PSTs could become more aware of changes of the way they think in chemistry through generating authentic representations of their visualisations of chemical phenomena”.

I also noted how the PSTs reflections on their metacognitive awareness evolved as the module progressed *“The PSTs reflections on their cognitive processes initially was quite surface, but gradually as the module continued the level of deeper awareness of their cognitive processes became more evident in their writing and comments in workshops”.*

In alignment with the module design outlined in Chapter 9, I reflected on the change in approach in Workshop 5. After transcribing the first four workshops, I observed and noted this shift; *“The module initially (weeks 1-4) focused on the PSTs experiencing strategies which incorporated metacognition, I am now conscious to move on to the PSTs analysing and modelling metacognitive teaching and learning strategies in chemistry”.* In a workshop reflection, I also noted how the PSTs emphasised the importance of reflecting on cognitive processes in chemistry. For example, when addressing the chunking of information using underlying concepts (Miller, 1956) the PSTs indicated an awareness of cognitive processes, which they felt would be important for their future roles as chemistry teachers, I noted, *“Discussing the cognitive processes around linking chemical phenomena to underlying concepts was something which tended to be highlighted by the PSTs in workshops as being particularly useful to them and something that they had not explicitly thought about before”.* In agreement with this awareness, Gilewski et al. (2022) argue meaningful learning is established by learners scaffolding new concepts upon their pre-existing knowledge, which is distinct from rote learning, in which only short-term retention is attained, and concepts are not integrated together. Following my reflections on the PSTs practicing and modelling metacognitive strategies

in the later workshops and in their assignments, I noted “*the fluency at which they modelled the metacognitive strategies was improving, and in particular they are including aspects of their own metacognition as part of their discourse*”.

A future development in the design of the methodology module could include a workshop session discussing the PSTs' audiovisual recordings of their teaching strategies. However, the challenge of incorporating this within the timeframe of a semester was an issue in the design in AR Cycle 5 and remains a practical issue.

10.6 Conclusions from the preservice education study (AR Cycles 4 & 5)

This chapter has discussed data from the PSTs in AR Cycle 5, as well as my experience while implementing the methodology module during this cycle. The overall research question for the PST study was: *What is the impact of explicitly integrating metacognitive strategies on preservice chemistry teachers' (PSTs') awareness and lesson planning in chemistry teaching in the Irish context?* This question was addressed through each of the sub-research questions discussed below.

10.6.1 Research Questions – Preservice education study

RQ What is the PST experience of metacognitive strategies in their own senior cycle chemistry experience?

The PSTs incorporation of metacognition was promoted in the design of the methodology module through increasing awareness of their voice in relation to their cognitive processes, which included the PSTs reflecting and describing how they learned chemistry and their experiences in senior cycle chemistry. An analysis of the PSTs data on their perception of their own senior cycle chemistry experience revealed two recurring themes (i) a reliance on memorisation and (ii) a lack of focus on the understanding of chemical phenomena. In discussions, the PSTs indicated they thought memorisation and a lack of a focus on understanding gave rise to difficulties they had in chemistry. For instance, when the PSTs were asked how they could have become better learners of chemistry when they were in senior cycle, their response was to reduce the emphasis on memorisation. It should be noted that the PSTs perception of senior cycle chemistry is subjective and influenced by a number of factors including the time elapsed since the PSTs were in senior cycle education. However, the PSTs descriptions of their experience in senior cycle chemistry, and the results of the related MOLES-S survey, provide evidence that the PSTs perception of their senior cycle chemistry experience was not

particularly metacognitively orientated. Therefore, given the literature on the importance of metacognition in learning (e.g. Zohar and Barzilai, 2013) particularly in chemistry due to the abstract nature of the subject (e.g. Rickey & Stacey, 2000; Lavi et al., 2019) and in the context of Irish second level education reforms (e.g. NCCA, 2015, NCCA, 2022), it is important that PSTs develop their understanding of metacognition in a domain specific way and are provided with opportunities to incorporate metacognition in chemistry as part of their PST education.

RQ How can a chemistry PST methodology module be designed to incorporate metacognitive strategies in a domain specific way?

The findings from the PST study suggest the methodology module design should focus on incorporating metacognition by (i) the PSTs experiencing metacognitive strategies which promotes their understanding of the value of metacognition as a learner, and (ii) PSTs should be provided with opportunities for discussion and planning for metacognitive strategies in chemistry. The module design of the final iteration (AR Cycle 5) reflected these areas of focus, with the episodes in the initial workshops centring on the PSTs' experience of metacognitive strategies. For example, the metacognitive use of representations in chemistry during the first three workshops provided PSTs with opportunities to voice their cognitive processes through associated descriptions and discussions, and to become more aware of how their cognitive processes evolved by reflecting on and refining previous iterations of their representations. Additionally, discussing and describing each other's representations gave the PSTs an opportunity to consolidate the awareness of their cognitive processes.

Following the analysis of the PSTs description of metacognition (Section 10.2.1) and how they would introduce metacognition (Section 10.3.1) the approach taken in AR cycle 5 where the PSTs experience and discuss metacognition in workshops while applying it to chemistry teaching and learning strategies rather than studying it as a theoretical concept was validated. My planning of the workshops, reflections, descriptive analysis, audiovisual recording analysis and PST MOLES-S data all indicate that metacognitive strategies were frequently embedded in the module. It was clear from the student responses and the MOLES-S data that the PSTs recognised and valued the module's emphasis on metacognition, which was reflected in comments from PSTs about expressing an awareness of their cognitive processes (e.g. thinking, visualisations, understanding, learning) and perspectives on chemistry problems or phenomena.

In the second half of the module, the focus shifted to how the PSTs could create opportunities for their students to understand the value of metacognition and apply it in chemistry teaching. The PSTs' responses indicate that they recognise the value of teaching metacognition through the use of metacognitive strategies, where explicit metacognitive instruction or discourse is embedded in metacognitive strategies rather than presented as a separate theoretical concept. This aligns with the changes I made to the design of the methodology module from AR Cycle 4 to AR Cycle 5. The PSTs also expressed the metacognitive use of the generation of representations as being part of metacognitive strategies in the chemistry context.

Evidence from the PSTs indicates at the end of the module, PSTs had awareness of their own metacognition in chemistry (e.g. reflections on their representations and MAI data), while also highlighting aspects which they could incorporate in their own teaching. However, it should be noted some of the PSTs did not include sufficient detail to indicate how they would include metacognition in their teaching of chemistry. This reflects the individual nature of learning from similar experiences.

As outlined in the senior cycle study (AR cycles 1-3), effective metacognitive teaching requires the teacher to be metacognitively aware and to have domain specific experience so that they can identify opportunities to incorporate metacognition in a domain specific way. These opportunities can be pre-planned, allowing them to naturally arise during the course of a lesson as a result of the teaching strategy and approach to chemistry. This includes embedding a supportive and encouraging environment where students feel comfortable voicing their cognitive processes through discussions and descriptions. In this regard the teacher may choose the appropriate metacognitive strategies, including teacher led metacognitive discussions, metacognitive prompts, metacognitive modelling by the teacher or student etc. Through the design and implementation of this module, the PSTs were given the chance to experience these strategies as learners, as well as opportunities to practice and discuss them from the teacher's perspective.

RQ How can the metacognitive use of representations be embedded in a Chemistry methodology module?

Based on findings from the first four AR cycles highlighting the value of generating representations of one's cognitive processes in chemistry (e.g. visualisations, thinking, understanding) and associated descriptions, discussions, and prompts, the methodology module was designed to include these elements. The generation of representations and

associated discussions in chemistry has a dual purpose as part of the design of a methodology module. Firstly, it addresses the PSTs' awareness of their own cognitive processes whilst also modelling their awareness of cognitive processes for others (fellow PSTs, their students). Secondly, the use of the generation of representations of cognitive processes by the PSTs provides opportunities for other metacognitive strategies e.g., thinking aloud, metacognitive modelling and teacher-led metacognitive discussions, and reflective writing. An important finding from this PST study in relation to the implementation of the generation of representations as a metacognitive strategy is the PSTs awareness of the need to discuss and prompt cognitive processes (e.g. understanding, visualising) before, during and after the generation of representations. It should be noted that some opportunities for this were missed both in my implementation of the strategy and in the PSTs descriptions of how they would implement the strategy in their future teaching. However, the data collected in the PST study (AR cycles 4 & 5) supports the findings of the senior cycle study (AR cycles 1-3) which indicate that the generation of representations of cognitive processes reacted to chemical phenomena with associated descriptions and/or discussions, can be used a domain specific approach for the incorporation of metacognition in chemistry teaching.

RQ What environmental factors are important in providing affordances for metacognition in a chemistry workshop for PSTs?

The comments by the PSTs as part of workshop discussions and the MOLES-S data indicate their perception of the methodology module was aligned with my aim to create and model a culture of metacognition as part of teaching chemistry in the workshops. The data analysis suggests the module effectively established a demanding and supportive metacognitive environment that PSTs recognised, engaged with, and valued, potentially influencing their future instructional practices. However, the structured approach with limited distributed control may be a consideration for further iterations. The PST study (AR Cycles 4 & 5) data is in agreement with the findings of in the senior cycle study (AR Cycles 1-3), which indicates an important element in the incorporation of metacognitive strategies includes students and PSTs feeling they can voice their cognitive processes and express their difficulties in chemistry in a supportive and encouraging environment. The mean scores in the MOLES-S categories such as *emotional support*, *teacher encouragement*, and *student voice* indicate that the PSTs perceived a safe space for expressing doubts and discussing difficulties in their cognitive processes openly. For

example, this supportive culture aimed to enable PSTs to voice and become more aware of their evolving cognitive processes by generating and refining representations without fear of making errors.

RQ How can the PSTs incorporate metacognition in their planning of lessons?

Following the adaptation of the methodology module design for AR cycle 5, which shifted focus from theoretical understanding of metacognition to discussing it through experiencing and analysing metacognitive strategies, the PSTs demonstrated aspects of how they would incorporate metacognition in chemistry. This included the PSTs recognising metacognitive opportunities within the strategies used in the workshops. The PSTs demonstrated examples of what Zohar and Barzilai (2013) refer to as pedagogical knowledge of metacognition, while their responses also indicate they see the value of metacognition in teaching chemistry. The PSTs recognise the significance of metacognition incorporated through explicit metacognitive instruction, metacognitive discussions and prompts, and teacher metacognitive modelling. Their strategies highlight the dynamic interplay between reflection, action, and scaffolding as part of incorporating metacognition in the teaching of chemistry.

Reflections by the PSTs at the end of AR Cycle 5, suggest an appreciation for fostering metacognitive awareness in their future classrooms. PSTs emphasised the importance of incorporating metacognition in chemistry by asking students to explain their cognitive processes, encouraging representations of cognitive processes at the submicroscopic, macroscopic and symbolic levels, and promoting self-reflection, which also indicates that they saw value in using metacognitive strategies in their teaching. The PSTs' responses suggest that they had not encountered such a metacognitively orientated environment in their own senior cycle chemistry experience. This recognition suggests a shift in their understanding and perhaps a desire to implement similar strategies in their own teaching, reinforcing the module's effectiveness in shifting perspectives on the domain specific value of metacognition in chemistry education.

Chapter 11 Conclusions and recommendations

As discussed in Chapter 2, literature emphasises the importance (i) of cognitive processes and representing chemistry related to the submicroscopic level (Johnstone, 1991), (ii) the particular relevance of metacognition in chemistry because of the abstract nature of the subject (Rickey & Stacy, 2000), (iii) the use of metacognitive teaching and learning strategies (Zohar & Barzilai, 2013). This AR describes my experience incorporating (i)-(iii) in both senior cycle chemistry and in the design of a PST chemistry methodology module. The specific research questions addressed in the senior cycle (AR cycles 1-3) and preservice education study (AR Cycles 4 & 5) were discussed at the end of Chapter 7 and Chapter 10 respectively. This chapter discusses and summarises the overall conclusions and actionable knowledge (Coghlan, et al., 2019) drawn from the findings across the five AR Cycles, including limitations, and possible future directions. As part of the overall conclusions, I suggest a model for integrating metacognition into the teaching and learning of abstract chemical concepts.

11.1 Conclusions

11.1.1 The death of a positivist

This research presents the story of a shift in my epistemological and ontological perspectives from predominantly positivist and objectivist, towards one which is grounded in subjectivism and interpretivism. This included an awareness of the evolution of my own cognitive processes, particularly the idea that all knowledge, including scientific knowledge, is understood from some point of view (Mounce, 2002), and the notion that one cannot step into the same river twice (Fragment XXII, cited in Geldard, 2000, p.53), highlighting the subjective nature of experience in the teaching, learning, and assessment of chemistry. This culminated in my realisation that it is the chemist who is at the centre of knowledge and research in chemistry. I noted this constant mental struggle I had while completing and writing this thesis. Upon completion of this research, I do not see objectivism or subjectivism as being an either-or choice, rather as lenses that one can view any research, idea, or phenomenon through. I now place an importance on being aware of cognitive processes in chemistry through both lenses rather than choosing either one as the only lens to which one should view research or knowledge. I see the strength in being aware of the duality of these philosophical stances as part of being a chemistry educator or indeed chemist. At the end of this research, I now question the existence if there is even a possibility of objectivity or positivism in research and

knowledge, and hence the play in title of this thesis “*the death of a positivist*”. It should be noted that I believe this should be taken in context, and as with the title of Seamus Heaney’s first published book of poetry, *Death of a Naturalist* (Heaney, 1966). His naturalist tendencies never completely faded, just as my positivist tendencies will never fully disappear.

This research presents my story of incorporating metacognition in chemistry as a teacher and teacher educator over the course of seven years during a time of education reform in Ireland. My development in terms of my understanding of metacognition in a chemistry context and pedagogical knowledge of teaching metacognition in chemistry was a central influence on the research. It was promoted through my theoretical study of metacognition and the practical incorporation of metacognitive strategies in the senior cycle and PST education studies (AR Cycles 1-5). In addition to the scholarly reflection on literature, the analysis of second-level lessons for evidence of metacognition and its subcomponents provided me with an opportunity to refine my conceptual framework for interpreting metacognition in chemistry (see Section 6.6). Taking myself as an example, I proposed that for teachers to avail of opportunities for metacognitive modelling or explicit metacognitive instruction in the context of chemistry, they must have experience and understanding of metacognition as it applies to chemistry. The more I developed my understanding of metacognition in chemistry, the more comfortable I became with incorporating metacognition in lessons. I found that for metacognition to become embedded in my practice in a domain specific way, the language used should be accessible and metacognition should be discussed and explained in the context of the cognitive processes related to the chemical phenomenon being addressed. It was also found that opportunities for metacognitive modelling or explicit metacognitive instruction often arose while I was generating representations of my cognitive processes related to chemical phenomena. In addition, the students and PSTs generation of representations of chemical phenomena provided rich opportunities for discussions, descriptions and prompting of their cognitive processes, thereby increasing metacognitive awareness in a domain specific context. As a teacher educator, I see the importance of experiencing and implementing metacognitive strategies in a domain specific way, before incorporating them in a PST workshop. While I have always advocated that a PST methodology module should focus on theory as much as practice, my experience as an action researcher in the PST study has revealed the importance of

bridging the gap between theory and practice through PSTs experiencing, analysing and planning metacognitive strategies so they see their value and relevance.

11.1.2 Metacognitive strategies in chemistry

The metacognitive teaching and learning strategies incorporated into the fifth-year study which were selected following trialling in the TY pilot studies (AR cycles 1 & 2) included metacognitive prompts, generation of representations, think aloud protocol, reflective writing, metacognitive led discussions, metacognitive modelling, and explicit metacognitive instruction. The findings of the fifth-year study (AR Cycle 3) indicated several metacognitive strategies were found to be difficult for me to embed in chemistry lessons, for example the regulatory checklist appeared to result in cognitive overload during tasks for students, and the SEM was found to be more suitable for text-based lessons or subjects.

As part of the general metacognitive approach, I found a supportive and encouraging environment was central in creating a metacognitively orientated environment in the senior cycle study and the PST education study. This included an emphasis in lessons/workshops on student/PSTs voicing their cognitive processes related to chemical phenomena at a particular point in time and increasing their awareness of how their cognitive processes in chemistry can evolve and how they can be consolidated. It was found that it is important to model metacognition, and this is part of creating a culture of metacognition in the chemistry classroom. Modelling metacognition by the teacher/teacher educator not only offers students/PSTs an accessible example of metacognition but also provides insight into the teacher's/teacher educator's cognitive processes in chemistry. This approach increases awareness of how the cognitive processes are performed in the subject and helps avoid the perception that 'the teacher just knows the chemistry'. An important finding for the implementation of metacognitive strategies is the need for metacognitive discussion and metacognitive prompts before, during and/or after other metacognitive strategies e.g., think aloud, reflective writing. Such metacognitive discussions and prompts provide opportunities to increase awareness of the voice, evolution, and consolidation of cognitive processes in chemistry.

As an action researcher, one of the difficulties I faced was maintaining constant awareness of both the cognitive and metacognitive elements of strategies, something that became increasingly clear as I progressed through the AR cycles (e.g. see conceptual

framework in Chapter 6, Section 6.6). This is particularly notable given my focus on incorporating metacognition in both senior cycle and PST education, supported by deep analysis and reflection on both literature and practice. Considering this, if substantive concepts like metacognition are to be included in education reforms or curricula, they must be sufficiently addressed in both in-service and PST education to ensure they become a meaningful part of students' teaching and learning experiences.

11.1.3 Representations – embedding metacognition in chemistry

While frameworks exist which provide a perspective on learning with visual representations (e.g. Ainsworth, 2006; Carolan, 2008; Prain & Tytler, 2012), through the AR cycles I became aware of the potential of using the generation and refinement of representations in chemistry as a means to provide opportunities to address metacognitive awareness in a domain specific way. I found this is a particularly relevant approach to chemistry due to the abstract nature of chemical phenomena, especially at the submicroscopic level. In the context of this AR, using representations to facilitate metacognitive discussions and prompts has proven to be a particularly effective approach that can be integrated into other metacognitive strategies in chemistry. Student or teacher generation of representations in chemistry can incorporate metacognition through the voicing of student or teacher cognitive processes e.g., think aloud protocols, metacognitive prompts or metacognitive discussions. This approach can contribute to fostering a metacognitive culture embedded within chemistry lessons. The generation of representations, accompanied by metacognitive discussions or descriptions, serves a dual purpose: it enhances the awareness of cognitive processes for the individual generating the representation and provides insight into that individual's cognitive processes for others. This, in turn, supports the development of metacognition within a chemistry context. I found that embedding the generation of representations as a metacognitive strategy requires discussing and prompting student/PST cognitive processes (e.g. visualisations, understanding) before, during, and after they generate representations of chemical phenomena. The focus should be on ensuring that the generated representation reflects the individual's cognitive processes at that moment, while also fostering an awareness of the origins of those processes and how they can evolve. This includes consolidating their cognitive processes to achieve greater alignment with theoretical accuracy. To achieve this: (i) students/PSTs need to be the generators, rather than merely interpreters, of the representations of their cognitive processes related to a chemical

phenomenon; (ii) the representations should be revisited after discussion and reflection on the cognitive processes behind them; and (iii) this process should occur in a supportive and encouraging environment that allows students to express their cognitive processes at that point in time. This approach to incorporating metacognition in chemistry education within the Irish context, based on this AR, contributes to the theoretical development of metacognition in chemistry education. It offers insights through practice, scholarly reflection, including the conceptual framework I developed within this context (see Chapter 6, Section 6.6) and the observational rubrics for identifying metacognitive events in chemistry lessons in this context (see Chapter 5, Section 5.1.1.1).

11.1.4 Preservice teacher methodology module design

As the teacher educator in the PST study (AR Cycles 4 & 5), I had four years of experience and scholarly reflection on metacognition in chemistry prior to the pilot methodology module (AR Cycle 4). This experience provided me with valuable theoretical and practical insights, such as the importance of a domain-specific understanding of metacognition in chemistry. While it may not be practical for every teacher or teacher educator to have the same level of theoretical or practical experience as I had, a conclusion from this research is that, to appreciate the nuanced nature of metacognition in practice, time to experience these metacognitive strategies from the learner's perspective is essential. I believe it is this experience that would help educators value these strategies and understand the domain-specific aspects of metacognition in chemistry.

The data collected indicated that the PSTs' perception of their experience in senior cycle chemistry was that it was not particularly metacognitively oriented. Hence, there is a need to prioritise metacognition in PST education as part of domain specific methodology modules, which may counteract the limited time the PSTs perceive they have spent in metacognitively orientated environments in their own education, while also aligning with current second-level education reforms in Ireland which include the promotion of metacognition (See Chapter 1, Section 1.2). Given the literature on the importance of metacognition in learning, particularly in chemistry due to its abstract nature (As discussed in Chapter 2), my experience of embedding metacognition as the teacher in the senior cycle study and the teacher educator in the PST study indicates the value of PSTs experiencing metacognitive strategies as learners, while also having opportunities to plan, and practice implementing metacognitive strategies in a domain specific context.

The methodology module design developed in this work contributes to PST education by explicitly focusing on opportunities to incorporate metacognition in a domain specific way. Opportunities for PSTs to deepen their understanding of metacognition in the methodology module were provided through direct experience with metacognitive strategies, while their pedagogical knowledge in applying metacognition in chemistry was promoted through activities where they practiced, discussed, and planned how they would incorporate these strategies in teaching chemistry. The PSTs recognised that metacognition is effectively incorporated when interwoven with content, rather than as a separate theoretical topic. This approach resonates with the adaptations I made to the module design from AR Cycle 4 to AR Cycle 5, demonstrating the evolving design as part of the continuous AR spiral in my work.

This AR found that to effectively embed metacognitive strategies in the design of a methodology module, these strategies should be made explicit by discussing metacognitive aspects before, during, and after implementing or modelling the strategies in workshops. In terms of the focus of the methodology module design (AR cycle 5), I introduced a shift in focus at the halfway point, from the PSTs experiencing metacognitive strategies to the PSTs analysing, modelling, and planning these strategies. This transition aimed to empower PSTs to consider how metacognition might influence their future teaching practices, an aspect they recognised as valuable.

Module workshop activities which involved the generation, discussion, and refinement of representations of chemical phenomena, provided opportunities for PSTs to voice their cognitive processes, and reflect on the evolution and consolidation of their cognitive processes, and hence become more aware of their own metacognition in a chemistry context. PSTs can gain valuable experience by utilising the generation and refinement of representations to create opportunities for incorporating metacognition in a domain-specific manner.

The findings of the PST study reinforce the importance of creating a supportive and encouraging ‘metacognitive environment’, which was consistent with insights from earlier AR cycles. This approach supported a culture of metacognition, aligning with the aim of modelling this culture in the workshops. An important aspect of the metacognitive approach in the methodology module was providing a supportive and encouraging environment for PSTs to voice their cognitive processes in relation to chemical

phenomena at a particular point in time. This suggests that establishing such an environment is foundational for incorporating metacognition, both for PSTs and their future students.

11.2 A model for integrating metacognition into the teaching and learning of abstract chemical concepts

This AR included my experience addressing metacognition related to theoretical or abstract concepts in chemistry, particularly awareness and regulation of cognitive processes related to the submicroscopic level. Based on the findings of this AR, I developed a model for integrating metacognition in relation to the theoretical aspects of senior cycle chemistry and it is presented in Figure 11.1a. Based on the findings from my own experience as a teacher in AR cycles 1-3 and the PST data in AR Cycle 5, the top half of the model addresses the teachers own experience of the metacognitive strategies, while also the development of their understanding of both ‘Metacognition’ and ‘Teaching strategies and pedagogical knowledge’ which enables them to avail of opportunities to integrate metacognition in lessons. Metacognition is highly complex, and the challenge lies in incorporating it in a domain-specific manner. Since the teacher plays a central role in creating and fostering a metacognitive environment in their lessons, the ‘Metacognitive Lens’ at the core of the model represents how the teacher's prior experiences and understanding of metacognition shape their perspective. This lens influences how the teacher identifies, designs, and utilises opportunities to promote student metacognition in chemistry through the implementation of teaching and learning strategies. The bottom half of the model represents the student’s development of metacognition in chemistry through their experience of the metacognitive strategies. As discussed in Section 2.6, the metacognitive strategies identified in this research also address many other aspects of teaching and learning. However, this research provides evidence from my experience as an action researcher in taking a domain-specific approach to incorporating metacognition in chemistry, with the metacognitive use of these strategies being central to the model I propose.

The ‘metacognitive lens’ in Figure 11.1a can be further detailed into a triad of cornerstones, as part of incorporating metacognition when teaching or learning abstract chemistry concepts. I suggest the necessity to embed an awareness and regulation of the (i) voice of cognitive processes, (ii) evolution of cognitive processes and (iii)

consolidation of cognitive processes in a supportive and encouraging environment as represented in Figure 11.1b. These three cornerstones emerged throughout the implementation and findings of this AR, forming part of my journey as an action researcher, a teacher, and a teacher educator. A key aspect of the model I propose is that a student's metacognition related to abstract chemical concepts can be addressed by providing opportunities for them to increase their awareness and regulation of the voice, evolution and consolidation of their cognitive processes. This should be an iterative process, which offers students recurring opportunities to voice, evolve, and consolidate their cognitive processes related to an abstract chemical phenomenon as part of metacognitive strategies. The student can also learn to embed the awareness and regulation of this iterative process as part of going beyond purely cognitive processes, i.e. metacognition, while also promoting student agency. This triad also provides a framework for the incorporation of metacognition in PST education, where awareness and use of this model including the metacognitively encouraging and supportive environment is incorporated into PST methodology modules.

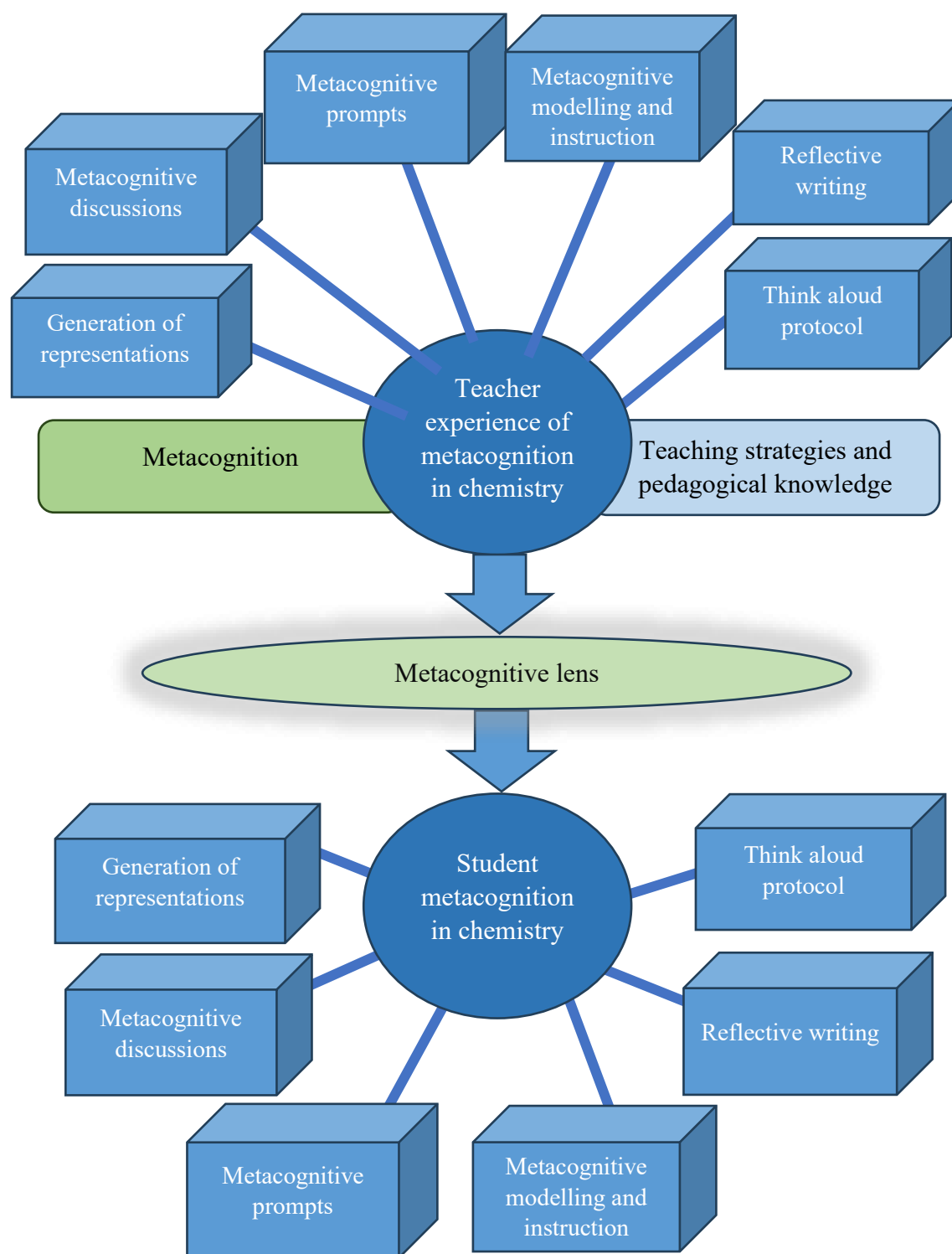


Figure 11.1a A model for integrating metacognition into the teaching and learning of abstract chemical concepts

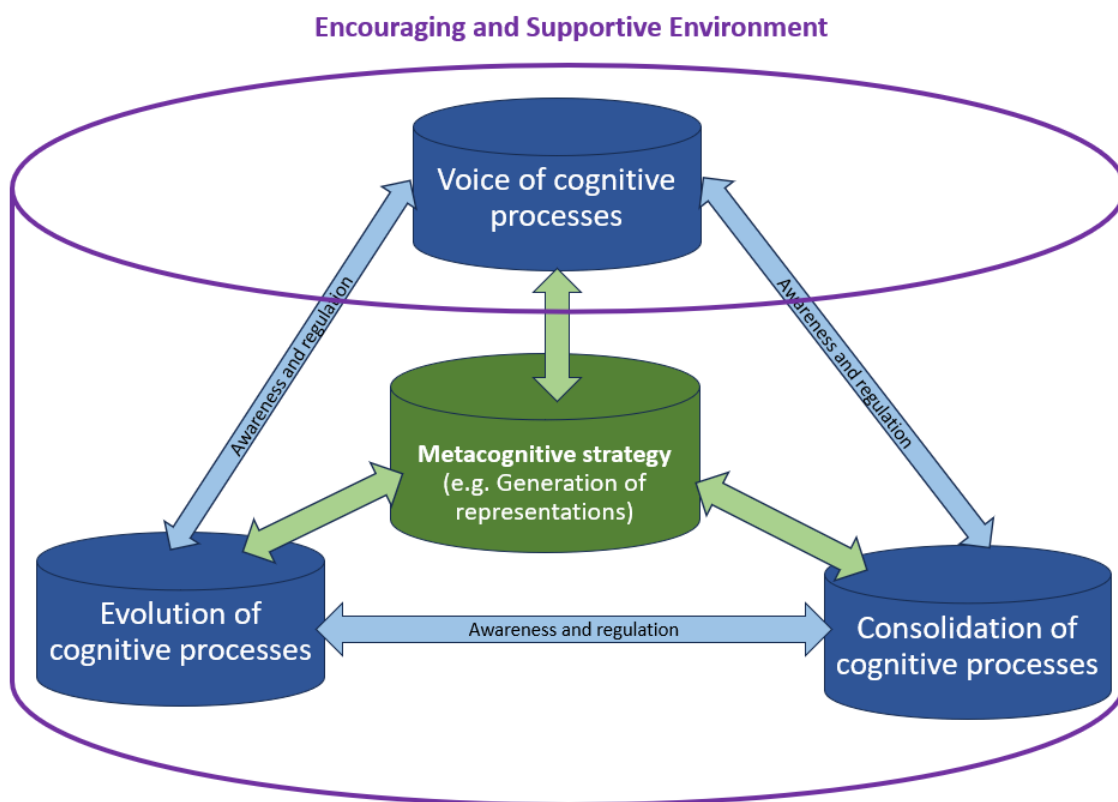


Figure 11.1b A metacognitive lens for the teaching and learning of abstract chemical concepts

11.3 Contributions to practice, theory and research

A number of contributions arise out of this AR. In terms of practice, I highlight the importance of teachers being intentional about providing opportunities for students to increase awareness of their cognitive processes and approach chemistry not just cognitively, but metacognitively. For example, I developed an appreciation for how the generation and refinement of representations can be used to provide opportunities to intentionally embed metacognitive discourse in chemistry lessons and PST workshops. I have also detailed my experience as an action researcher, including the challenges and opportunities encountered while embedding metacognition in chemistry education. For example, the need to have both experience of the metacognitive strategies from the point of view of the learner and the teacher to develop an appreciation of their value and implementation in a domain specific way. As such, my work underscores the necessity of embedding these metacognitive strategies into both pre-service and in-service teacher subject specific education programs. Ensuring that teachers have the understanding and experience necessary to use metacognitive strategies in domain-specific contexts may

help bridge the gap between theory and practice in relation to incorporating metacognition in second level teaching in Ireland.

The theoretical implications of this research highlight the need to expand existing models of metacognition to develop domain-specific interpretations and strategies to incorporate metacognition in meaningful domain specific ways. The continuous scholarly reflection in this AR formed the conceptual framework for metacognition in chemistry (see Section 6.6) and culminates in a model for chemistry teachers to incorporate metacognition by viewing teaching strategies through a metacognitive lens (Figure 11.1b). This model highlights the importance of the teacher's prior learning experience and understanding of metacognition in a domain-specific context, in addition to the metacognitive strategies they implement.

This thesis illuminates my journey as a researcher while incorporating metacognition in senior cycle and preservice teacher chemistry education and provides insights into how educators can incorporate metacognition in a domain specific way. These insights can encourage further exploration of the relationship between metacognition and subject-specific pedagogy, particularly in abstract disciplines such as chemistry. Additionally, my shift from a positivist to an interpretivist stance as an action researcher opens avenues for examining how researchers' epistemological and ontological beliefs influence the design, implementation, and interpretation of educational research.

11.4 Limitations

It should be noted that aspects of the limitations of this study were discussed throughout this research and embedded in the chapters for each AR cycle, related to the data collection, analysis and findings made. Additional limitations to note include the potential bias that may arise from creating a supportive environment in the lessons. For example, the students, PSTs, and I might have developed a bias in terms of having a positive disposition towards the strategies being implemented, which could have influenced how we answered questions and reflected on both the lessons/workshops and the metacognitive strategies.

It is important also to note that the data was analysed through my interpretation of metacognition in chemistry (see Chapter 6, Section 6.6), as well as my understanding of how the strategies were implemented in the lessons and workshops (e.g. see Chapter 5, Section 5.1.1.1.). While the research was overseen by supervisors and I presented my

research at various conferences and in publications, my interpretation was central, which raises potential concerns about the influence of a single perspective. Additionally, the students and PSTs participants in the AR cycles were not completing their chemistry courses in isolation; other subjects, modules, or external factors unrelated to their participation in this research may have contributed to changes in the participants' use and awareness of metacognition in chemistry.

11.5 Recommendations

The following recommendations emerge from the current research,

- Metacognition should be embedded into the new senior cycle subject specifications and pedagogy documentation. Due to its relevance to student learning, new curriculum documentation should include the domain specific pedagogy related to metacognition as part of the senior cycle reform. For example, this research presents the power of generating representations to incorporate metacognition in chemistry through descriptions and discussion of cognitive processes before, during, and after the generation of the representation.
- Metacognition is of particular importance in relation to senior cycle curriculum reform in Ireland (NCCA, 2022). Within the context of new curricula there are opportunities as part of the workshops for supporting the development of in-service teachers' understanding of metacognition and its incorporation into subject specific teaching and learning strategies. As part of this, the facilitators of the in-service education for teachers also require support in developing their understanding of metacognition and its incorporation in teaching and learning strategies. As discussed in relation to the model represented in Figure 11.1a, it was found in this research that for the teacher instructor to provide workshops on the implementation of metacognitive strategies they first require experience of the strategies from the learner's perspective and time to analyse the strategies.
- Teacher education programmes should include metacognition within their domain specific methodology modules. This research provides an example of how that can be done in the domain of chemistry. The emphasis should be on the incorporation of metacognition in a domain specific way and not only as part of theoretical education modules. Central to the preservice teacher education should be the importance of a culture of metacognition in the methodology module

workshops and the incorporation of this in senior cycle classrooms. Methodology modules in chemistry teaching should include both addressing the PSTs own metacognition through experiencing metacognitive strategies, and the PSTs pedagogical knowledge as part of planning and practicing how they would incorporate metacognition in their teaching.

11.5.2 Future research

This research opens up several avenues for future exploration, particularly in the integration of metacognition into domain-specific learning contexts like chemistry. Metacognition in chemistry could be further explored through the lens of ‘underlying concepts’ or ‘key ideas’ in chemistry, which may influence the structure of curricular documentation and the planning of schemes of work by chemistry teachers. Research opportunities also exist which explore the use of analogies and metaphors, which in themselves are mental constructs, as possible strategies for the incorporation of metacognition in chemistry. Opportunities for future research could explore the incorporation of metacognition specifically through experimental work in second-level chemistry in the Irish context, investigating how laboratory activities promote students' awareness of their cognitive processes.

Another promising direction is to examine how metacognitive strategies can be adapted and applied to other STEM disciplines, extending the domain-specific approach to fields like physics, biology, and mathematics. This could help establish a comprehensive understanding of how metacognition can be embedded across different subjects.

Further research could also explore the interplay between teachers' epistemological and ontological beliefs and their ability to effectively implement metacognitive strategies.

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Appendices

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Appendix A Example of PST study episode descriptive analysis (AR Cycle 5)

Week 1 Episode 2 Discussion Related to the MOLES-S Survey

Purpose:

To encourage the PSTs to think about their own thinking and learning and their experience of how thinking orientated their own experience in learning chemistry has been and how this in turn how this experience can be used to improve their own teaching.

Description

The PR asked the PSTs to reflect on when they were a student of chemistry, this was to focus the PSTs on putting themselves in the shoes of the students in their classes in the future.

“how often was I asked what I think in chemistry; or did I write it out what I asked my opinion in it was I asked how I did I solved that problem; did I think about how I solved that problem; or do you solve a problem by using trial and error without ever examining how you solve that problem” (Video 00000, T19.30-T19.45).

The PR asked the PST's *“What do you call the time after a question before you answer the question or you give this student a chance to answer the question”* and S3 answered *“wait time”* (Video 000000, T20.04-T20.07). The PR indicated the value of giving students the time to think as one of the most important things you can do in a chemistry classroom. *“That is one of the strongest things you can do [to provide an environment for students to think}, give students time to think, give them time to think. When you're about to ask a question, and I'm sure you do this in education modules, don't call their name until you give them all the time to think. Because what happens once you call their name, what do the other 23 do? S2 “stop thinking”* (Video 00000, T20.07-T20.14). Referred to in the PR reflection and how an emphasis was placed on allowing for time to think *“The PR asked the PSTs what is one of the most powerful things you can do with questioning to allow for thinking? After a delay one of the PSTs indicated ‘Wait time’. The PR emphasised the importance for wait time and the time at which you call a student s name when questioning play an important role in student thinking in the classroom”* (PR reflections workshop 1, pp. 1).

The PR introduced the questions from episode 2 as described in the plan such as how did they learn chemistry. (i) think about how they learn chemistry, (ii) think about their difficulties in learning chemistry, (iii) think about how they could become better learners of chemistry. (Activity sheet week 1 pp. 1) (See Figure W1E2-1- PowerPoint slide extract used in Workshop 1).

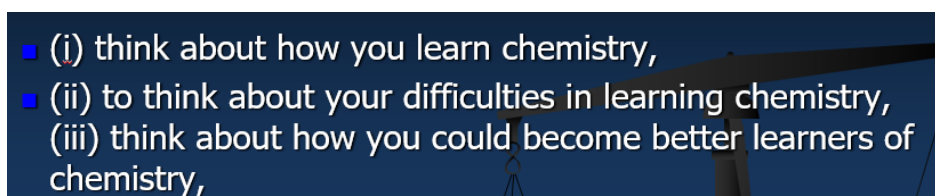


Figure W1E2-1- PowerPoint slide extract used in Workshop 1

The PR emphasised the importance of being very honest in their answers. The PR indicated that they would not have found their “learning legs or thinking legs or their chemistry legs

until after they had finished their undergraduate studies" (Video 00000, T21.28-R21.32). The importance of the PSTs being honest in relation to this was also confirmed in the PR workshop reflection "The PR emphasised there are no wrong answers, it is more about the learning process and the PSTs looking at themselves as learners (PR reflections workshop 1, pp. 2). The PR indicated this was because of the time that they had while they started teaching to look up materials and alternative descriptions to. The PR emphasised that these questions were about them as students of chemistry and that the module would move on to them as teachers of chemistry. The PR highlighted that they would be given 5 minutes to complete this and to be as rich as possible and that sometimes when you get extended time then it can lead to groups talking about things other than the task you intend as a teacher. "Try to think about it, [in relation to the questions] see what you write There's a week come along couple of questions back but try not to think in terms of you do "5 minutes how do you how do you become better learners now I don't expect you to come up with revolutionary ideas really what I'm doing is getting you to question the whole process it's not" (Video 00000 T23.00-T23.30).

Examining the PST's generated work examples After 5 minutes approx. (Actual, Video 000000, T24.40-32.53).

S12 indicated; *Videos for visual learning through experimentation. Rote learning. Memorising the content.*

(i) think about how they learn chemistry,

- videos for visual learning.
- learned through experimentation
- rote learning
- memorising the content

S1 indicated *learning off information started doing exam papers in fifth-year and learned off answers. Done calculations all the time but never understood what they meant. Done all the experiments plus calculations.*

(i) think about how they learn chemistry,

- learning off information
- Started doing exam papers in 5th yr, learnt off exam answers
- Done calculations all the time but never understood what they meant
- Done all the exps + calculations

S3 indicated *majority was memorization learning of definitions not fully understanding why/what relevance certain concepts have how they relate to everyday life applications*

(i) think about how they learn chemistry,

- Majority is memorisation, learning off definitions
- ~~possibly~~ not fully understanding why / what relevance certain concepts have
 - how do they relate to everyday life - applications

S2 indicated *mainly rote learning of definitions and topics. Lots of repetition of questions and topics. More brute force in learning topics and high workload. Supplemented with some experience. Worked for me but not for all students in the class.*

(i) think about how they learn chemistry,

- Mainly rote learning of definitions + topics
- lots of repetition of questions + topics
- More brute force in learning topics and high workload.
- Supplemented with some experiments.
- Worked for me but not for all students in the class.

S5 indicated *visual learner used videos. reading the book. Writing notes*

Part 1

(i) think about how they learn chemistry,

- Visual learner - videos
- Reading the book
- Writing notes

S4 indicated, *memory, note taking, study, Textbook. Textbook. Videos. Teacher called out individual students to read plus answer questions. Repetition*

(i) think about how they learn chemistry,

- Memory (note-taking, study)
- Textbook
- Videos
- Teacher called out individual students to read + answer Qs.
- Repetition

S10 indicated; *traditional classroom. Focused on memorization. Textbook read out in class. Experiments were hands on but the "Why" was never explained.*

(i) think about how they learn chemistry,

- Traditional classroom
- Focus on memorisation.
- Textbook read out in class.
- Experiments were hands on but the "why" was never explained.

S7 indicated a lot of learning of answers. Using exam papers as reference but resulted in just learning how to answer certain questions. Not much inquiry in the experiments just following steps.

(i) think about how they learn chemistry,

- a lot of learning off answers
- using exam papers as reference, but resulted in just learning off how to answer certain questions
- not much enquiry in experiments, just following steps

S9 indicated memorization of knowledge and methods. Repetition.

(i) think about how they learn chemistry,

- Memorisation of knowledge and methods
- Repetition

A recurring theme in the PST's generated answers about how they learn chemistry included a focus on repetition on memorization.

In relation to the PST's generated work on there are difficulties in learning chemistry;

S12 indicated; certain topics dash organic chemical reactions. Exam type questions applying all the knowledge content to answering questions.

(ii) to think about their difficulties in learning chemistry,

- certain topics - organic chemical reactions
- exam type questions - applying all the knowledge / content to answering questions

S1 indicated- never really understood the why of the chemistry we were studying. Bonding-no clue

(ii) to think about their difficulties in learning chemistry,

→ Never really understood the ~~the~~ "why" of the chemistry we were studying.

→ bonding - no clue

S3 indicated; many different concepts. many different experiments. remembering colour changes. Calculations.

(ii) to think about their difficulties in learning chemistry,

• many different concepts / many different experiments remembering colour changes / calculations

S2 indicated; difficulty in understanding concepts, especially the atom. More emphasis on material rather than understanding. Not enough real life examples.

(ii) to think about their difficulties in learning chemistry,

- Difficulty in understanding concepts (esp the atom)
- More emphasis on the material rather than the understanding
- Not enough real life examples.

S5 indicated; oxidation and reduction. Sections of Heats of reactions.

(ii) to think about their difficulties in learning chemistry,

- Oxidation + Reduction
- sections of heats of reactions

S4 indicated organic chemistry was very long and complicated, a lot of memorisation required. Class could be boring if the main focus was the textbook (Difficult to concentrate).

(ii) to think about their difficulties in learning chemistry,

- Organic Chemistry - very long and got complicated
 - A lot of memorisation require
- CLASS could be boring if the main focus was the textbook (difficult to concentrate).

S10 indicated the reasoning behind experiments was never explained. I would only learn the steps of Stoichiometry/oxidation reduction etc. I never understood what the calculations meant.

(ii) to think about their difficulties in learning chemistry,

- The reasoning behind the experiments. was never explained
- I would only learn steps of stoichiometry / oxidation reactions / etc. & never understood what the calculations meant.

S7 indicated difficulty to understand experiments, why we were carrying out certain steps. Organic chemistry reactions/ thermochemistry didn't understand why? Struggling with any inquiry questions or new questions I was unfamiliar with.

(ii) to think about their difficulties in learning chemistry,

- difficult to understand experiments, why we were carrying out certain steps
- organic chemistry reactions / thermochemistry didn't understand why?
- Struggled with any inquiry questions or new questions I was unfamiliar with

Some examples of how the PST responded to the question about how they think about how they could become better learners of chemistry.

S12 indicated *if I try to understand the topics instead of just learning them off.*

(iii) think about how they could become better learners of chemistry,

- if I tried to understand the topics instead of just learning them off

S1 indicated; *answer more in depth questions. Practice the calculations knowing what the numbers meant*

(iii) think about how they could become better learners of chemistry,

- Ask ^{more in depth} questions
- Practice the calculation
↳ knowing what the numbers meant

S3 indicated; *As a teacher-make concepts tie into everyday life relatable to students. Investigations inquiry based learning less teacher talk time. As a student- Aim to understand topics less and less emphasis on memorization or recall.*

(iii) think about how they could become better learners of chemistry,

As teacher/
• make concepts tie into everyday life
- relatable to students

• Investigations / IBL / less teacher talk time

As student/

• aim to understand topics / less emphasis on memorisation or recall

S2 indicated; using different teaching methods (videos, experiments). an open mind on learning. Try and visualise the concepts and use real life examples and where they are used.

(iii) think about how they could become better learners of chemistry,

- using different teaching methods (Videos, experiments)
- open mind on learning
- try and visualise the concepts and use real life examples and where they are used.

S4 indicated asking the teacher questions. Practising how to do exam questions. Watch videos using online resources.

(iii) think about how they could become better learners of chemistry,

• Asking the teacher questions
• Practicing how to do exam questions
• Watch videos, use online resources

S10 indicated we were never encouraged to learn in different or better ways. The teacher used A1 size fits all approaches.

(iii) think about how they could become better learners of chemistry,

• We were never encouraged to learn in different or better ways.
• The teacher used a "one size fits all" approach.

S7 indicated; more inquiry into topics and concepts. More questioning from the teacher. More in depth explanations/ use of examples/ demonstrations. Questioning on experiments/concepts.

(iii) think about how they could become better learners of chemistry,

- more inquiry into topics and concepts
- more questioning from teacher
- more in depth explanations / use of examples / demonstration
- Questioning on experiments concepts

The PST's were asked for their general feedback on the questions in a brainstorm session. S3 indicated that there was a focus on *"There was certainly an emphasis on memorization to get full marks, something that we picked up and something we were trained to do"* (S3, Video 0000-T33.10-T33.18). the PR asked whether that was something that they picked up themselves or something that they were taught to do. S3 indicated that it was *"something that they picked up and it was something they were trained to do, and that there was certainly an emphasis on exams in every chapter"* (S3, Video 0000, T33.20-33.32). PR asked "did that carry on in third level" S3 responded *"it was a bit more independent in third level, and we had Odilla and she was more open to a variety of different levels."* as 12 indicated that day to learn chemistry based on "memorisation, and similar to what S3 has said". S10 indicated their experience was similar to the first two PST who shared in that *"was a very traditional classroom the teacher read off the textbook the only variation they would get was that the students would be asked to read from the textbook"* (S10, Video 0000, 34.25-34.28). The PR probed S10 by asking what type of learner would benefit from that type of lesson. S10 responded with *"someone who can absorb All the information from the textbook"*. The PR indicated the issues with students who could have a high capability in chemistry but when they rely on the textbook if they have dyslexia, Einstein being an example, this can cause problems even though their understanding of chemistry could be quite good. S1 indicated *"Learning stuff off by heart repetition as well being asked to do exam papers over and over and over again but never fully comprehending the answers just learn it off and that's it"* (S1, Video 0000- 35.26-35.31). The PSTs responses were also noted in the PR weekly reflection and reference was made to the need to provide opportunities for thinking in chemistry rather than learning off text opens chemistry up to students *"The PR indicates that we could have kids who could be brilliant chemists but may fall through the cracks in this types of teaching because of additional needs like dyslexia."* (PR Reflection Week 1, pp.2).

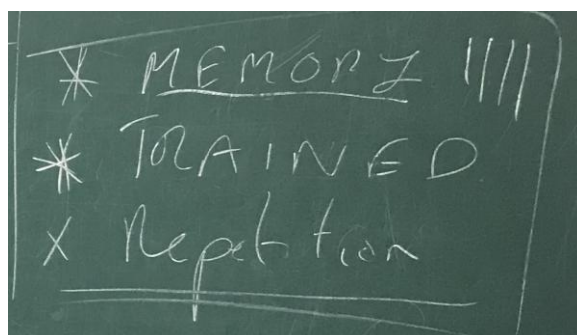


Figure W1E2-2 Extract from chalkboard during brainstorm where memory was indicated by five PSTs.

PR wishes to highlight that it is important to check once perception and indicate the positives and negatives. The PR asked for the positives of rote learning and memory by memorization that some students who have a good memory can recall information in chemistry. "I always try and check myself, in that I'd say oh what are the positives to that, so we have said some people who perhaps have a brilliant memory. When they have difficulty, if it is repetition, they come under pressure (PR, Video 000000, T35.30-36.00).

The PR then asked when would even that type of student find difficulties then they have learned of chemistry through repetition and memorization. "Getting A's in exams when they would have difficulty if they have learned through repetition" (Video 0000 35.45-35.50). S2 indicated "if the question is worded differently". PR indicated "the knowledge of chemistry it should be in a pliable thing I think you can bend to fit different situations, and to me English is the same we use words to communicate, but we must use them in a thoughtful way, but likewise in chemistry, it's a great subject to teach, because of the fact think about it,, if you can move away from the repetition you will make a difference student understanding in chemistry" if you are learning things off, if you are relying on memory, what are you doing." (Video 00000, 36.50-37.02) S1 "repetition" (Video 00000, T36.56-T37.06). "there's all types of memory, you can put things on the floor of your brain, then you can gradually move them back by repetition into the long term memory. Going back is very static and chemistry is not static and that is something we want to focus on in this module. (Video, 00000, T37.36-T37.42)" This episode's sequence was also outlined in the PR reflection on the workshop;

"The PR describes the necessity and the condition that chemistry knowledge needs to be flexible and durable such that students can deal with unseen questions and novel problems in chemistry. Small changes make a big difference. The PR outlines that this module is not just focusing on the results of the students the PST will teach but also the future chemists that they will have influence on. That the chemistry that they study on should be pliable" (PR Reflection Week 1, pp.2).

The principle of thinking and learning and asked the PSTs to brainstorm what they believe is the difference or no difference between thinking and learning. (Figure W1E2-1). "Is there a difference, and if there is a difference, what is that difference? ``And if they are the same, what makes them the same?" (Video 00000, T38.32- T38.36)

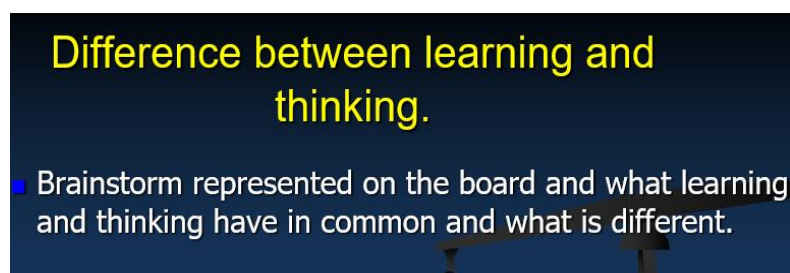


Figure W1E2-3- PowerPoint slide used in Workshop 1

The PR used an example of how they are aware of someone who is training to be a pilot and learns the language they need to use when talking to air traffic control. "learning to fly little little planes and they must learn how to speak to ATC, the air traffic control, all they do is repeat the sentences they use to talk to ATC, it's incredibly comfortable for them. Why is it comfortable? (PR, Video 00000, T38.55 – T39.30). S9 answered "it's the same thing over and

over " (Video 00000, 39.36-39.40). The same thing applies in this module where I ask you questions not to make you uncomfortable specifically rather to get you to think. And isn't that the job of us as teachers, the students are sitting in front of us comfortable then something is going wrong" (Video 00000, T39.34-T39.42)

The PRs weekly reflection confirms the aims of this passage of the episode.

"PR introduces the question of learning and thinking and comfort in a classroom. The PR gives the example of how they know some training to be a pilot and to learn the language to use with ATC they do when they get spare time in the e.g. while drive is that they repeat over and over the sentences that are used when talking to ATC, the PR indicates how this process is incredibly comfortable for them. The PR asks the PSTs why it is comfortable for them and PST 12 indicates "it's because they do not have to think ". PR outlined yes because it is the same thing over and over. The PR indicates that in these workshops, that when the PR asks a question that they are trying to put undue pressure on the PSTs, rather that is out job as teachers of chemistry to make sure that students are not thinking that are uncomfortable as explain" (PR Reflection Week 1, pp. 3).

They indicated the way they are learning it is through repetition and they indicated that the person finds the process of repetition comfortable. This was done to encourage the students to think about the principle of mental comfort in learning. the PR indicated that there is no wrong answer. S3 indicated that *"they are not the same thing, that you need a small amount of thinking to learn something and then once you have learned it you can build on it it's sort of like learning is the destination and thinking about it is how you get there"* (S3, Video 0000, T40.14-40.35). The PR indicated that this is the heart of what we want to address in this module. The PR highlighted that the PST's are *"teaching chemistry not skills, not a focus on how to use a pipette, they could train monkeys to use pipets. They have very little self-awareness; some might say they have some. but human beings that's what separates us as thoughtful beings. Kinda like those times when you say to yourself, oh I really don't understand this chemistry. I have an exam tomorrow so I'm gonna learn it off or something. That's survival right but what you should also do is acknowledge that's what you have done. And when you have the time to go back and do try and think about it. I cannot overemphasise the importance of time in chemistry"*(S3, Video 0000, T41.25-42.39). This dialogue was further explained in the PR weekly reflection on the workshop" The principles intended by the PR were also emphasised on the PRs reflection on the workshop. *"The PR highlights how the PSTs job will be teacher chemistry, not a focus on physical skills like using a pipette. An example used by the PR is how Monkeys can be taught to manipulate tools and they have much less self-awareness than human's beings. But as thoughtful beings. An example of how cognitive conflict can occur just before an exam and instead of trying to understand the chemistry the PSTs may have just learned it off. That's survival, but that it is important to recognize that is what you have done, that this is how you got the chemistry result and to go back and understand the chemistry when you have an opportunity"* (PR Reflection Week 1, pp. 3).

Interpretation Week 1 Episode 2

The PST's work in this episode indicated their experience of chemistry included repetition memorization doing calculations without understanding the concept behind the calculation or how the calculation is related to concepts. Answering exam papers came up several times tailoring answers for exam questions definitions is a word which was repeated in the

descriptions (see above). Module was to encourage the preservice teachers to think about their own thinking and learning and how their experience was in learning chemistry. The PSTs do seem to be aware of the impact of memorization and the pitfalls of repetition in relation to understanding chemistry. Evidence collected in this episode indicates that the PST did reflect on their own experience of learning chemistry and that of how they were taught chemistry. This module is about promoting a deeper level of thinking and awareness of thinking in chemistry. It was introduced here gradually so as to not overwhelm the PST's and bring them in with the module aims. The subject of thinking and eliciting thinking can be a difficult one to comprehend

Appendix B ‘Chemistry Metacognitive Journal’ Senior Cycle study (AR Cycles 1-3)

Extracts from the developed student metacognitive journal in the Senior Cycle study (AR Cycles 1-3)

Date _____
Topic _____

[illegible][illegible][illegible]

2

Section B Strategic Evaluation Matrix SEM Tasks

Strategy	How to Use	When to Use	Why to Use
Skim	Search for headings, highlighted words, previews, summaries	Prior to reading an extended text	Provides conceptual overview, helps to focus one's attention
Slow down	Stop, read, and think about information	When information seems especially important	Enhances focus of one's attention
Activate prior knowledge	Pause and think about what you already know. Ask what you don't know	Prior to reading or an unfamiliar task	Makes new information easier to learn and remember
Mental integration	Relate main ideas. Use these to construct a theme or conclusion.	When learning complex information or a deeper understanding is needed.	Reduces memory load. Promotes deeper level of understanding.
Diagrams	Identify main ideas, connect them, list supporting details under main ideas, connect supporting details	When there is a lot of interrelated factual info	Helps identify main ideas, organise them into categories. Reduces memory load.

Section B Strategic Evaluation Matrix SEM Tasks

Date _____ -

Article _____ -



(i) Skim

After skimming the article for 60 seconds I think the article is about

(ii) Activate prior knowledge

I already know the following about the topics in this article

(iii) Slow down

Now that I have read the article slowly I think the article is about

(iv) Mental integration

The theme of this article is

(v) Diagrams

Draw the main ideas in this article and connect them.

Section C Visualisation– representations of chemical phenomenon

Date _____ -

Concept _____ -



The way in which I visualise the chemical phenomenon/concept that was just discussed in class looks like (represent your thinking using sketches with notes)

Additional questions would like to know the answer to are;

.....

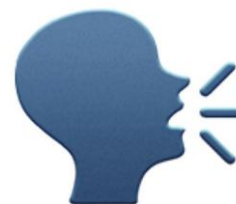
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Section D Regulatory Checklist (RC) for problem solving

Date _____ -

Problem solving Sheet _____ -

Write Brief sentence indicating that you addressed the following while completing the problem solving task



Planning - Before beginning problem solving task

1. What is the nature of the task?

2. What is my goal?

3. What kind of information and strategies do I need?

4. How much time and resources will I need?

Monitoring- During problem solving task

1. Do I have a clear understanding of what I am doing?

2. Does the task make sense?

3. Am I reaching my goals?

4. Do I need to make changes?

Evaluating- After problem solving task

1. Have I reached my goal?

2. What worked?

3. What didn't work?

4. Would I do things differently next time?

Appendix C Fifth-year study scheme of work (AR Cycle 3)

This scheme of work is based on activating knowledge when encountering chemical phenomena. This approach is to aid awareness and regulation of student thinking and constantly revisiting previous thinking thereby aiding the incorporation of metacognition.

States of Matter	
Approach to teaching and learning of topic An understanding of the states of matter is fundamental to chemistry as chemistry is the study of matter and how it changes. Why do things exist in the four states of matter? The principle of energy and matter and how they interact. Particle nature of matter and the movement of particles within matter. The principle of conservation of mass and how matter undergoes chemical and physical changes without loss in total mass.	
Chemical phenomena uncovered	Teaching and learning strategies which incorporate metacognition
Classification of the matter element, compound, mixture. Motion of particles in solids, liquids and gases. Diffusion States of matter at the molecular level Revision of JC chemical Bonding- covalent bonding Electrostatic attraction Electronegativity - Polarity - melting and boiling points Law of conservations of mass, introduction to balanced equations NH ₃ and HCl, ink and water, smoke and air.	Reflective writing Metacognitive prompts Regulatory Checklist (RC) Representations of thinking Metacognitive modelling by the teacher

Gas Laws		
Approach to teaching and learning of topic One of the really interesting states of matter are gases. Gases have interesting properties, and the fact that molecules in a gas are apart from each other most of the time makes them different to solids and liquids. The motion of the molecules that make up a gas is also an interesting aspect of them. We will look at laws that govern gases.		
Chemical phenomena uncovered	Tasks	Teaching and learning strategies which incorporate metacognition
Describing parameters gases, Temperature, pressure and volume (units: K Pa, m ³ ,). Standard temperature and pressure (s.t.p.). Molar volume at s.t.p., molar mass, relative molecular mass (Mr). Boyle's law. Charles's law. Gay-Lussac's law of combining volumes. Avogadro's law. Combined gas law The kinetic theory of gases (non-mathematical treatment): ideal gases; assumptions of kinetic theory. Equation of state for an ideal gas: $PV = nRT$ (units: Pa, m ³ , K). Reasons why gases deviate from ideal gas behaviour. Determination of the relative molecular mass of a volatile liquid (conical flask or gas syringe may be used). Converting moles to grams, litres and number of particles. Converting grams and litres to moles, Simple calculations, including correction of gas volumes to s.t.p. (units: Pa, cm ³ , K). Calculations involving $PV = nRT$ (units: Pa, m ³ , K).		Reflective writing Metacognitive prompts Representations of thinking Student think aloud protocol Metacognitive modelling by the teacher Metacognitive prompts Explicit metacognitive instruction Think aloud protocol. Representations of thinking Metacognitive prompts Representations of thinking

Atomic Structure	
Approach to teaching and learning of topic Further particle nature of matter. How to arrive at our understanding of matter at the moment we must recognise the scientists who achieved milestone discoveries. Understanding the nature of atoms and the characteristics of the subatomic particles. What holds electrons in their locations, principle of electrostatic forces in atoms. Masses of different elements, and how atoms of the same element can have different masses. What subatomic particle has a big influence on mass without changing elements. What are ions, why would an atom have a charge, what must have happened to the atom to give it a charge.	
Chemical phenomena uncovered.	Teaching and learning strategies which incorporate metacognition
Matter is composed of particles, which may be atoms, molecules or ions. Atoms. Minute size of atoms. Properties of electrons, protons and neutrons (relative mass, relative charge, location within atom). Very brief outline of the historical development of atomic theory : Dalton: atomic theory; Crookes: vacuum tubes, cathode rays; Stoney: naming of the electron; Thomson: negative charge of the electron; e/m for electrons (experimental details not required); Millikan: magnitude of charge of electrons as shown by oil drop experiment (experimental details not required); Rutherford: discovery of the nucleus as shown by the α-particle scattering experiment; discovery of protons in nuclei of various atoms; Bohr: model of the atom; Chadwick: discovery of the neutron. Atomic number (Z), mass number (A), isotopes; hydrogen and carbon as examples of isotopes. Relative atomic mass (A_r). The ^{12}C scale for relative atomic masses Use of the mass spectrometer in determining relative atomic mass. Calculation of approximate relative atomic masses from abundance of isotopes of given mass number (e.g., calculation of approximate relative atomic mass of chlorine). Fundamental processes that occur in a mass spectrometer: vaporisation of substance, production of positive ions, acceleration, separation, detection (mathematical treatment excluded)	Regulatory Checklist (RC) Representations of thinking Think aloud protocol. Metacognitive prompts Student think aloud protocol Regulatory Checklist (RC) Explicit metacognitive instruction Metacognitive modelling by the teacher Teacher led metacognitive discussion. Reflective writing

Ionic Bonding	
Approach to teaching and learning of topic. After there has been a transfer of electrons the ions have a reaction the resulting ions (anion and cation) stay together. The principle of the attraction that exists between oppositely charged ions is discussed and developed. This should be attainable for students by reflection on what they have already understood of chemical formulas, oxidation numbers and electrostatic attraction. Properties of ionic compounds will be examined, and students will be encouraged to explain the properties based on the properties of ions.	
Chemical phenomena uncovered	Teaching and learning strategies which incorporate metacognition
Positive and negative ions. Minute size of ions. Ionic bonding as electron transfer. Sodium chloride crystal structure. Characteristics of ionic substances. Tests for anions in aqueous solutions: chloride, carbonate, nitrate, sulphate, phosphate, sulphite, hydrogencarbonate. Representation of ionic bonds using dot and cross diagrams. Examination of a model of the NaCl crystal. Ionic materials in everyday life (two uses, e.g. salt tablets to replace salt lost by sweating).	Metacognitive modelling by the teacher Metacognitive prompts Metacognitive modelling by the student Student think aloud protocol Explicit metacognitive instruction Metacognitive modelling by the teacher Teacher led metacognitive discussion. Reflective writing Student think aloud protocol

Covalent Bonding	
Approach to teaching and learning of topic. The students will examine simple covalent bonding using Bohr model diagrams initially. Before moving on to look at simple sigma and pi bonding. The sloshing of electrons within molecules will be examined and the principal of intermolecular bonding and how it affects such things as reactivity, solubility, boiling point, melting point of molecular compounds.	
Chemical phenomena uncovered.	Teaching and learning strategies which incorporate metacognition
Molecules. Minute size of molecules. Covalent bonding as the sharing of pairs of electrons. Single, double and triple covalent bonds. Distinction between sigma and pi bonding. Polar and non-polar covalent bonding. Intermolecular forces: van der Waals', dipole-dipole, hydrogen bonding. Distinction between intramolecular bonding and intermolecular forces. Effect of the intermolecular forces on the boiling point of a covalent substance. Characteristics of covalent substances. Representation of covalent bonds using dot and cross diagrams. Polarity test for liquids (use of charged plastic rod). Testing solubility in different solvents of ionic and covalent substances. Polar and non-polar materials in everyday life Comparison of the boiling points of H_2 and O_2 , of C_2H_4 and $HCHO$, and of H_2O and H_2S .	Representations of thinking Think aloud protocol. Metacognitive modelling by the student Metacognitive prompts Regulatory Checklist (RC) Representations of thinking Explicit metacognitive instruction Metacognitive modelling by the teacher Teacher led metacognitive discussion. Student think aloud protocol Reflective writing

Chemical Compounds	
Approach to teaching and learning of topic The language of chemistry with symbols etc can be seen to many students as relatively confusing. We must work on seeing how the system of symbols for elements makes chemistry easier to understand and quicker. We must use the periodic table to write all kinds of formulas and understand why the chemical formulas make sense from a stability and charge point of view. What increases the stability of atoms and how can atoms of different elements increase the stability of each other.	
Chemical phenomena uncovered.	Teaching and learning strategies which incorporate metacognition
Compounds. Simple chemical formulas.	Metacognitive prompts
Stability of noble gas electron configurations.	Metacognitive modelling by the student
Bonding and valency in terms of the attainment of a stable electronic structure. Octet rule and its limitations.	Representations of thinking
Using the octet rule to predict the formulas of simple compounds – binary compounds of the first 36 elements (excluding d-block elements) and the hydroxides, carbonates, nitrates, hydrogencarbonates, sulphites and sulphates of these elements (where such exist).	Metacognitive modelling by the teacher
Use of oxidation numbers in nomenclature of transition metal compounds.	Student think aloud protocol
Variable valency of transition elements (Cu, Fe, Cr and Mn only).	Teacher led metacognitive discussion.
Uses of helium and argon related to their chemical unreactivity.	Reflective writing
	Explicit metacognitive instruction

Chemical Equations	
Approach to Teaching and learning of topic Some simple chemical reactions will be demonstrated, and students will be asked to form chemical equations based on what they see before and after reactions. Building up to an understanding of a chemical equation represents equal mass on both sides but different chemicals. Hence a chemical change has taken place. How can we be sure we do not break the law of conservation of mass.	
Chemical phenomena uncovered.	Teaching and learning strategies which incorporate metacognition
Law of conservation of mass. Chemical equations. Balancing chemical equations. Calculations based on balanced equations using the mole concept (balanced equations will be given for all calculations). Percentage yields. Calculations in g and kg rather than tonnes. Calculations involving masses and volumes. Calculations involving excess of one reactant. Calculation of percentage yields.	Representations of thinking Metacognitive prompts Metacognitive modelling by the teacher Regulatory Checklist (RC) Teacher led metacognitive discussion. Explicit metacognitive instruction Student think aloud protocol Reflective writing

Oxidation and reduction		
Approach to Teaching and learning of topic Transfer of electrons between atoms. Why does it occur, principle around stability. If there is loss of electrons another species is causing that loss and it itself must be gaining electrons. The ability to predict oxidation numbers will allow students to work with many oxidation and reduction reactions. A skill they will learn by using their knowledge of atomic radius, ionisation energies, they will be able to move to writing the chemical formulas of compounds. They will then be able to use this knowledge to investigate if a reaction is a redox reaction or not using chemical equations and oxidation numbers.		
Chemical phenomena uncovered	Tasks	Teaching and learning strategies which incorporate metacognition
Oxidation and reduction through electronegativity Oxidation states and numbers. exclude peroxides, except for hydrogen peroxide. Oxidation and reduction in terms of oxidation numbers. Balancing redox equations (ionic equations only – ignore spectator ions). Calculation of oxidation numbers of transition metals (in their compounds). Bleach as an example of oxidising agents (e.g. NaOCl) or reducing agents (e.g. SO ₂).		Representations of thinking Strategic evaluation matrix (SEM) Metacognitive modelling by the teacher Teacher led metacognitive discussion. Reflective writing Student think aloud protocol Metacognitive prompts Explicit metacognitive instruction Regulatory Checklist (RC)

Acids and Bases	
Approach to Teaching and learning of topic Why are substances classified as acids and bases? (LC Chemistry – mostly uses Bronsted Lowry theory of acids and bases some history on Arrhenius theory). Why would one species be more prone to being an acid or a base than another. Using the students' knowledge of electronegativity, they will look at why some substances tend to be acidic, some basic and some neither. The contrast where oxidations and reduction is the transfer of electrons, acids and bases involves the transfer of protons (H^+). How if one species is acting as acid another species is acting as a base.	
Chemical phenomena uncovered	Teaching and learning strategies which incorporate metacognition
Acidic, basic (alkaline) substances and electronegativity Neutralisation – formation of a salt from an acid and a base. Arrhenius and Brønsted-Lowry theories of acids and bases (for aqueous solutions only). Conjugate acid-base pairs. Household acids and bases. Everyday examples of neutralisation, e.g. use of lime in agriculture, use of stomach powders for acid indigestion.	Representations of thinking Explicit metacognitive instruction Metacognitive modelling by the teacher Teacher led metacognitive discussion Strategic evaluation matrix (SEM) Student think aloud protocol Regulatory Checklist (RC) Reflective writing Metacognitive prompts

The Mole	
Approach to Teaching and learning of topic When we talk about matter it is fundamental that we have a way of describing the number of atoms ions molecules in chemistry. We already use quantities such as a dozen to describe the amount of something to make life easier. We have a quantity known as mole to describe the amounts of atoms, ions or molecules in chemistry.	
Chemical phenomena uncovered.	Teaching and learning strategies which incorporate metacognition
Avogadro constant. The mole is the SI unit for the amount of substance containing the Avogadro number of particles. Calculation of relative molecular mass from relative atomic masses. Converting moles to grams, number of particles. M_r determination using a mass spectrometer (simple treatment only – interpretation of mass spectra not required). Converting grams to moles, and number of particles to moles. Converting moles to the number of atoms of a molecular species.	Explicit metacognitive instruction Reflective writing Metacognitive prompts Representations of thinking Student think aloud protocol Metacognitive modelling by the teacher Teacher led metacognitive discussion Reflective writing Strategic evaluation matrix (SEM) Metacognitive prompts Regulatory Checklist (RC)

Concentration of Solutions (Time needed: 8 class periods)	
Approach to Teaching and learning of topic. How the concentrations of solutions are described in everyday life. Why is it important to use moles per litre in chemistry, molecules and atoms ions react. Students will revisit moles, and this will lead into moles per litre for solutions. The principles of how to dilute solutions will be examined, and why dilute solutions when working with chemicals.	
Chemical phenomena uncovered.	Teaching and learning strategies which incorporate metacognition
Solutions. Expression of solution concentration in mol l ⁻¹ (molarity), g l ⁻¹ and also in % (w/v), % (v/v), % (w/w). Colour intensity as a function of concentration (simple treatment only). Primary standards. Standard solutions. Calculation of molarity from concentration in grams per litre and vice versa. Calculation of number of moles from molarity and volume. Simple calculations involving percentage concentrations. Use of % (v/v), e.g. wine. Calculation of the effect of dilution on concentration. Mandatory experiment Preparation of a standard solution of sodium carbonate.	Reflective writing Metacognitive prompts Explicit metacognitive instruction Representations of thinking Student think aloud protocol Metacognitive modelling by the teacher Teacher led metacognitive discussion. Regulatory Checklist (RC)

Volumetric Analysis Acids and bases	
Approach to Teaching and learning of topic Students become more familiar with the difference between volumetric analysis and gravimetric analysis as used in chemistry. Students become more familiar with the level of accuracy involved in using the instruments in volumetric analysis. The application and use of reactions which describe acid base reactions. The linking of concentration of solutions and mass dissolved will be examined further. How to use the known concentrations of solutions to find the unknown concentration of solutions.	
Chemical phenomena uncovered.	Teaching and learning strategies which incorporate metacognition
Apparatus used in volumetric analysis. Correct titrimetric procedure. Acid-base titrations. Solving volumetric problems from first principles, where the formula method is not applicable. (Either method may be used when both methods are applicable.) Calculation of the relative molecular mass of a compound and of the amount of water of crystallisation in a compound from titration data. (Balanced equations will be given in all volumetric problems.) Solving volumetric problems, using the formula method. Mandatory Experiment Standardisation of a hydrochloric acid solution using a standard solution of sodium carbonate. Mandatory Experiment Determination of the concentration of ethanoic acid in vinegar. Mandatory Experiment Determination of the amount of water of crystallisation in hydrated sodium carbonate.	Metacognitive prompts Representations of thinking Regulatory Checklist (RC) Metacognitive modelling by the teacher Teacher led metacognitive discussion. Reflective writing Explicit metacognitive instruction Student think aloud protocol

Reaction Rates	
Approach to Teaching and learning of topic. How do we measure the rate of a reaction? What are looking for a change in. Students come up with procedures for measuring rates of reactions in the laboratory. Looking at different rates of reactions in everyday life. Why is it important to know the rate of a reaction?	
Chemical phenomena uncovered.	Teaching and learning strategies which incorporate metacognition
Rate of reaction. Distinction between average and instantaneous rate. Plotting and simple interpretation of reaction rate graphs. Calculation of instantaneous rate from graphs. Mandatory Experiment Monitoring the rate of production of oxygen from hydrogen peroxide, using manganese dioxide as a catalyst.	Representations of thinking Metacognitive modelling by the teacher Explicit metacognitive instruction Teacher led metacognitive discussion. Reflective writing Regulatory Checklist (RC) Student think aloud protocol Metacognitive prompts

Factors Affecting Rates of Reaction	
Approach to Teaching and learning of topic Why are some reactions faster than others? Students will come up with ideas on why some reactions are faster than others. Examining the rates of reactions at the sub-micro level and what factors influence the rate of a reaction.	
Chemical phenomena uncovered.	Teaching and learning strategies which incorporate metacognition
Factors Affecting Rates of Reaction, Concentration. Particle size. Temperature. Nature of reactants. Catalysts. Activation energy and influence of temperature on the rate of reaction, using reaction profile diagrams. Surface adsorption and intermediate formation theories of catalysis; the effect of catalysts on activation energy Studying the effects on the reaction rate of (i) concentration and (ii) temperature, using sodium thiosulfate solution and hydrochloric acid. Demonstration of the oxidation of potassium sodium tartrate by hydrogen peroxide, catalysed by cobalt(II) salts. Demonstration of the effects on reaction rate of (i) particle size (ii) catalysts. Dust explosions. Enzymes as catalysts produced by living cells Catalytic converters: (i) nature of catalysts (ii) reactions catalysed (iii) environmental benefits. Catalyst poisons. Demonstration of the oxidation of methanol using a hot platinum or nichrome catalyst.	Reflective writing Metacognitive prompts Explicit metacognitive instruction Representations of thinking Metacognitive modelling by the teacher Teacher led metacognitive discussion. Reflective writing Regulatory Checklist (RC) Metacognitive prompts Student think aloud protocol Metacognitive modelling by the teacher Strategic evaluation matrix (SEM)

Periodic table	
Approach to Teaching and learning of topic Classifying elements will allow us to move through all of our study of chemistry with having to research each element's characteristics each time we interact with it. Classifying elements is a positive approach to using what is already known about elements to do new things. By first attempting to classify the elements themselves students will then look at the history of classifying elements up to the modern periodic table.	
Chemical phenomena uncovered.	Teaching and learning strategies which incorporate metacognition
Elements. Symbols of elements 1–36. The periodic table is a list of elements arranged so as to demonstrate trends in their physical and chemical properties. Brief statement of the principal resemblances of elements within each main group, in particular alkali metals, alkaline earth metals, halogens and noble gases. Electronegativity. Periodic variation of electronegativity – explanation for general trends in values: (i) down a group (ii) across a period. History of the periodic table, including the contributions of Dobereiner, Newlands, Mendeleev and Moseley. Comparison of Mendeleev's table with the modern periodic table. Arranging elements in order of relative atomic mass; note differences compared with the modern periodic table. Demonstration of the reaction with water of lithium, sodium and potassium. History of the idea of elements, including the contributions of the Greeks, Boyle, Davy and Moseley.	Metacognitive prompts Representations of thinking Metacognitive modelling by the teacher Teacher led metacognitive discussion. Reflective writing Metacognitive prompts Explicit metacognitive instruction Metacognitive modelling by the teacher Student think aloud protocol Strategic evaluation matrix (SEM)

Electronic Structure of Atoms	
Approach to teaching and learning of topic Up until now we will have used the Bohr model to explain the chemistry. Now we must look at how electrons are arranged within an atom before we go on to use this information to explain bonding, forces that exist within molecules, between molecules, melting points, boiling points, acids and bases, oxidation and reduction. A lot of chemistry will involve messing with bonds. And because bonds are made up of electrons we must first look at how electrons arrange in the atom, before we can then discuss how electrons are arranged in bonds.	
Chemical phenomena uncovered.	Teaching and learning strategies which incorporate metacognition
Energy levels in atoms. Organisation of particles in atoms of elements nos. 1–20 (numbers of electrons in each main energy level). Classification of the first twenty elements in the periodic table on the basis of the number of outer electrons. Emission and absorption spectra of the hydrogen atom – Balmer series in the emission spectrum as an example. Line spectra as evidence for energy levels. Energy sub-levels. Heisenberg uncertainty principle. Wave nature of the electron. (Non-mathematical treatment in both cases.) Atomic orbitals. Shapes of s and p orbitals. Building up the electronic structure of the first 36 elements. Electronic configurations of ions of s- and p-block elements only. Arrangement of electrons in individual orbitals of p-block atoms. Atomic absorption spectrometry Analysis of heavy metals in water, e.g., lead, cadmium. (AAS). Sodium street lights, fireworks. Mandatory experiment Flame tests (Li, Na, K, Ba, Sr and Cu only). Viewing of emission spectra of elements using a spectroscope or a spectrometer.	Reflective writing Metacognitive prompts Regulatory Checklist (RC) Representations of thinking Metacognitive modelling by the teacher Teacher led metacognitive discussion. Reflective writing Metacognitive prompts Explicit metacognitive instruction Metacognitive prompts

Atomic radius and ionisation energy (Time needed: 6 class periods)	
Approach to teaching and learning of topic How can we measure the atomic radius of an atom while taking the Heisenberg uncertainty principle into account? What affects an atom's atomic radius, how does the atomic radius change between elements. Electrons are on the surface of the things we touch, the molecules we walk through every day because they are fundamentally made up of atoms which have electrons on their surface. How difficult is it to remove electrons from the surface of atoms? What affects the difficulty in removing successive electrons from an atom. What effects remove electrons from atoms of different elements?	
Chemical phenomena uncovered.	Teaching and learning strategies which incorporate metacognition
Atomic radii (covalent radii only). Explanations for general trends in values: (i) down a group (ii) across a period (covalent radii of main group elements only). First ionisation energies. Explanations for general trends in values: (i) down a group (ii) across a period (main group elements) and for exceptions to the general trends across a period. Second and successive ionisation energies. Evidence for energy levels provided by successive ionisation energy values. Dependence of chemical properties of elements on their electronic structure. Explanations in terms of atomic radius, screening effect and nuclear charge for general trends in properties of elements in groups I and VII. Mandatory experiment; Redox reactions of group VII elements – halogens as oxidising agents (reactions with bromides, iodides, Fe^{2+} and sulphites). Demonstration of the reaction with water of lithium, sodium and potassium.	Reflective writing Metacognitive prompts Representations of thinking Teacher led metacognitive discussion. Student think aloud protocol Regulatory Checklist (RC) Reflective writing Explicit metacognitive instruction Metacognitive modelling by the teacher

Shapes of Molecules	
Approach to teaching and learning of topic A revision to the structural formula of compounds and this will then lead into how atoms are arranged around a central atom in simple molecules. What determines the arrangement of atoms around a central atom. How do lone pairs and bonding pairs interact around a central atom?	
Chemical phenomena uncovered.	Teaching and learning strategies which incorporate metacognition
Shapes of some simple molecules. Using electron pair repulsion theory to explain shapes of molecules of type AB _n for up to four pairs of electrons around the central atom (refer to bond angles). (Shapes of molecules with pi bonds are not to be considered.) Relationship between symmetry and polarity in a molecule (dipole moments not required). Use of models or balloons to illustrate molecular shapes.	Reflective writing Metacognitive prompts Representations of thinking Metacognitive modelling by the teacher Teacher led metacognitive discussion. Student think aloud protocol Explicit metacognitive instruction

Structure of Aliphatic Hydrocarbons	
Approach to Teaching and learning of topic Introducing a wide range of organic compounds and why there is a need for a classification system. Revision of molecular and empirical formulas. Similarities draw to the classification of living things. Introducing the alkanes alkenes and alkynes, including the physical and chemical properties. Links made back to electronegativity, and stability.	
Chemical phenomena uncovered.	Teaching and learning strategies which incorporate metacognition
Alkanes, alkenes and alkynes as homologous series. For alkynes, only ethyne to be considered. Systematic names, structural formulas and structural isomers of alkanes to C-5. Structures, but not isomers, of hexane, heptane, octane, cyclohexane and 2,2,4-trimethylpentane (iso-octane) to be considered. Systematic names, structural formulas and structural isomers of alkenes to C-4. Alkenes: non-polar double bond. Structure and nomenclature up to C-4. Planar Carbon Physical properties [physical state, solubility (qualitative only) in water and in non-polar solvents]. Use of models. Use in making plastics. Use of models Demonstration of the solubility properties of methane, ethene and ethyne.	Reflective writing Metacognitive prompts Representations of thinking Teacher led metacognitive discussion. Reflective writing Explicit metacognitive instruction Metacognitive prompts Metacognitive modelling by the teacher Student think aloud protocol

Exothermic and Endothermic Reactions	
Approach to Teaching and learning of topic Examination of bond energy and the different types of bonds. Taking a look at explaining why different bonds would have different bond energies. Examining how to represent the changes in chemical energy as a reaction proceeds. Why do some chemicals react with each other at certain temperatures? Developing the principles of activation energy and heat changes during reactions. The law of conservation of matter and the law of conservation of mass will be examined with the view of improving a students overall understanding of a chemical reaction.	
Chemical phenomena uncovered.	Teaching and learning strategies which incorporate metacognition
Chemical reactions can result in a change in temperature. Exothermic and endothermic reactions (and changes of state). Combustion of alkanes and other hydrocarbons. Heat of reaction (general term). Sign of ΔH. Bond energy. Heat of combustion. Bomb calorimeter as an instrument for accurately measuring heats of combustion. Heats of combustion of different fuels. Heat of formation. Law of conservation of energy. Hess's law. Simple calculations of heat of reaction, using heats of formation of reactants and products. Simple calculations of heat of formation, using other heats of formation and one heat of reaction. (Other kinds of heat of reaction calculation are not required.) Demonstration of an exothermic and an endothermic reaction. Determination of the heat of reaction of hydrochloric acid with sodium hydroxide. Illustrating bond energies by showing how the C–H bond energy in methane is calculated. Use of the bomb calorimeter in determining calorific values of foods. Kilogram calorific values of fuels, and their uses (calculations not required).	Reflective writing Metacognitive prompts Representations of thinking Metacognitive modelling by the teacher Teacher led metacognitive discussion. Reflective writing Metacognitive prompts Explicit metacognitive instruction Metacognitive modelling by the teacher

Appendix D Interview post- teaching placement questions (AR Cycle 5)

1. What was your teaching placement like, what subjects were you teaching.
2. What sort of skills did you emphasise?
 1. In week 10 you indicated that chemistry can be stripped back to key concept, electronegativity. Can you give examples of what you mean by this?
 2. You indicated in workshop then the importance of using different ways of visualisation to paint a clearer picture by switching between the symbolic, submicroscopic and macroscopic levels.
 3. You indicated in workshop 10 that you would exclude questions like a calculation on a titration instead as them what happen in the titration. Why was this one of the take away messages for you?
 4. You indicated in a workshop in the module that talking out loud and explaining as one of the best ways of indicating student thinking. Why do you think this is the case? Can you give an example from you teaching placement?
 5. You also indicated visualisation as an example of a method which gives the teacher an idea of student knowledge. Can you give an example of how you used this on teaching placement?
 6. What is metacognition in chemistry teaching and learning. If you did, can you give an example of how you used the work on metacognition from the module on your teaching placement?
 7. What impact, if any, did the module have on your teaching while on teaching placement? Can you give specific examples.

Appendix E Research ethics forms

Ollscoil Chathair Bhaile Átha Cliath
Dublin City University



Mr James Trimble
School of Chemical Science

14th January 2019

REC Reference: DCUREC/2018/234

Proposal Title: Questioning strategies to promote and assess, cognition metacognition and conceptual understanding in chemistry: An analysis

Applicant(s): Mr James Trimble, Dr Odilla Finlayson, Dr James Lovatt

Dear Colleagues,

Further to expedited review, the DCU Research Ethics Committee approves this research proposal.

Materials used to recruit participants should note that ethical approval for this project has been obtained from the Dublin City University Research Ethics Committee.

Should substantial modifications to the research protocol be required at a later stage, a further amendment submission should be made to the REC.

Yours sincerely,

A handwritten signature in blue ink that reads 'Dónal O'Gorman'.

Dr Dónal O'Gorman
Chairperson
DCU Research Ethics Committee



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Ollscoil Chathair Bhaile Átha Cliath,
Baile Átha Cliath, Éire

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Mr. James Trimble
School of Chemical Sciences

Dr. Odilla Finlayson
School of Chemical Sciences

Dr. James Lovatt
School of STEM Education, Innovation & Global Studies

15th July 2020

REC Reference: DCUREC/2020/144

Proposal Title: Teaching and Learning strategies to promote and assess, cognition, metacognition and conceptual understanding in chemistry: An analysis

Applicant(s): Mr. James Trimble, Dr. Odilla Finlayson and Dr. James Lovatt

Dear Colleagues,

Further to expedited review, the DCU Research Ethics Committee approves this research proposal.

Materials used to recruit participants should note that ethical approval for this project has been obtained from the Dublin City University Research Ethics Committee.

Should substantial modifications to the research protocol be required at a later stage, a further amendment submission should be made to the REC.

Yours sincerely,



Dr Geraldine Scanlon
Chairperson
DCU Research Ethics Committee



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From: rec dcu
Sent: Monday 9 August 2021 08:49
To: James Trimble
Cc: Odilla Finlayson; James Lovatt
Subject: Re: Extension Request DCUREC/2020/144

Dear James,

Thank you for submitting the amendment for your research project DCUREC/2020/144 . I can confirm that the REC vice-chair has completed their review and issued approval for the amendment and all associated documentation. Please accept this email as formal approval.

Wishing you the very best for your research.

Kind regards

Adam Platt (on behalf of REC)

Riarthóir Coiste Eitice um Thaighde | DCU Research Ethics Committee Administrator
Tacaíocht Taighde & Núálaíochta | Ollscoil Chathair Bhaile Átha Cliath
Research and Innovation Support | Dublin City University

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Campas Ghlas Naíon | BÁC 9

Research and Innovation Support | Invent Building | Dublin City University | Glasnevin Campus
| Dublin 9



Informed Consent - For Parent(s)/Guardians (Senior cycle study)

Title of Research Study

Questioning strategies to promote and assess cognition, metacognition, and conceptual understanding in chemistry: An analysis.

Principal investigator

James Trimble

Contact details.

Laboratory Room X158, School of Chemical Sciences, DCU Glasnevin Campus, Dublin 9, Ireland.

Email james.trimble2@mail.dcu.ie

Phone 01 7005375

Supervisors of the research

Dr Odilla Finlayson (School of Chemical Sciences DCU) odilla.finlayson@dcu.ie

Dr James Lovatt (STEM Education, Innovation & Global Studies) james.lovatt@dcu.ie

Clarification of the purpose of the research

This study involves examining the normal practice occurring in a second level chemistry classroom for evidence of cognition, metacognition and conceptual understanding prompted through use of various types of teacher-student, student-teacher, and student-student questioning, dialogue and investigations.

Parent – please complete the following (Circle Yes or No for each question)

My son's participation in this project is voluntary. I understand that my son will not be paid for his participation. My son may withdraw and discontinue his participation at any time without giving a reason. If my son declines to participate or withdraw from the study, his data will not be used as part of this research, and his withdrawal will be kept confidential.	Yes / No
I understand an audiotape will be used during data collection and a transcription of dialogue may be made. I understand my son's dialogue may be used as part of this research and included in a thesis.	Yes / No
I consent to a general videotape being made of lessons in which my son is present, and I understand notes may be made of the video recording and it may be used as part of a thesis by the principal investigator, James Trimble.	Yes / No
I give consent to my son's participation in surveys which will assess his approach to learning, cognition and metacognition and conceptual understanding in chemistry.	Yes / No
I understand that the researcher will not identify my son or his school by name in any way and the data collected will be used only for the purposes of this research project. I understand that my son's confidentiality as a participant in this study will be protected.	Yes / No
I understand all primary data collected will be kept confidential, and it will be stored in a secure file accessible to the principal investigator and supervisors only. I understand only the principal investigator, James Trimble, will have access to the key used to anonymise participants. I understand all primary data will be destroyed within five years of completion of the research.	Yes / No
I understand only the principal investigator and other students (classmates) will be present in data collection and only the principal investigator will have access to raw notes or transcripts or survey material. I understand I will have access to an online copy of the completed research.	Yes / No

Continued overleaf

I am willing to consent to my sons' participation in focus group discussions during the data collection period.	Yes / No
I consent to my son's normal generated classroom work which is generated during the data collection period being used as part of this research. I understand his name will be anonymised.	Yes / No
I have read and understand the plain language statement provided to me. I have had all my questions answered to my satisfaction.	Yes / No
I have been given a copy of this consent form and the plain language statement, and I am aware of the data controller contact details and have researched my rights under GDPR legislation.	Yes / No

Signature:

I have read and understood the information in this form and the plain language statement for the research. My questions and concerns have been answered by the researchers, and I have a copy of this consent form. Therefore, I consent to my son taking part in this research project

Parent(s)/Guardian(s) Signature: _____

Name in Block Capitals: _____

Witness: _____

Date: _____

For further information, please contact: James Trimble

Phone: 01 7005375

Email james.trimble2@mail.dcu.ie

Personal Data – GDPR Compliance

Data Controller Dublin City University

DCU Data Protection Officer – Mr. Martin Ward (data.protection@dcu.ie Ph: 7005118/7008257)

Confidentiality of information provided is subject to legal limitations

Participants should be aware that confidentiality of information provided cannot always be guaranteed by researchers and can only be protected within the limitations of the law - i.e., it is possible for data to be subject to subpoena, freedom of information claim or mandated reporting by some professions.

If participants have concerns about this study and wish to contact an independent person, please contact:

The Secretary, Dublin City University Research Ethics Committee, c/o Research and Innovation Support, Dublin City University, Dublin 9. Tel 01-7008000, e-mail rec@dcu.ie

Informed Assent - For student participant (Senior cycle study)

Title of Research Study

Questioning strategies to promote and assess, cognition, metacognition, and conceptual understanding in chemistry: An analysis

Principal investigator

James Trimble

Contact details

Laboratory Room X158, School of Chemical Sciences, DCU Glasnevin Campus, Dublin 9, Ireland.

Email james.trimble2@mail.dcu.ie

Phone 01 7005375

Supervisors of the research

Dr Odilla Finlayson (School of Chemical Sciences DCU) odilla.finlayson@dcu.ie

Dr James Lovatt (STEM Education, Innovation & Global Studies) james.lovatt@dcu.ie

Clarification of the purpose of the research

This study involves examining the normal practice occurring in a second level chemistry classroom for evidence of cognition, metacognition and conceptual understanding prompted through use of various types of teacher-student, student-teacher, and student-student questioning, dialogue and investigations.

Participant – please complete the following (Circle Yes or No for each question)

I understand my participation in this project is voluntary. I understand that I will not be paid for my participation. I may withdraw and discontinue his participation at any time without giving a reason. I understand that If I decline to participate or withdraw from the study, my data will not be used as part of this research, and his withdrawal will be kept confidential.	Yes/ No
I understand an audiotape will be used in the data collection period and a transcription of dialogue will be made. I understand my dialogue may be used as part of this research, and included in a thesis.	Yes / No
I consent to a general videotape being made of lessons in which I am present, and I understand notes may be made of the video recording and it may be used as part of a thesis by the principal investigator, James Trimble.	Yes / No
I consent to participation in surveys which will assess his approach to learning, cognition and metacognition and conceptual understanding in chemistry.	Yes / No
I understand that the researcher will not identify me or my school by name in any way and the data collected will be used only for the purposes of this research. I understand that my confidentiality as a participant in this study will be protected.	Yes / No
I understand all primary data collected will be kept confidential, and it will be stored in a secure file accessible to the principal investigator and supervisors only. I understand only the principal investigator, James Trimble, will have access to the key used to anonymise participants. I understand all primary data will be destroyed within five years of completion of the thesis.	Yes / No
Only the principal investigator and other students (classmates) will present data collection and only the principal investigator will have access to raw notes or transcripts or survey material. I understand I will have access to an online copy of the completed thesis.	Yes / No

Continued overleaf

I am willing to volunteer to participate in a focus group as part of this study	Yes / No
I consent to my normal generated classroom work which is generated during the data collection period being used as part of this research. I understand my name will be anonymised.	Yes / No
I have read and understand the plain language statement provided to me. I have had all my questions answered to my satisfaction.	Yes / No
I have been given a copy of this consent form and the plain language statement, and I am aware of the data controller contact details and have researched my rights under GDPR legislation.	Yes / No

Signature:

I have read and understood the information in this form and the plain language statement for this research. My questions and concerns have been answered by the researchers, and I have a copy of this consent form. Therefore, I consent to take part in this research project

Participants Signature: _____

Name in Block Capitals: _____

Witness: _____

Date: _____

For further information, please contact: James Trimble

Phone: 01 7005375

Email james.trimble2@mail.dcu.ie

Personal Data – GDPR Compliance

Data Controller Dublin City University

DCU Data Protection Officer – Mr. Martin Ward (data.protection@dcu.ie Ph: 7005118/7008257)

Confidentiality of information provided is subject to legal limitations

Participants should be aware that confidentiality of information provided cannot always be guaranteed by researchers and can only be protected within the limitations of the law - i.e., it is possible for data to be subject to subpoena, freedom of information claim or mandated reporting by some professions.

If participants have concerns about this study and wish to contact an independent person, please contact:

The Secretary, Dublin City University Research Ethics Committee, c/o Research and Innovation Support, Dublin City University, Dublin 9. Tel 01-7008000, e-mail rec@dcu.ie

Plain language statement (Preservice chemistry teacher study)

Title of Study

An analysis of teaching and learning strategies which promote and assess cognition, metacognition and conceptual understanding in chemistry, and to establish the extent to which these principles influence each other in second level chemistry education.

Introduction to the Research Study

Principal investigator

James Trimble

Contact details

Laboratory Room X158, School of Chemical Sciences, Lonsdale Building, DCU
Glasnevin Campus, Dublin 9, Ireland.

Email james.trimble2@mail.dcu.ie

Supervisors of the research

Dr Odilla Finlayson (School of Chemical Sciences DCU) odilla.finlayson@dcu.ie

Dr James Lovatt (School of Education, DCU) james.lovatt@dcu.ie

Dr. Mary Pryce (School of Chemical Sciences) mary.pryce@dcu.ie

About the Study

This study involves examining the normal practice occurring in an undergraduate chemistry module Teaching and Assessing Leaving certificate chemistry (CS422) for evidence of cognition, metacognition and conceptual understanding prompted through use of various teaching and learning strategies. Each lesson will be based on normal concepts from the Leaving Certificate chemistry course and conceptual understanding will be improved through the use of investigations. By participating in this research, you will be contributing to the research as a sample of students which is being carried out as part of PhD in The School of Chemical Sciences Dublin City University by James Trimble. The supervisors for this research project are Dr Odilla Finlayson, Associate Professor in Science Education in the School of Chemical Sciences at Dublin City University, Dr James Lovatt, Associate Professor in Science Education at Dublin City University. Dr. Mary Pryce Associate Professor in Inorganic Chemistry in the School of Chemical Sciences at Dublin City University.

This research project is focused on the use of various teaching and learning strategies as part of normal practice in an undergraduate chemical education module in third level education in Ireland. More specifically it focuses on how the use of various types of teaching and learning strategies can be used to facilitate higher levels of cognition and metacognition chemistry. Cognition is defined as the process of acquiring knowledge and understanding through thought, experience, and the senses. Metacognition is often defined as how one thinks about or reflects on one's own thinking. In addition this research aims to analyse the role of various teaching and learning strategies such as metacognitive prompts and inquiry based learning, in achieving the conceptual understanding outlined in the Leaving Certificate chemistry syllabus. The data collection will focus on monitoring normal practice which is already occurring in the classroom. The strategies of teaching, learning used during the data collection period are well established in the literature and are part of normal best practice.

Participant involvement, data collection and storage

Any student participating in this research can be assured of their names being anonymised and any data collected will be used only as part of this research. In addition, while there is a possibility that a participant's understanding in chemistry may not be improved, a participant's understanding will not be adversely affected by having their data used as part of this research. Your involvement in this research study may contribute to improvements in the field of chemical education in the future. Any participant can withdraw having their data used as part of this study at any time without giving a reason.

The data collected in this study will consist of audiotaping of one lesson (2 hours in length) per week as part of the data collection period. A general video recording of the whole classroom will be made of each lesson. This video will be made from the centre of the classroom at the back pointed front and centre. The main aim of the general video will focus on the teacher's demeanour and positioning in the classroom. Participants will also be asked to complete a short survey before and after the eight weeks of data collection. This survey will assess each participant's approach to learning, cognition and metacognition and conceptual understanding in chemistry before and after the data collection period. Participants may volunteer for an interview/focus group following the completion of the module. Participants may decline or withdraw from having their data used as part of this study at any time without giving a reason.

Any data collected will be stored electronically in a password protected file and in the case of any hard copy material in a locked filing cabinet, accessible only to the principal investigator, James Trimble. All primary material will be destroyed upon completion of the thesis. An electronic version of the final thesis will be made available to all participants in research. All names will immediately be anonymised, and letters coded by the principal investigator. All reasonable measures will be taken to ensure the privacy of all participants in this study.

If you are willing to assist in this research, please fill out the attached consent form. If there are any questions surrounding the research, please do not hesitate to contact me.

Kind Regards,

James Trimble

Phone 01 7005375

Email: james.trimble@mail.dcu.ie

Personal Data – GDPR Compliance

Data Controller Odilla Finlayson

DCU Data Protection Officer – Mr. Martin Ward (data.protection@dcu.ie Ph: 7005118/7008257)

Confidentiality of information provided is subject to legal limitations

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If participants have concerns about this study and wish to contact an independent person, please contact:

The Secretary, Dublin City University Research Ethics Committee, c/o Research and Innovation Support, Dublin City University, Dublin 9. Tel 01-7008000, e-mail rec@dcu.ie

Informed Consent Form- (Preservice teacher study) For those who wish to participate.

Title of Research Study

An analysis of teaching and learning strategies which promote and assess cognition, metacognition, and conceptual understanding in chemistry, and to establish the extent to which these principles influence each other in second level chemistry education.

Principal investigator

James Trimble

Contact details

Laboratory Room X158, School of Chemical Sciences, DCU Glasnevin Campus, Dublin 9, Ireland.

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Supervisors of the research

Dr Odilla Finlayson (School of Chemical Sciences DCU) odilla.finlayson@dcu.ie

Dr James Lovatt (School of Education, DCU) james.lovatt@dcu.ie

Dr. Mary Pryce (School of Chemical Sciences) mary.pryce@dcu.ie

Clarification of the purpose of the research

This study involves examining the normal best practice occurring in a third level chemistry education classroom for evidence of cognition, metacognition and conceptual understanding prompted through use of various types of teaching and learning strategies.

Participant – please complete the following (Circle Yes or No for each question)

My participation in this project is voluntary. I understand that I will not be paid for my participation. I may withdraw and discontinue participation at any time without giving a reason. If I decline to participate or withdraw from the study, my data will not be used as part of this research, and my withdrawal will be kept confidential.	Yes / No
I understand an audiotape will be used in the data collection period and a transcription of dialogue will be made. I understand my dialogue may be used as part of this research and included in the thesis.	Yes / No
I consent to a general videotape being made of lessons in which I am present, and I understand notes may be made of the video recording and it may be used as part of a thesis by the principal investigator.	Yes / No
I am willing to participate in surveys which will assess my approach to learning, cognition and metacognition and conceptual understanding in chemistry before and after the twelve-week data collection period.	Yes / No
I understand that the researcher will not identify me or my university by name in any way and the data collected will be used only for the purposes of this research project. I understand that my confidentiality as a participant in this study will be protected.	Yes / No
I understand all primary data collected will be kept confidential, and it will be stored in a secure file. I understand all primary data will be destroyed upon completion of the thesis.	Yes / No
Only the principal investigator and other students will be present during data collection and only the principal investigator will have access to raw notes or transcripts or survey material. I understand I will have access to a copy of the completed thesis.	Yes / No

Declaration and signature require overleaf

I have read and understand the plain language statement provided to me. I have had all my questions answered to my satisfaction.	Yes / No
I have been given a copy of this consent form and the plain language statement, and I am aware of the data controller contact details and have researched my rights under GDPR legislation.	Yes / No

Signature:

I have read and understood the information in this form and the plain language statement for the research. My questions and concerns have been answered by the researchers, and I have a copy of this consent form. Therefore, I consent to take part in this research project.

Participants Signature: _____

Name in Block Capitals: _____

Witness: _____

Date: _____

For further information, please contact: James Trimble

Phone: 0876349717

Email james.trimble@mail.dcu.ie

Personal Data – GDPR Compliance

Data Controller Odilla Finlayson

DCU Data Protection Officer – Mr. Martin Ward (data.protection@dcu.ie Ph: 7005118/7008257)

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If participants have concerns about this study and wish to contact an independent person, please contact:

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Appendix F Analysis of the use of metacognitive strategies in Senior Cycle Chemistry lessons (AR Cycles 1-3)

Visual and Audio Analysis of the use of Metacognitive Teaching and learning strategies.		
Category Name	Description of Behaviour	Examples
Metacognitive prompts	Teacher provides metacognitive cues, questions or checklists that are used during activities.	<i>You know you are meant to be challenged and be a bit uncomfortable, even confused in class. You can't just write this stuff out; you need to think about it in your head. Never think you're alone when you can't understand these things. Think about a possible way you could do this, it's about thinking (PR).</i> <i>How are you visualising a double bond? Has the way you visualise it changed after today's discussion about p orbitals? Is there anything about a double bond you are still not clear on? (PR).</i> <i>Please don't sit there and do nothing, think about what I just said, you've never seen this before, why would I expect you to get this right. Just draw something based on your thinking at this moment, what you think it might look like, there's always a reason for what you draw when you are thinking, so you shouldn't dismiss your own thinking at this point, it came from somewhere (PR).</i>
Reflective writing	Teacher asks students to write diaries or journals about their thinking and learning, reflective essays, or written responses to reflective prompts. Teacher asks students to write about their thinking and learning.	<i>At the start of every lesson, not just for this but for every class, to clue yourself in, you should always ask yourself what you already know about the topic. In your journals write a few sentences about what you already know about the topic of balancing equations.....and if you would do it in your head in every class then automatically, that would be our goal. Whether what you write is right or wrong it's about thinking about what you already know (PR).</i> <i>This will help you look back at an exam, and how you prepared for the exam. This is a test wrapper. We fill this in after an exam. This is almost more important than the answers that you filled in. This will help you identify your thinking and strategies beforehand and during and look at the exam and your successes (PR).</i>

Teacher led metacognitive discussions	Teacher engages in a whole class and group discussions of thinking and learning processes, discussions in which teachers talk with their students about their thinking and learning in order to encourage and develop metacognitive thinking.	<i>There's no problem like what you've done is perfect. You know, I ask why, why he they do it right? Yeah. what you've done is perfect. I just want to be able to do it. You know why I asked you BTd, I don't want you to have to study and after this lesson, in great detail. You know, I sometimes think of learning chemistry like dropping breadcrumbs..... that if you don't leave a few breadcrumbs about your thinking, for example what you used to solve the problem, and you might still get the answer after doing the question 20 times. If you don't understand how your thinking got you from point A to point B, then you might just be repeating a procedure in your short-term memory without overly thinking about it in quick succession. What other subject does this sometimes happen in your experience?</i> Maths (BTD) <i>Yeah, what happens in maths if you do 20 of the same type of question. What happens after the second or third question? (PR)</i> <i>You just look back at how you did the last question (DHE)</i> <i>Yeah, what are you just doing? (PR)</i> Remembering (DGD) <i>Exactly. What we want to be able to do is both be aware of the thinking strategies we use in chemistry, to understand, or to solve, and also be able to select from various strategies we use (PR).</i>
Explicit Metacognitive instruction	Teacher uses explanations and demonstrations regarding specific cognitive or metacognitive strategies and knowledge construction activities which require students to construct their metacognitive knowledge.	<i>Metacognition is a bit like Hansel and Gretel and the breadcrumbs, in chemistry you must know how you get to the answer as well as the answer. It should be more than just getting the answer, it's about thinking about what your thought processes were while you were reaching your answer, how you could have altered the thought processes and be aware of other thought processes that could have been used. A nice way to do this is to think aloud so others can hear our thinking (PR).</i> <i>Metacognition is like watching your thinking when trying to understand a concept, being aware of it and how you make decisions to change your thinking. It is intentionally looking at how we are thinking about chemistry, before, during and after looking at a concept or problem. When we find a problem difficult, for example we are looking at electron orbitals which is a change to the Bohr model, we ask ourselves is there another way of thinking about this, perhaps if we try to visualise the chemistry, where are the electrons, what way are they moving, where are they likely to be (PR).</i>

Student representations	Teacher uses (or asks students to use) visual representations in order to help students represent and share their thinking and learning. Teacher uses (or asks students to use) a representation to present their knowledge in relation to a chemical phenomenon.	<i>Based on the representations you already created, how you visualise polar substances and non-polar substances as a solid, liquid and gas at the submicroscopic level (PR).</i> <i>Are you okay? (Directed at a student who isn't drawing) It doesn't have to be perfect, draw what you think, or how you visualise the bonds. Don't put the pressure on yourself for it to be absolutely right, build up to your final diagram, add bits in when you think of them, it's about what you think based on what you already know in chemistry, show it in your representation (PR).</i>
Teacher Metacognitive modelling	Teacher refers to activities in which the teacher demonstrates how he/she activates and applies metacognitive knowledge and metacognitive regulation in the course of learning, in order to model these practices for the students.	<i>I never went down that road of learning things off. What I want to demonstrate here is, I don't have some serious memory, I know I have to understand it, I know I have to connect it to some underlying concept in my mind. And that's where I would like to get you guys as well. But it doesn't mean that you use the same thinking processes as me. You need to figure out the ways that work for you. If someone asked me how I got to this point here, well I always thought that if I am calling it a base, then it must be a base. Whether it is a conjugate or not, go in this direction, because I will teach you later about that (equilibrium) because the reaction can go in the backward direction. What will it be doing if it goes from Cl- to HCL, what would it be doing? (PR).</i> <i>Acting as a base. (Student BGN)</i> <i>It's as simple as that. Now that might seem like a long way around, I guarantee you, in chemistry, because the content is short, the long way around is the best way around because it means you rely very little on your memory (PR).</i> <i>When you ask me a question in class, I always take a second to establish the answer in my own mind, as I do not have prepared lines to draw on, I realise I must give myself a chance to think and evaluate what I am going to answer with, I think about what I know which is relevant, what way I think about it, before I respond. The questions you ask are very interesting at times, and some cannot think of the answer to the post (PR).</i>

Student ‘think aloud protocol’	Students are asked to self-report the cognitive and metacognitive processes being used to complete a task	<i>Do you want to draw the first one on the board, it doesn't have to be right, you can draw whatever one you like (student that was struggling earlier and only had one done) That's great you didn't take out a book, doesn't have to be perfect in the theoretical sense, just describe you thinking so you are aware, and the class is aware of your thinking (PR).</i> <i>As you are drawing your representation of how you visualise the water of crystallisation, describe your thinking for the student next to you as you draw your diagram (PR).</i> <i>So I tried to separate it out into an acid first. Just to get everything laid out, the acid is 0.01 moles per litre, and we know the molarity of that and you're 25cm³ and that was 22.8cm³ and we know that this was 3.55 grams then I wanted to go and get the value of that. So, I used $V_a \times M_a$ over n_a is equal to $V_b \times M_b$ over n_b {KQN writes figures into formula on board} (Student KQN)</i> <i>Where did you get those figures and what do you think they mean? (PR)</i> <i>So, the volume of the acid and then molarity of the acid from the question and I got this as the number of moles from the equation. So, there is the volume and there is the number of moles there. And to get rid of this and multiply everything by two, because both sides are equal. So, these cancel, then I get 2.5 is equal to M_b. I get M_b is equal to 0.05 moles per litre so that's the sodium carbonate we changed that to grams per litre so when you add the molecular mass up on the periodic table it's equal to 106 grams for 1 mole. So, I thought about the amount of base, and I don't have 1 mole. I have 0.5moles so 0.05 multiplied by 106 so that gives you 5.3 grams per litre so that's how much base it is and that's how much I think reacted with the acid. That's the way I think about it. I think about what I really got and that it was done in a 500cm³ volumetric flask. So, if you times up original mass of 3.55 by two you get 7.1 grams per litre so then to get the H₂O of crystallisation you do that minus 5.3 grams and you get 1.8 grams per litre which is the H₂O and then basically after that then divided by 7.1 and then times it by 100 and you get 25%” (KQN, Think aloud protocol)</i>

(adapted from Zohar & Barzilai 2013; Brown & Palincsar & Armbruster 1984; Tishman, Perkins & Jay 1995; Veenman et al., 2006; Zohar & Ben-David, 2008)

Appendix G Analysis of events which addressed metacognitive awareness in Senior Cycle Chemistry lessons (AR Cycles 1-3)

Indicators of Dialogue/Strategies for Metacognitive Awareness		
Category Name	Description of Behaviour	
Declarative knowledge	Teacher or student refers to understanding, or the student's understanding of thinking and knowing in general. Teacher refers to knowledge of their (or students) skills, intellectual resources, and abilities as a learner.	<i>I don't know if there are any exceptions made in the modern periodic table (Student, BGN).</i> <i>I don't understand how to calculate the water of crystallisation (student DGD).</i> <i>I think of it as I think about the equals sign in mathematics, I think of it as a balance between the two side of the [chemical] equation (DJC)</i> <i>I like drawing it out, that's the way I think about it anyway (KQN)</i>
	Teacher or student examines (or asks students to examine) their capabilities, strengths and weaknesses, or academic/task preferences; comparative judgments about their own abilities; knowledge of a given topic.	<i>I knew of molecules, I am good at thinking about that, but didn't know how to use them in a different equation. (Student FRK)</i> <i>What are you still unsure about in relation to what we did today, record it in your journal (PR).</i> <i>Is there anything you still don't get about polar and non-polar bonds, if you don't want to say it write it in the journal now (PR).</i>
	Teacher or student analyses (or asks students to analyse) their knowledge or current understanding of a topic.	<i>So you must be very self-aware about these things. If I was in your position and the 10% I did not study came up in the test, I would be delighted then. Because that basically means of the 90% that I studied and then the other 10% I learned from this test (PR).</i>

Category Name	Description of Behaviour	
Procedural Knowledge	Teacher or student applies (or asks students to apply) knowledge for the purposes of completing a procedure or process. Teacher discusses (or asks students to discuss) Knowledge about how to implement learning procedures (e.g., strategies). Teacher or student refers to (or asks students to refer to) their own or asks students for their expression of their long term memory knowledge in relation to elements of the task Teacher or student reflects (or asks students to reflect) on the nature of the task at hand, including the difficulty level of the task and the similarities and differences between the current task and other tasks. Teacher or student compares (or asks students to compare) across tasks identifying similarities and differences. Teacher makes a judgement (or asks students to make a judgement) about the level of difficulty of cognitive tasks or rates the tasks on the basis of pre-established criteria or previous knowledge	<i>There is a huge amount of chemistry in what we did today, to get your head around. But it's not like when this class is over, we will never revisit this, do you understand (PR).</i> <i>What about this question here men, it looks way, way, way, more complicated than it is (PR).</i> <i>I learned how to use the formula $PV=nRT$ and how to do the experiment correctly. I also learned more about the stoichiometry steps involved in the calculation and what they mean. (Student FJT)</i> <i>I know how to calculate the molarity of acids and bases from titration results and to use the ratio of acid to base from the chemical equation (Student LKN).</i> <i>There is an amount of self-awareness about a test as well, this is important. There is an amount of self-awareness. You need to ask yourself; How did I study for this test, what strategies did I use? Am I engaging enough in class, what am I actually doing when in class, am I thinking about chemistry at the molecular level? And what I achieve in this test that's what it's about (PR).</i> <i>You need to imagine different things in chemistry. That's why I ask to draw things, because otherwise you're just learning words. Words that maybe if you change the order of the words, they mean something completely different. Knowing to apply a procedure to learning, like drawing out the chemistry, gives you space to think about what you know (PR).</i>

Conditional Knowledge	Teacher or student refers to (or asks students to refer to) knowing the “why” and “when” aspects of cognition. Teacher or teacher asks students to determine under what circumstances specific processes or skills should transfer. Teacher or student discuss when and why to use learning procedures. Teacher or student demonstrates (or asks students to demonstrate) the explicit expression of one's own knowledge in relation to strategies used or performed during a cognitive task, where a strategy is cognitive or behavioural activity that is employed so as to enhance performance or achieve a goal. Teacher or student defines, explains, (or asks a student to define, explain) how she/he has done or learned something. Teacher or student explains (or asks students to explain) procedures involved in a particular task.	<i>Don't get caught in the numbers, and not think about what you are doing, never do that. {ask} What am I doing? Mass of one proton is 1.67×10^{-27}. The only reason I give you that number is men. Is, you know, sometimes if we don't talk about grams the whole thing can get very abstract or something. Like it is a mass, it's just an incredibly small mass (PR).</i> Student ‘think aloud protocol’ in lessons. <i>The solutions were easier to find if I lean on a picture in my head rather than just numbers (Student FRK)</i> <i>I know how I came up with that answer after I drew it out (Student QUN).</i> <i>I suppose the traditional way would be, that you would come in and dilute it twice because it is too strong and then just move on. But because we dwell on it for a few minutes, there are three or four different experiments where we dilute solutions before titrations. Do you know why? (PR).</i> <i>This bit was missing for me. I could never understand why we weren't visualising chemistry when I was in school. you know the way we concentrate on what's going on and we try to picture it in our heads. Like for me that's the only way I could have learned chemistry and I think it is the only way you can learn chemistry. Because otherwise you are just learning off an essay about chemistry (PR).</i> <i>When do you think you would use an electron cloud representation? Why would you use it, what chemistry would you be trying to represent? (PR).</i>

(Adapted from Whitebread et al., 2009)

Appendix H Analysis of events which addressed metacognitive regulation in Senior Cycle Chemistry lessons (AR Cycles 1-3)

Indicators of Dialogue/Strategies for Metacognitive regulation		
Category Name	Description of Behaviour	
Planning	Teacher or student decides (or asks students to decide) on procedures necessary for performing the task, individually or with others.	<i>what I would prefer is if you try it yourself. Try not to use the book. You can use the book if you wish. I guarantee you; you have it in you. And it's about being challenged. And then we can fix the challenge (PR).</i>
	Teacher sets or clarifies (or asks students to set or clarify) task demands and expectations.	<i>I know how the number of atoms is calculated from moles grams and litres; I need to be able to use the ratio from the equation. (Student FRK).</i>
	Teacher (allocates or asks students to allocate) individual roles and negotiates responsibilities.	<i>I need to find out how many moles are in 250cm³ (Student DGD)</i>
	Teacher sets (or asks students to set) goals and targets.	<i>Represent what you already know about chemical equilibrium, use whatever type of drawing you like, include notes to explain your thinking (PR).</i>
	Teacher decides (or asks students to decide) on ways of proceeding with the task.	<i>This is a challenging sheet now, don't get overwhelmed, just think, you don't have to write much in chemistry (PR).</i>
	Teacher seeks (or asks students to seek) and collect necessary resources	

Monitoring	Teacher or student assesses (or encourages students to assess) the quality of task performance (of self or others) and the degree to which performance is progressing towards a desired goal. Teacher (or teacher asks students) to review progress on task (keeping track of procedures currently being undertaken and those that have been done so far) Teacher rates (or teacher asks students to rate) effort on-task or rates actual performance. Teacher rates (or teacher asks students to rate) makes comments on current memory retrieval. Teacher checks (or encourages students to check) their behaviours or performance, including detection of errors Self-corrects	<i>Try not to use the book. You can use the book if you wish. I guarantee you; you have it in you to think about these things in chemistry and find a solution. And it's about being challenged in your thinking. And then we can fix the challenge the penny will drop but you must bear with it, you must challenge yourself, think about it, try a different way about thinking about it before looking up the answer in the book or elsewhere (PR).</i> <i>I know I am not going to solve it by staring at the numbers, I need to try something else (Student DHE)</i> <i>I am thinking about if the number of molecules actually equal at a given volume, temperature, and pressure, or is the difference just too insignificant to matter (Student BTD)</i> <i>I need you to get better at thinking when getting over difficulties when you are trying to understand chemistry in the moment, And that means after a while guys, you stop hitting a brick wall, and you learn how to get over it. And that's something I try to do here in class all the time. It keeps challenging you. Then it's just practice. Then after a while you don't need me to get over the wall you get over it yourself (PR).</i>

Evaluation	Student or teacher verbalises or behaves, (or asks a student to verbalise or behave) related to reviewing task performance and evaluating the quality of performance (by self or others) Student or teacher explains (or asks students to explain) their own learning or explain the task. Student or teacher evaluates (or asks students to evaluate) the strategies they used. Student or teacher rates (or asks students to rate) the quality of their performance. Student or teacher observes or comments (asks students to observe or comment) on task progress, or to test the outcome or effectiveness of a strategy in achieving a goal.	<i>I probably have to look at past exam papers to see how the content from class is applied in exams (Student BGN)</i> <i>I am confused about the positive result for the flame test for sodium. I didn't have enough time to complete all the equations (Student BTB)</i> I see what you are doing, and it's correct actually, but it's just not what it stands for. It was a great attempt by a good man. Like what you are saying is perfect. But it's just it turns out that is not what it stands for (PR). Is there anyone confused on that now, speak now if you are. Analogies are complicated in themselves, but sometimes they make things a bit more real life (PR).

(Adapted from Whitebread et al., 2009)

Appendix I Extract from the methodology module detailed plan (AR Cycle 5)

Week 1 Overview

General details	Visualisation and representations	Metacognition
Prior conceptual knowledge in teaching chemistry	Internal and external visualisations	Role of education in general-encourage students to think.
PCK: Electronegativity- States of matter, Kinetic molecular theory.	Three levels of representation in chemistry, sub-micro, symbolic and macro	What is the purpose of all teaching strategies?
Article from the literature Week 1; Concept Learning versus Problem Solving	External and internal visualisations of the states of matter	MOLES-S survey – Senior cycle Experience (chemistry or other senior cycle science subject)

Week 1 Detail

Main aims of this workshop are:

To facilitate an introduction from the pre-service teachers (PSTs) and the Practitioner/Researcher (PR), introduction of the overall module assessment strategy, highlight the overall engagement with this module, introducing the research, signing agreements, conducting surveys MOLES-S.

to encourage PSTs to reflect on their own thinking and learning in chemistry to date

to ask the PSTs to examine what strategies they believe they could use which would encourage students to think in chemistry lessons

Introduce the three pillars, namely visualisation (external and Internal), metacognition and key concepts in chemistry teaching

To highlight the role of prior conceptual knowledge in chemistry

This initial workshop is very much an introduction to the three pillars of visualisation (external and Internal), metacognition and prior conceptual knowledge in chemistry. The aim of this workshop is to encourage PSTs to reflect on their own thinking and learning in chemistry, both in upper senior cycle and in the 3rd level laboratory modules experience, with the aim of introducing the concept of awareness of thinking while learning through the use of visualisation and prior conceptual knowledge in chemistry. Secondly the workshop aims to ask the pre-service teachers to examine what strategies they believe they could use which would encourage students to think in upper senior cycle chemistry. This workshop is conducted in a manner where the idea of thinking and awareness of thinking is introduced without emphasis on the term of metacognition or its definition. This is to prevent PSTs relying on the definition of metacognition in a catch all statement “thinking about thinking”, but instead a focus on allowing time gaining a deeper understanding of the concept of

metacognition, by first highlight the PSTs own awareness of thinking, use of visualisation in their own learning in chemistry and how they think about concepts in chemistry and that of the strategies they believe would help students of chemistry.

Episode 1 - Completion of MOLES-S Survey (15 minutes)

Purpose

To give the PSTs a chance to complete the MOLES survey on their experiences in 2nd level chemistry and in their 3rd level chemistry laboratories.

Implementation

The initial part of the workshop Metacognitive Orientation Learning Environment Scale - Science (MOLES-S) Survey will be used to highlight the pre-service teachers' experience of metacognition in the previous learning. The pre-service teachers are given the (MOLES-S) Survey. This instrument measure pre-service teachers' perceptions of the extent to which certain psychosocial dimensions are evident in metacognitive learning environments. This survey asks pre-service teachers to answer questions which require them to reflect on (i) their experience of senior cycle chemistry (or physics or biology if they did not do senior cycle chemistry) and (ii) their experience of third level chemistry laboratory modules.

Evaluation

The results of the PSTs given answers

Episode 2 – Discussion Related to the MOLES-S Survey (15 minutes)

Purpose:

To encourage the pre-service teachers to think about their own thinking and learning and their experience of how thinking orientated their own experience in learning chemistry has been and how this in turn how this experience can be used to improve their own teaching.

Implementation:

Pre-service teachers are asked in pairs to (i) think about how they learn chemistry, (ii) to think about their difficulties in learning chemistry, (iii) think about how they could become better learners of chemistry, (iv) discuss with each other about how they learn chemistry (activity sheet with prompt questions).

Key ideas are reported back to the whole group – possible points that could arise are, completing lots of examples, writing our definitions, learning from experiments, using past exam papers, using questions from textbooks.

Important here was to link 'learning' and 'thinking' – what experiences have they had to date that encourage 'thinking about learning'. RP asks PSTs if there is a difference between learning and thinking. Brainstorm represented on the board and what they have in common and what is different. Possible answers may be that there are levels of learning, rote learning etc which require less thinking than others. PST's may suggest that thinking helps with on the spot problem solving. This episode links to the next in that PSTs to highlight thinking as a process in the chemistry classroom, where to solve understanding chemistry concepts, making connections through key concepts to link different topics, unseen problems in chemistry, form hypothesis, make educated

assumptions, rely on a chemistry student's ability to learn to think and necessity to be given the time to think and the practice at thinking skills.

Episode 3: Discussion of classroom strategies which promote or provide opportunities for the development of student thinking

Purpose: To elicit ideas from the PST on strategies that they could use in the classroom to encourage thinking and how they, as teachers, could use some of these.

Implementation

Turned successful learned chemistry,

Continues to build on pre-service teacher's reflections on their completion of the MOLES survey.

In this episode, PSTs are asked to discuss in pairs and report back to the whole group on what classroom strategies they have experienced or strategies they believe would encourage senior cycle chemistry students to think about chemistry concepts and how they would represent their own thinking.

Key strategies identified either through discussion (or added in by RT) are, wait time in questioning, students sketching their thoughts about a chemistry concept, problem based questions, context based questions, inquiry based laboratories, been asked to review a test, formative feedback on tests, reflections on how they understand a concept, reflections on how they solved or didn't solve a problem.

This leads to a discussion in relation to the purpose of their role as teachers of chemistry in the classroom and their role in creating a 'thinking classroom'. Each of the PST will be asked to contribute to a brainstorm about what they believe is the fundamental role of a chemistry teacher in the classroom. With the aim of bringing to the pre-service teachers the notion that fundamentally it is to give students the environment where they learn to think about chemistry concepts, represent these in various ways with the overarching aim of deepening student understanding of the chemistry concepts. What would you think of chemistry? How do you show a deeper understanding of chemistry, apply it to different concepts, represent it in different ways? Embedded within this conversation, the idea of the necessity for students to track their thinking and be aware of their thought processes so that they can change strategy when attempting to understand a concept of dealing with a problem or overcoming cognitive conflict (30 minutes). Cognitive conflict is raised as a key component of supporting student thinking and learning. This could appear as (i) in the classroom as when introducing a concept, a teacher uses probing questions, to establish the underlying or fundamental chemistry within a topic or a chemistry idea. For example, electronegativity – polarity-states of matter.

Episode 4: Representations and visualisations in chemistry

Purpose: How visualisation supports and can be used to represent both thinking and understanding in chemistry, given the time for both external representations and internal visualisations. Also addressing Johnson's Triangle of representations and how students and teachers visualise each of Johnstone's Triad of representations.

Implementation:

In the next portion of the workshop, (40 minutes) will be based on These ideas will be introduced through the lens of the chemistry of H_2O . Clarification will be given by the researcher practitioner RP in relation to the difference between internal and external visualisation.

PR asks the pre-service teachers to draw how they visualise H_2O as a gas, a liquid, and a solid in any representation they wish, showing any intra- and intermolecular bonding.

PR asks how did they come up with the external representation they have just drawn and what conceptual chemistry they have shown, (Key ideas might be particulate nature of matter, movement of particles, size, closeness etc; are there misconceptions identified).

Building on previous activity, PR introduces after an introduction/revision to Johnstone triangle, PSTs are asked in pairs to give three representations macroscopic, sub-microscopic and symbolic of H_2O in all three states of matter. A discussion on three levels or representation of chemistry, sub-micro, symbolic and macro based on students presenting their diagrams and in relation to how well their diagrams represent the concept of rust formation.

How the representations allow the student to think about the process – requires more thinking deeper about the concept while they are drawing; therefore, this approach can support student learning and conceptual understanding. Representations link to the process of thinking as well as displaying concepts. Possible points made by RP include from teacher perspective, it allows them to determine student understanding and identify possible misconceptions. RP introduces the power of visualisations (and their power as applied to JT) for teaching – and that it will be reinforced each week as one of three pillars in teaching and learning of chemistry, prior conceptual knowledge, metacognition and visualisation.

Episode 5: Key Concepts

Purpose

In the final portion of the workshop the focus shifts to the pre-service teacher's perception of themselves as chemistry teaching and the concepts which they believe are fundamental to the understanding of topics at leaving certificate level.

Implementation

Pre-service teachers will be asked to indicate what concepts they believe to be central to their own understanding of chemistry and more specifically for leaving certificate chemistry students they will teach in their careers. The links between the chemistry of states of matter can be linked to the chemistry of acids and bases through electronegativity.

A discussion in relation to what benefit of 'central concepts' in chemistry are useful throughout the Leaving curriculum – what ideas appear multiple times. This discussion would be future developed to include what are the characteristics of a "central concept in chemistry". A summary given by the PR given will include an emphasis of how central concepts allows for a level of chunking information and reducing pressure on the working memory of chemistry students, by applying understanding of the same concepts to a variety of topics in chemistry. This also provides the opportunity for the development of metacognition and students are aware of applying thinking approaches to more than one topic while also monitoring their thinking in relation to new topics by linking back to previous thinking.

As part of their weekly reflection task on an article from the literature there will be two tasks.

Task 1 Pre-service teachers will be asked to make a list with an associated explanation which concepts which are fundamental to Leaving Certificate chemistry.

Task 2. The article chosen this week (Article from the literature Week 1; Concept Learning versus Problem Solving) was chosen as it addresses the principle of prior conceptual knowledge and focuses on the underlying concepts when addressing student understanding of topics.

Summary 'take home messages' from week 1

Teachers need to be conscious of their own thinking and learning in chemistry

A central role of a teacher in chemistry is to encourage students to think.

The three pillars (visualisation, prior conceptual knowledge, and metacognition) and their inclusion in a concurrent approach in teaching chemistry are introduced.

In terms of metacognition while not directly mentioned it is implied through awareness of thinking in chemistry this week.

Representing chemistry in itself is a process of thinking in chemistry.

Visualisation is introduced as a means to add a richness to a description of thinking or chemistry concepts.

The conceptual nature of chemistry is reinforced and how addressing key concepts allows for a reduction of cognitive overload while also allowing for chunking in chemistry.

Appendix J Fifth-year study quantitative survey data (AR cycle 3)

Table J1 Mean student score for each item within the subcategories of the MOLES-S survey in the fifth-year study

MOLES subcategory	MOLES item	Mean Score (1-5)	
Metacognitive demands	Students are asked by the teacher to think about how they learn chemistry.	4.5	4.3
	Students are asked by the teacher to explain how they solve chemistry problems.	4.8	
	Students are asked by the teacher to think about their difficulties in learning chemistry.	4.2	
	Students are asked by the teacher to think about how they could become better learners of chemistry.	4.1	
	Students are asked by the teacher to try new ways of learning chemistry.	3.7	
Student-student discourse	Students discuss with each other about how they learn chemistry.	3.0	3.0
	Students discuss with each other about how they think when they learn chemistry.	3.1	
	Students discuss with each other about different ways of learning chemistry.	2.8	
	Students discuss with each other about how well they are learning chemistry.	3.4	
	Students discuss with each other about how they can improve their learning about chemistry.	2.9	
Student-teacher discourse	Students discuss with the teacher how they learn chemistry.	3.3	3.4
	Students discuss with the teacher about how they think when they learn chemistry.	3.7	
	Students discuss with the teacher about different ways of learning chemistry.	3.0	
	Students discuss with the teacher about how well they are learning chemistry.	3.6	
	Students discuss with the teacher about how they can improve their learning of chemistry	3.2	
Student voice	It is OK for students to tell the teacher when they don't understand chemistry.	4.9	4.4
	It is OK for students to ask the teacher why they have to do a certain activity.	4.3	
	It is OK for students to suggest alternative chemistry learning activities to those proposed by their teacher.	3.7	
	It is OK for students to speak out about activities that are confusing	4.8	
	It is OK for students to speak out about anything that prevents them from learning.	4.5	
Distributed control	Students help the teacher plan what needs to be learned.	2.3	2.4
	Students help the teacher decide which activities they do.	2.1	
	Students help the teacher to decide which activities are best for them.	2.6	
	Students help the teacher decide how much time they spend on activities.	2.7	
	Students help decide when it is time to begin a new topic.	2.5	
Teacher encouragement and support	The teacher encourages students to try to improve how they learn chemistry.	4.6	4.4
	The teacher encourages students to try different ways to learn chemistry.	4.3	
	The teacher supports students who try to improve their chemistry learning.	4.8	
	The teacher supports students who try new ways of learning chemistry.	4.5	
	The teacher encourages students to talk with each other about how they learn chemistry.	3.9	
Emotional support	Students are treated fairly.	4.9	4.7
	Students' efforts are valued.	4.6	
	Students' ideas are respected.	4.9	
	Students' individual differences are respected.	4.7	
	Students and the teacher trust each other.	4.6	

Table J2 Mean scores for the *metacognitive awareness* items of MAI

MAI Subcategory	MAI Item	Pre (1-5)	Post (1-5)	Change
Metacognitive declarative knowledge	<i>I understand my intellectual strengths and weaknesses.</i>	3.7	4.3	0.6
	I know what kind of information is most important to learn.	3.3	3.7	0.4
	I am good at organising information.	3.0	3.4	0.4
	<i>I know what the teacher expects me to learn.</i>	3.4	4.2	0.8
	I am good at remembering information.	3.5	3.7	0.2
	<i>I have control over how well I learn.</i>	3.5	4.1	0.6
	I am a good judge of how well I understand something.	4.0	4.0	0.0
	I learn more when I am interested in the topic.	4.7	5.0	0.3
Metacognitive procedural knowledge	<i>I try to use strategies that have worked in the past.</i>	4.0	4.7	0.7
	I have a specific purpose for each strategy I use.	2.7	3.3	0.6
	<i>I am aware of what strategies I use when I study.</i>	3.2	3.9	0.7
	I find myself using helpful learning strategies automatically.	3.0	3.5	0.5
Metacognitive conditional knowledge	I learn best when I know something about the topic.	4.3	4.7	0.4
	I use different learning strategies depending on the situation.	3.2	3.4	0.2
	I can motivate myself to learn when I need to	3.6	3.8	0.2
	I use my intellectual strengths to compensate for my weaknesses.	3.8	4.2	0.4
	<i>I know when each strategy I use will be most effective.</i>	2.7	3.5	0.5

Pre - at the start of the fifth-year study, post- at the end of the fifth-year study

Table J3 Mean scores for *metacognitive regulation* items of MAI

Subcategory	MAI item	Pre (0-5)	Post (0-5)	Change
Planning	I pace myself while learning in order to have enough time.	3.2	3.8	0.6
	I think about what I really need to learn before I begin a task	3.2	3.7	0.5
	<i>I set specific goals before I begin a task.</i>	2.6	3.6	1.0
	I ask myself questions about the material before I begin.	2.8	3.1	0.3
	I think of several ways to solve a problem and choose the best one.	2.9	3.5	0.6
	I read instructions carefully before I begin a task.	3.4	3.9	0.5
	I organise my time to best accomplish my goals.	3.0	3.2	0.2
Information management strategies	<i>I slow down when I encounter important information.</i>	3.8	4.5	0.7
	I consciously focus my attention on important information.	3.7	4.2	0.5
	I focus on the meaning and significance of new information.	3.6	4.1	0.6
	I create my own examples to make information more meaningful.	3.3	3.8	0.5
	<i>I draw pictures or diagrams to help me understand while learning.</i>	2.7	3.6	0.9
	I try to translate new information into my own words.	4.1	3.9	-0.2
	I use the organisational structure of the text to help me learn.	3.4	3.8	0.5
	I ask myself if what I'm reading is related to what I already know.	3.8	3.8	0.0
	I try to break studying down into smaller steps.	3.5	3.7	0.2
	I focus on overall meaning rather than specifics.	3.5	3.6	0.1
Comprehension monitoring	I ask myself periodically if I am meeting my goals.	3.2	3.7	0.5
	<i>I consider several alternatives to a problem before I answer.</i>	3.6	4.3	0.7
	I ask myself if I have considered all options when solving a problem.	3.1	3.4	0.3
	I periodically review to help me understand important relationships.	2.8	3.1	0.3
	<i>I find myself analysing the usefulness of strategies while I study.</i>	2.5	3.3	0.8
	<i>I find myself pausing regularly to check my comprehension.</i>	3.0	3.6	0.6
	I ask myself questions about how well I am doing while I am learning something new.	3.3	3.5	0.2
Debugging strategies	<i>I ask others for help when I don't understand something.</i>	3.3	4.0	0.7
	I change strategies when I fail to understand.	3.4	3.9	0.5
	I re-evaluate my assumptions when I get confused.	3.9	4.2	0.3
	I stop and go back over new information that is not clear.	3.7	4.3	0.6
	I stop and reread when I get confused.	4.7	4.8	0.1
Evaluation	I know how well I did once I finished a test.	3.6	3.8	0.2
	I ask myself if there was an easier way to do things after I finish a task.	3.2	3.5	0.3
	I'll summarise what I've learned after I finish.	3.0	3.2	0.2
	I ask myself how well I accomplish my goals once I'm finished.	3.2	3.5	0.3
	I ask myself if I have considered all options after I solve a problem.	3.0	3.3	0.2
	I ask myself if I learned as much as I could have once I finish a task.	3.4	3.4	0.0

Pre - at the start of the fifth-year study, post- at the end of the fifth-year study Change- difference in pre/post

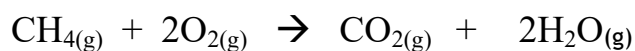
Table J4 Mean scores for MSLQ - *Learnings strategies*

Items in the MSLQ learning strategies	Pre (1-7)	Post (1-7)	Change
<i>Metacognitive Self-Regulation</i>			
During class time I often miss important points because I'm thinking of other things.	4.2	4.1	-0.1
When reading for this course, I make up questions to help focus my reading.	3.8	3.9	0.1
When I become confused about something I'm reading for this class, I go back and try to figure it out.	5.8	5.8	0.0
If course materials are difficult to understand, I change the way I read the material.	4.1	4.9	0.8
Before I study new course material thoroughly, I often skim it to see how it is organised.	4.1	4.9	0.8
I ask myself questions to make sure I understand the material I have been studying in this class.	4.5	5.3	0.8
I try to change the way I study in order to fit the course requirements and teacher's teaching style.	4.1	4.5	0.4
I often find that I have been reading for class but don't know what it was all about.	5.0	4.3	-0.7
I try to think through a topic and decide what I am supposed to learn from it rather than just reading it over when studying.	4.5	4.6	0.1
When studying for this course I try to determine which concepts I don't understand well.	2.6	5.5	2.9
When I study for this class, I set goals for myself in order to direct my activities in each study period.	1.8	4.1	2.3
<i>Critical Thinking</i>			
I often find myself questioning things I hear or read in this course to decide if I find them convincing.	3.9	4.9	1.0
When a theory, interpretation, or conclusion is presented in class or in the readings, I try to decide if there is good supporting evidence.	4.6	4.8	0.2
I treat the course material as a starting point and try to develop my own ideas about it.	3.5	4.1	0.6
I try to play around with ideas of my own related to what I am learning in this course.	4.1	4.4	0.3
Whenever I read or hear an assertion or conclusion in this class, I think about possible alternatives.	2.4	4.4	2.0
<i>Organisation</i>			
When I study the readings for this course, I outline the material to help me organise my thoughts.	4.3	4.7	0.4
When I study for this course, I go through the readings and my class notes and try to find the most important ideas.	5.3	5.4	0.1
I make simple charts or tables to help me organise course material.	3.3	3.1	-0.2
When I study for this course, I go over my class notes and make an outline of important concepts.	4.6	4.4	-0.2
<i>Elaboration</i>			
When I study for this class, I pull together information from different sources, such as lectures, readings, and discussions.	2.9	3.6	0.7
I try to relate ideas in this subject to those in other courses whenever possible.	4.6	5.3	0.7
When reading for this class, I try to relate the material to what I already know.	5.5	6.0	0.5
When I study for this course, I write brief summaries of the main ideas from the readings and the concepts from the lessons.	3.5	3.6	0.1
I try to understand the material in this class by making connections between the readings and the concepts from the lectures.	4.5	5.3	0.8
I try to apply ideas from course readings in other class activities such as lessons and discussion.	2.4	5.5	3.1
<i>Rehearsal</i>			
When I study for this class, I practise saying the material to myself over and over.	4.3	3.8	-0.5
When studying for this class, I read my class notes and the course readings over and over again.	4.8	3.8	-1.0
I memorise key words to remind me of important concepts in this class.	4.8	4.8	0.0
I make lists of important terms for this course.	1.9	3.3	1.4

Pre - at the start of the fifth-year study. Post- at the end of the fifth-year study. Change- difference in pre/post

Appendix K Test used in the fifth-year study based on state exam papers (AR Cycle 3)

Q. 1 Methane burns in air according to the equation



If 2.5 moles of methane are reacted fully with oxygen calculate

The moles of carbon dioxide formed

The number of moles of water formed

The number of moles of oxygen consumed

When crystals of ammonium dichromate $[(\text{NH}_4)_2\text{Cr}_2\text{O}_7]$ are heated strongly, they decompose fully according to the following balanced equation.



When 12.6 g of these crystals were heated strongly, calculate

(i) how many moles of ammonium dichromate reacted, (6)

(ii) the mass of chromium (III) oxide (Cr_2O_3) formed, (6)

(iv) the number of molecules of water produced. How many atoms did this quantity of water contain? (7)

Question 2 (i) What is an ideal gas? (4)

(ii) Give one reason why a real gas like carbon dioxide deviates from ideal behaviour. (3)

(ii) Assuming ideal behaviour, how many moles of carbon dioxide are present in 720 cm^3 of the gas at 10°C and a pressure of $1 \times 10^5 \text{ Pa}$? Give your answer correct to one significant figure. (9)

(iv) How many molecules of carbon dioxide are present in this quantity of carbon dioxide? (3)

State Charles' law.

----- - (6)

State Avogadro's law.

----- - (6)

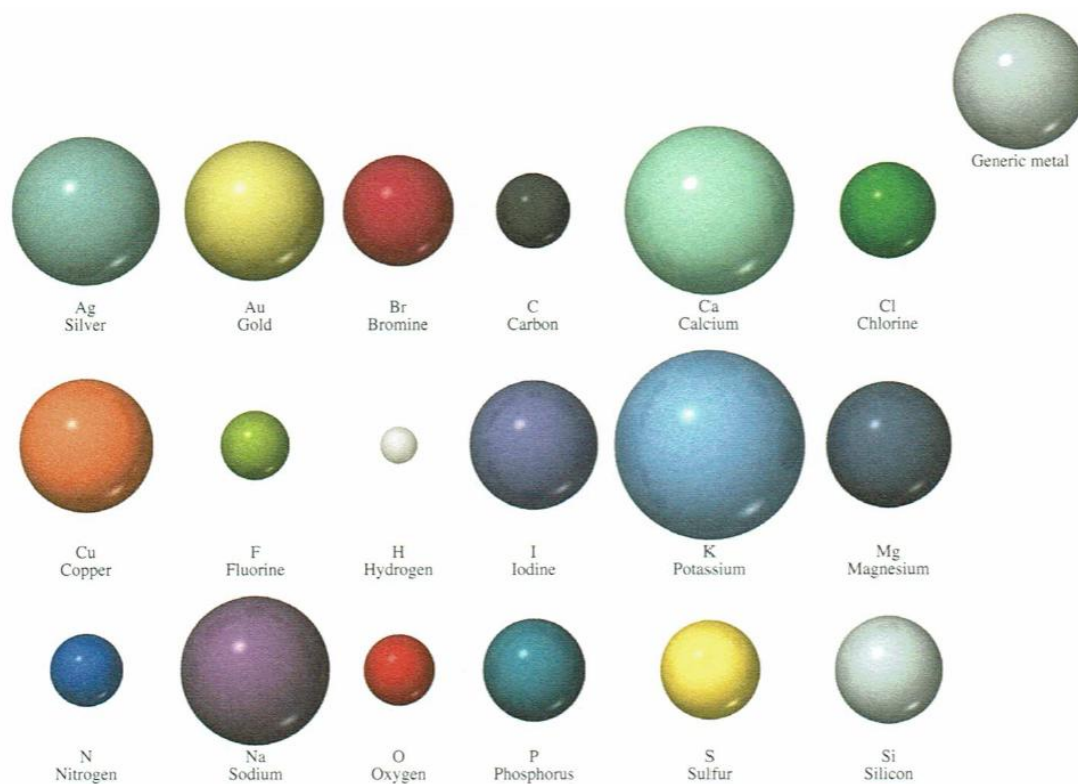
In an experiment to determine the relative molecular mass of a volatile liquid a sample of the liquid is vaporised at a given temperature and pressure and its volume measured. The mass of the sample is also measured.

(a) What is meant by a volatile liquid?

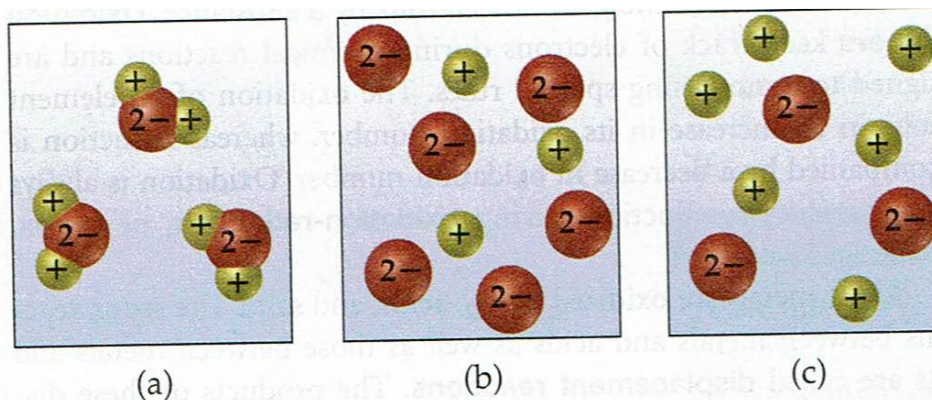
Give an example of a liquid suitable for use in this experiment. (5)

Appendix L Example of generated test to including the generation of representations in the fifth-year study (AR Cycle 3)

Use the colour chart below for atoms throughout the test.

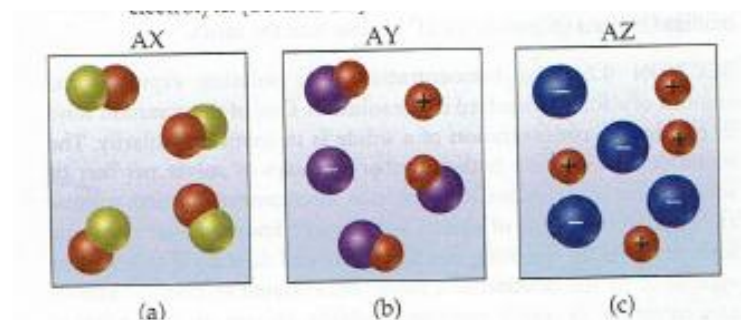


1. Which of the following diagrams best describes a solution of Li_2SO_4 in water? (water molecules not shown)



2. Give a reason for your answer in question 1

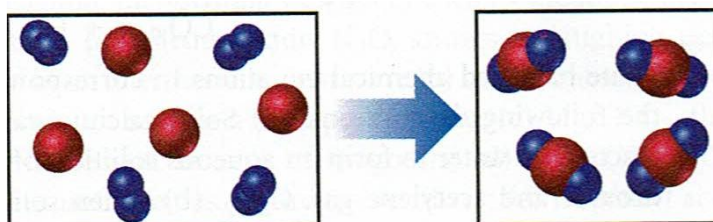
3. Three different substances, AX, AY, and AZ, dissolved in water as shown below. Identify each of the substances as strong acid, weak acid or non-acid.



- a) _____ -
 b) _____ -
 c) _____ -

4. Give a reason for each of your answers in question 3

5. The reaction between reactant A (blue spheres) and reactant B (red spheres) is shown below.



Based on this diagram, which equation best describes the reaction

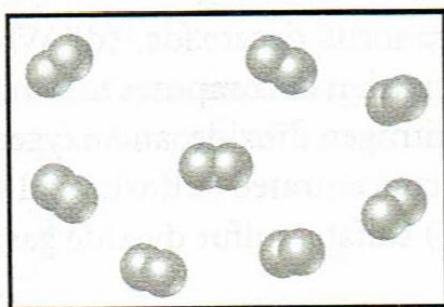
- (a) $A_2 + B \rightarrow A_2B$
 (b) $A_2 + 4B \rightarrow 2AB_2$
 (c) $2A + B_4 \rightarrow 2AB_2$
 (d) $A + B_2 \rightarrow AB_2$

6. Give a reason for each of your answer in question 5

7. Using diagrams similar to the diagrams above, represent each of the other three reactions from Question 5. (label the diagrams with each of the reactions letters)

8. H_2 and CO react to form CH_3OH

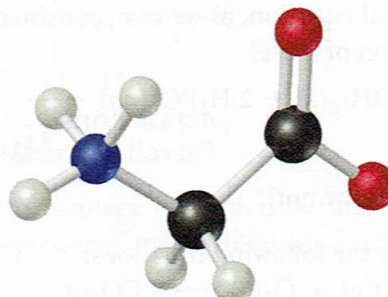
The following drawing represents a sample of H_2



Make a corresponding drawing of the CO need to react completely with H_2 .

9. How did you arrive at the number of CO molecules in your diagram?

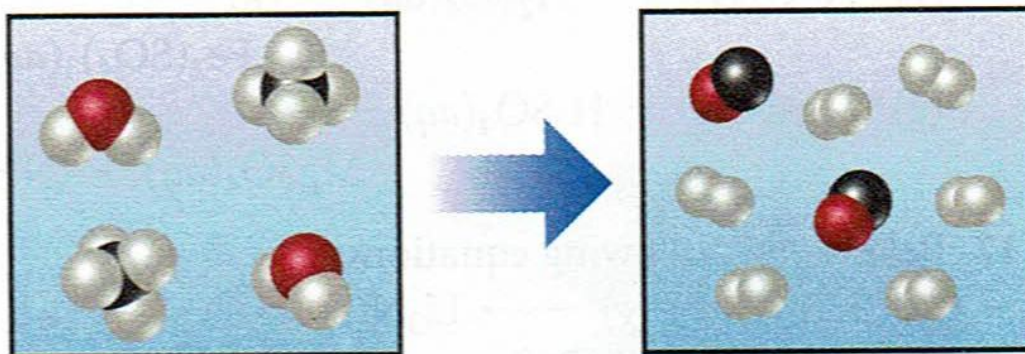
10. Glycine is an amino acid used by organisms to make proteins. The molecule is shown on the right.



- (a) Write its molecular formula _____ -
- (b) Determine its molar mass (use colour chart for elements at the start of the test).
_____ -
- (c) Calculate the mass of three moles of glycine

_____ -

Q.11 The following reaction represents a reaction between CH_4 and H_2O . The products are CO and H_2 .



Based on this reaction how many moles of each product can be obtained starting with 4.0 moles of CH_4 .

Appendix M Workshop summary detail – Pilot Methodology module (AR Cycle 4)

Workshop 1. Levels of representation and cognitive processes in chemistry

Discussion on the following:

- the role of the chemistry teacher in the classroom.
- classrooms which encourage thinking as being characterised by an environment where student's thoughts, answers and questions are valued and used to promote thinking.
- cognitive overload and the 'chunking' strategy
- Johnstone's triangle in chemistry

(The PSTs completed the MAI inventory - see Chapter 3, Section 3.3.2)

Workshop 2. Introduction of the principle of metacognition

Discussion on the following:

- the theoretical description of metacognition.
- Introduction of metacognitive questions and prompts as a teaching and learning strategy.
- Introduction to *Teacher explicit instruction of metacognition*
- PSTs use of the 'think aloud protocol'.

(PSTs completed MOLES-S in relation to their senior cycle experience in chemistry see Chapter 3, Section 3.3.2)

Workshop 3. Generating representations of chemical phenomena to display cognitive processes, to introduce PSTs to metacognitive awareness and its subcomponents.

- theoretical description of the subcomponents of Metacognitive Awareness; declarative knowledge, procedural knowledge, conditional knowledge and as they apply to chemistry.
- Thinking aloud protocol
- Teacher metacognitive modelling,

Workshop 4. Cognition in chemistry- through the chemistry triplet.

- metacognition and its importance in chemistry teaching (including the use of Johnstone's triangle)
- Generation of representations.
- Strategic evaluation matrix (SEM)

Workshop 5. Developing student metacognitive regulation in chemistry.

- theoretical description of metacognitive regulation, and its subcomponents planning, monitoring, and evaluation and as they apply to chemistry.
- the analysis and discussion of generated representations in chemistry.
- think aloud protocol.
- *Metacognitive prompts.*
- Metacognitive Awareness Inventory for Teacher (MAIT) (See Chapter 3, Section 3.3.3).

Workshop 6. Metacognition in the generation of representations in chemistry.

- Addressing the subcomponents metacognitive awareness and regulation through the generation and refinement of representations in chemistry.
- Reflective writing, pre and post surveys in chemistry.
- Incorporating metacognitive regulation subcategories of planning, monitoring, and evaluation into chemistry lessons.
- Think aloud protocol.

Workshop 7. Problem solving and teaching and learning strategies which promote metacognitive regulation in chemistry.

- Regulatory checklists
- overcoming cognitive conflict for students.
- Teacher metacognition Inventory TMI (See Chapter 3, Section 3.3.3).
- Metacognitive strategies e.g., metacognitive prompts, metacognitive modelling, , and explicit instruction on metacognition.

Workshop 8. Developing metacognitive regulation through the refinement of representations.

- Thinking aloud strategy relating to the generation of representations in chemistry.
- Metacognitive discussion- metacognitive awareness in terms of their declarative knowledge through activation of knowledge.

- Description of PSTs understanding of a chemical phenomenon which addressed the subcomponents of metacognitive awareness (See Section 5.1.2).

Workshop 9. Identification of techniques for assessing metacognition in chemistry.

- Evaluation of metacognition in chemistry.
- Assessing student thinking and metacognition in chemistry
- monitoring and discussing student generation of representations e.g., asking students to think aloud, to assess metacognitive regulation.
- PSTs description of implementing the metacognitive strategies which addressed the subcomponents of metacognitive awareness (See Section 5.1.2).

The PSTs completed MOLES-S (in relation to the module).

Workshop 10. To revise the metacognitive teaching learning strategies as they apply to a chemical phenomenon.

- Revision of the theoretical aspects of metacognition in chemistry
- metacognitive strategies and the subcomponents of metacognition they would address.
- PSTs implementing the metacognitive strategies (See Section 5.1.2).

The PSTs completed MAI.

Appendix N Workshop summary detail – Methodology module (AR Cycle 5)

Workshop 1 – PSTs cognitive processes in chemistry.

Workshop 1 focussed on the PSTs' awareness of their own cognitive processes in chemistry. Initially, the PSTs completed the MOLES-S survey on their experience in senior cycle chemistry. A discussion of the items of the MOLES-S survey followed to encourage the PSTs to think about how metacognitively orientated their own chemistry lessons had been and how this experience influenced their cognitive processes in chemistry. They then reflected (in pairs) on the following prompts: *(i) think about how you learn chemistry, (ii) think about your difficulties in learning chemistry, (iii) think about how you could become better learners of chemistry, (iv) discuss with each other how you learn chemistry.* The PSTs then reported back to the group on classroom strategies they had experienced.

To develop the PSTs' awareness of cognitive processes related to chemical phenomena at the submicroscopic level and to introduce them to the power of generating representations of cognitive processes in chemistry, the PSTs were asked to represent how they visualise H₂O molecules as solid, liquid and gas and these representations were discussed. In the final part of the workshop the emphasis shifted to the concepts which the PSTs believe are fundamental to the understanding of chemical phenomena on the Leaving Certificate Chemistry curriculum (DES, 2002).

Metacognition, while not directly discussed in this workshop, is incorporated through discussion of the PST's own cognitive processes and experience in learning chemistry.

Workshop 2 – PSTs' metacognition in chemistry

An important aspect of this workshop was introducing the term '*metacognition*' without a reliance on the "*thinking about your thinking*" or other catch-all definitions. The aim is to promote PSTs understanding of metacognition more deeply through experience and reflection rather than through knowledge of a definition. This included using the MAI survey where the PSTs were asked to (i) describe what they think the MAI is asking them about and (ii) within the MAI which items they believe are similar and would hence group together.

I then moved on to explicitly address metacognition in the context of chemistry. This was firstly done by asking the PSTs what they thought cognition in chemistry was, and then I linked their awareness of the cognitive processes to one of the subcomponents of metacognition. The PSTs were asked questions for a brainstorm on the board- *What do you do if you cannot grasp a*

concept in chemistry? What do you do when you cannot solve a problem-based question in chemistry? What do you do when you are frustrated with chemistry? These questions were used to encourage the PSTs to examine how they respond to conceptual difficulties or difficulties with problem-solving in chemistry and to increase awareness of the cognitive processes they use.

I then modelled explicit instruction of metacognition by firstly addressing cognitive processes in chemistry using some examples.

(i) Conceptualising topics e.g., thinking about the key concepts which address several topics. (ii) Visualising concepts – how the students develop mental images of chemical bonds, 2D or 3D etc. (iii) Problem solving – how students solve for K_c in chemical equilibrium (iv) learning concepts – how students may use previous knowledge to construct new information (PR).

I then gave comparative examples as examples of metacognition in chemistry.

Awareness, control and monitoring of your own cognitive processes for: (i) conceptualising topics – how you can switch between concepts while trying to link topics through concepts, for example polarity and electronegativity which explain intermolecular bonding in water; (ii) visualising concepts – you are conscious that the mental images can have motion added to them, e.g., behaviour of liquid water which is not possible in a drawing of a visualisation; (iii) problem solving- how do I related to my previously used cognitive processes like understanding visualisation at the submicroscopic level; (iv) learning concepts – that you can be aware of how you construct concepts mentally using several different sources (PR).

The concept of metacognition was further discussed by using the examples from the second level study (AR Cycles 1-3) e.g., when I used the story of Hansel and Gretel and breadcrumbs as an analogy of tracking and awareness of one's cognitive processes while studying chemistry.

PSTs had been given an article (Nakhleh & Mitchell, 1993) to reflect over the previous week. This paper used two problem types - algorithmic and drawings. The PSTs reflections were discussed using prompt questions including “*What thinking would one use in answering algorithmic vs the visuals*”. “*Did the problems assess different learning / what cognitive processes were involved etc...?*”

Later in the workshop the representations of H_2O from the previous week were discussed by sharing examples. The purpose of this was to focus on the PSTs' awareness and regulation of their cognitive processes followed by refinement of their representations. Following the group discussion, PSTs were then asked to generate new representations of the H_2O as a gas, a liquid,

and a solid. The PSTs then swapped their representations with a partner and were asked to write a paragraph on what they thought the other PSTs' cognitive processes were, before discussing in pairs how they visualise and understand H₂O at the submicroscopic level and how they represented these cognitive processes.

At the conclusion of this task, I demonstrated metacognitive modelling to illustrate how visualising chemistry and creating representations of my visualisations enhanced my own understanding of chemical phenomenon. I highlighted how this approach could support my teaching by providing evidence of students' cognitive processes when combined with descriptions, discussions, and prompts (in AR Cycles 1-3). I also emphasised awareness of awareness of switching between, the macroscopic, submicroscopic and symbolic levels of cognitive processes related to chemical phenomenon, as well as them being levels of representing chemistry.

As part of the reflection tasks for this workshop, with the aim of addressing the PSTs awareness of their own cognitive processes and the cognitive processes of others, PSTs were asked to complete two problems in chemistry, and to describe their cognitive processes as they went through the problems in a similar way to the metacognitive modelling I had demonstrated. In a second reflection task, to reinforce the workshop tasks on awareness of visualising and understanding chemistry at the submicroscopic level, PSTs were asked to use notes and representations to model their own cognitive processes related to the transfer of electrons occurring in the reaction taking place when magnesium is burned in the presence of oxygen to form magnesium oxide.

Workshop 3 – PSTs' metacognitive knowledge in chemistry

As a group discussion, the PSTs were asked to evaluate the underlying concepts shown in each other's representations of H₂O as a gas, a liquid, and a solid from the previous workshops, any refinements they would make to each other's representations, and to reflect on what changes in their cognitive processes occurred over the last three workshops in relation to the chemical phenomenon of H₂O as a gas, a liquid, and a solid. The purpose of this was to address the PSTs' awareness of their own cognitive processes and that of other PSTs. The PSTs were asked to redraw their representations of H₂O as a gas, a liquid, and a solid, while also answering the following prompt questions: *(i) Describe how your thinking and understanding of intermolecular and intramolecular bonds has changed; (ii) how your thinking in relation your visualisation of intramolecular and intermolecular interactions has changed; (iii) Describe*

how your thinking in relation to underlying concepts involved in intramolecular and intermolecular bonds has changed. These questions address MDK, MCK, ME. Throughout the refinement of representations over the first three workshops, focusing on the PSTs cognitive processes related to H₂O at the submicroscopic level, the emphasis was on addressing awareness of the cognitive processes and understanding evident through the generation and refinement of the PSTs representations.

Further discussion on how the PSTs respond to conceptual or problem-solving difficulties from the last workshop led to me highlighting that most of the responses were about looking externally for the solution for these situations. e.g., textbook, peer etc. I then emphasised that if they were to take a metacognitive approach, they would first look internally, examine what cognitive processes they used before in a similar question, take the time to activate their knowledge, and think about how to visualise what is happening at the submicroscopic level. The aim of this episode was to promote PSTs' awareness of their MPK and MCK in relation to how they use cognitive processes in chemistry.

Later in the workshop, I introduced metacognitive awareness without explicitly using the terms MDK, MPK, or MCK. Using a worksheet containing questions that addressed MDK, MPK, or MCK, the PSTs were asked to work in pairs to answer these questions in relation to an acid-base problem. Examples of questions included with the subcomponent being aimed at in brackets are given in Table 9.2.

Table 9.2 Extract from a worksheet on MDK, MPK and MCK in a workshop task

Extract from question for context;
<i>(a) An indigestion tablet contains a mass of 0.30 g of magnesium hydroxide [Mg(OH)₂] as its only basic ingredient. Write a balanced chemical equation for the reaction between magnesium hydroxide and hydrochloric acid (HCl_(aq)), the acid produced in the stomach. Calculate the volume of 1.0 M HCl neutralised by two of these indigestion tablets. Give your answer correct to the nearest cm³</i>
Examples of prompt questions extracted from the worksheet
<i>What chemistry factual and conceptual knowledge do you know about the question Part (a) above? (MDK)</i> <i>Before starting the question Part (a) do you think you would be able answer it fully? (MDK)</i> <i>In relation to question Part (a), what parts do you think you would be confident at? What would you be unsure of? (MDK)</i> <i>Without actually doing Part (a), describe your thinking on how you would complete part (a) above? (MDK, MPK, MCK) What procedure would you use to answer the question? (MPK)</i>

Where did you learn the procedure, you have described for completing Part (b) above (MDK)
Why did you use the procedure you state to solve part (a), are there alternative procedures, explain (MCK)

Following the completion of the task, the PSTs shared examples of their responses to the prompt questions to the group, while I highlighted aspects of MDK, MPK, or MCK they presented and aligned it with my interpretation of these subcategories in chemistry (see the conceptual framework in Section 6.6).

As part of the reflection assignment for this workshop, the PSTs were asked to describe their current understanding of what metacognition is in the context of chemistry, based on their experience in the module so far.

Workshop 4-PSTs' metacognitive regulation in chemistry

The metacognitive component of this workshop was to focus on the PSTs' own metacognitive regulation. The subcomponents of MP, MM, and ME in chemistry were addressed through carefully designed tasks and activities, where the PSTs were provided with opportunities to engage with these subcomponents

Addressing MP in the initial episode, the PSTs were asked to identify an underlying concept and link it to as many senior cycle chemistry topics as possible, and these were shared on the board. The PSTs were asked to comment on the validity and the reasoning for the examples shown. e.g. if the topic of states of matter was addressed then they may link that back to their cognitive processes related to the concept of electronegativity.

Following the group discussion, the PSTs were given a topic (in pairs), and they were asked to discuss with each other what underlying concepts apply to the topic. Following this, and as part of a brainstorm, the group discussed recurring underlying concepts identified. I highlighted how awareness of cognitive processes related to underlying concepts in relation to chemistry phenomena reduces cognitive overload, and allows for chunking of information (Miller, 1956). I discussed how the awareness of reaching cognitive overload is an important aspect of one's MDK and MM. and how awareness of this could encourage one to implement alternative cognitive processes (e.g. visualising the submicroscopic level). The purpose of this episode was to promote development of PST metacognitive regulation, through discussing how concepts can be used to link different chemical phenomena, hence increasing awareness of

“*chunking*” (De Groot, 1965; Zhilin & Tkachuk., 2013) of information to reduce cognitive overload in chemistry lessons.

In a further episode in the workshop, I modelled an example of my own cognitive processes, in relation to trends in the boiling point of alkanes. The focus then moved to the PSTs articulating their cognitive processes in relation to a topic in chemistry and their understanding of metacognition. This involved ‘Thinking aloud’, by describing their understanding of metacognition as it applies to chemistry. To promote metacognitive evaluation, PSTs were asked to describe how their thinking has changed, and how they would refine their description of metacognition they submitted in the previous workshop.

In a later episode, two PSTs modelled their own cognitive processes related to the generation of representations on the reaction of ethanoic acid and sodium hydroxide. I used metacognitive prompts during the PSTs think aloud protocol, including “*are there alternative visualisations possible? Are there alternative ways of thinking to understand the concept? What concepts give rise to the chemistry involved? etc.*” In this episode the PSTs experience three metacognitive teaching strategies which will be introduced later in the module i.e., explicit teaching of metacognition, think aloud protocol, and teacher metacognitive modelling.

In the last episode of the workshop, PSTs discussed ways they could increase awareness of the cognitive processes that result in misconceptions. I presented examples of the PSTs assignments from a previous workshop on the reaction of magnesium burning in the presence of oxygen to form magnesium oxide. The PSTs discussed the examples of work and how their representations could be improved to include underlying concepts, e.g. show electron cloud distortion resulting from the relative electronegativity between atoms etc. PSTs were asked to again generate a representation of how they visualise the submicroscopic interactions for this reaction. The PSTs then completed a set of prompt questions (on metacognitive regulation) while completing the task again (i) *List three questions you would ask yourself before beginning this task.* (ii) *What are the underlying chemistry concepts of this task?* (iii) *Describe any alternatives to your visualisation* (iv) *Summarise what you have learned from completing this task for the second time and how has your understanding, thinking, or visualisations changed.*

The reflection tasks related to this workshop focused on metacognitive regulation through the use of prompt questions on the chemical process where a bracelet was cleaned by converting the silver sulphide back to metallic silver using aluminium. Prompt questions included (i)

Before beginning this question, list three questions you would ask yourself; (ii) What are the underlying key chemistry concepts of this question; (iii) From the chemical reaction and the initial information in the question, represent this reaction at the macroscopic, sub-microscopic and symbolic levels; (iv) Complete a solution to each part of the question using representations of how you visualise the chemistry; (v) Describe any other ways to visualise the chemistry involved; (vi) What aspects of chemistry have you learned from completing this task. The workshop's reflection tasks aim to further promote the PSTs generation of representations of chemical phenomena to promote awareness and regulation of their thinking in chemistry.

Workshop 5 - PSTs' identification of metacognitive teaching and strategies

The emphasis in Workshop 5 shifted from the development of the PSTs own metacognition to how to implement metacognitive strategies in their own teaching of chemistry. In this workshop the strategies of 'teacher explicit instruction on metacognition', 'teacher modelling metacognition', and 'metacognitive prompts' as a teacher were discussed as part of a metacognitively orientated classroom.

In the first episode, the PSTs answered prompt questions on a worksheet which address metacognition, generation of representations and concepts in relation to the different in boiling points of butane (-0.5°C), diethyl ethyl (34.6°C), butan-2-ol (99.5°C), butan-1-ol (117.7°C). The prompt questions included (i) *Draw a representation of how you visualise each of the compounds (i.e., include several molecules) as they exist at room temperature - 25°C ; (ii) Consider or explore the interactions that occur between the molecules of each compound and predict the order of their boiling point from lowest to highest; (iii) Clearly show your thinking through representations and explanatory notes for the order you have suggested in part (ii).* Two PSTs were asked to describe their cognitive processes related to this task to the rest of the group using the 'think aloud' protocol (See section 9.3.2). The PSTs were asked to discuss the representation of their visualisations on the board and to 'think aloud' by describing the cognitive processes (e.g. thinking, visualisations, learning) which helped them predict the order of the compounds based on boiling point. I used prompt questions to clarify and encourage the voicing of the PSTs cognitive processes e.g. *Where did you see this chemistry before? Is there a different way to visualise that molecule? What underlying concept gives rise to the partial charges you have shown etc. What have you learned from while doing this task and has your thinking changed?*

In a further episode, the emphasis was on the identification of the metacognitive strategies that I modelled. This episode involved my modelling of metacognition strategies in relation to redox reactions through the underlying concepts of electronegativity and collision theory including, *explicit instruction on metacognition in chemistry*, *metacognitive prompts*, *metacognitive modelling*, and the *generation of representations of how I visualise the chemistry*. The PSTs were asked to answer a series of prompt questions in relation to the teaching episode, where the PSTs were asked to describe examples of my use of (i) *metacognitive modelling*, (ii) *metacognitive prompts*, (iii) *explicit instruction on metacognition*, (iv) *examples of visualisation and how I described my visualisations*, (v) *underlying concepts included*. The PSTs shared examples of their responses as part of a whole group discussion. This was used as part of a discussion on metacognitive strategies embedded in the teaching of chemical phenomena. I then emphasised the importance of the PSTs' developing their own authentic and unique voice in terms of incorporating their own metacognition as part of teaching and learning chemistry.

In the final episode of the workshop, I discussed the *Chemistry Concept Assignment* (see detail in Table 9.4), which aimed to bring together the various aspects of the module to date. The PSTs completed this assignment in pairs, the purpose of this was to encourage the PSTs to discuss and refine their cognitive processes as they incorporate them into a joint assignment, thus increasing awareness of their own cognitive processes and the cognitive processes of others.

Workshop 6 - PSTs' Implementation of metacognitive teaching and strategies

The metacognitive component of this workshop was to continue the focus on PSTs increasing awareness of metacognitive strategies in chemistry. Similar to the previous workshops, there are episodes where I modelled metacognitive strategies in chemistry and where the PSTs identify and describe the strategies. Additional episodes involved the PSTs demonstrating metacognitive strategies in chemistry. An initial episode of the workshop aimed to embed the use of metacognitive prompts and metacognitive modelling into the teaching of chemical equilibrium. The PSTs described and drew representations of five things they visualise when they see chemical equilibrium, and this was followed by a brainstorm session on the board, where the PSTs shared their ideas with the whole group. I demonstrated metacognitive modelling by explaining analogies I use when thinking and visualising chemical equilibrium at the submicroscopic level. The PSTs answered prompt questions based on my metacognitive

modelling (i) *What analogies were used? Explain any issues or difficulties in understanding the analogies any contribute to.* (ii) *What representations of visualisations were used? Explain any issues you can think of with the visualisations used?* (iii) *What underlying concepts were discussed and had you thought of them when thinking about chemical equilibrium previously?*

In a subsequent episode the PSTs engaged in the think aloud protocol and metacognitive modelling, where the PSTs were asked to, in pairs, explain their cognitive processes to each other in relation to their generated representations of the submicroscopic, symbolic and macroscopic levels of the reaction between nitrogen and oxygen to form nitrogen monoxide. This was followed by a discussion on the cognitive and metacognitive aspects to the pair work using prompt questions e.g. (i) *Do you think working in a group helps you become more aware of ways of thinking or visualising chemistry?* (ii) *Did you discover a different way to visualise the three levels of the chemistry in this task.* (iii) *Did your thinking change because of how the other member of your pair gave an indication of their thinking in the concept.* (iv) *Did you think you discussed any underlying concepts in your group? If so, have you thought of them previously? Explain.*

Workshop 7- Representations of thinking in organic chemistry through metacognitive modelling and metacognitive prompts

This workshop included PSTs describing their cognitive processes in chemistry, through the generation and refinement of their representations to provide PSTs with more experience of thinking aloud and metacognitive modelling as teaching strategies. The initial episode in the workshop again involved the refinement of thinking in chemistry through analysis of PSTs generated work. The PSTs swapped a copy of their 'Chemistry Concept Assignment' (from workshop 5) with another pair in the group. The PSTs were asked to evaluate, in pairs, a PSTs 'Chemistry Concept Assignment' from workshop 5. This was done using prompt questions e.g. (i) *Is the explanation of the thinking present and/or clear in each section of the assignment? Explain. Have you any additional suggestions?* (ii) *Under each of the headings can you provide alternative ways of thinking for this topic.* (iii) *Have they included representations of their visualisations of the chemistry and/or their thinking? Are there additional/alternative representations of how you visualise the chemistry, give examples* (iii) *Are their concepts/experiments/ applications/ideas/teaching strategies missing? Give examples and explain.* (iv) *What have you learned from this task about the thinking of the author of the*

assignment and your own thinking in chemistry? This was followed by a whole group discussion where the PSTs feedback on the assignments was shared.

In an episode later in the workshop I asked the PSTs about how organic reaction mechanisms were taught when they were students in senior cycle chemistry, and this led to a brainstorm on the board of what the PSTs think and visualise when they see organic reaction mechanisms. The aim of these tasks was to encourage the PSTs to reflect on their own cognitive processes in relation to organic reaction mechanisms and how they learned organic chemistry. Following on from the discussion, the PSTs were asked to represent several molecules of propene with several molecules of chlorine, they were then asked to predict what would be formed when these molecules react. The PSTs were asked to represent how they visualise the mechanism occurring in a closed container rather than a series of steps using chemical formula. The aim of this was to encourage the PSTs to think about and visualise the chemistry taking place at the submicroscopic level, rather than thinking of the mechanism as a series of symbolic representations on a page. A PST then demonstrated their understanding using the ‘think aloud protocol’ and metacognitive modelling while explaining the generation of their representations of how they visualise and understand the reaction mechanism to the whole group. The purpose of this was to give the PSTs the opportunity to practise demonstrating their cognitive processes through discussing their visualisations and understanding while generating representations of a chemical phenomenon.

Workshop 8 - Metacognitive strategies in experimentation.

The metacognitive aspects of this workshop focused on the PSTs discussing the submicroscopic and symbolic levels of cognitive processes during experimental activities. I discussed the importance of embedding an awareness of visualising and understanding the macroscopic, symbolic, and submicroscopic levels of chemical phenomenon during experimental activities and addressing awareness of cognitive processes related to underlying concepts involved. I discussed the value of metacognitive prompts during experimental activities to prevent a focus on only the macroscopic level of cognitive processes.

In a brainstorm exercise, the PSTs were asked to reflect on their experience of senior cycle chemistry experiments as a student. The purpose of this was to activate an awareness of their own cognitive processes related to experiments in senior cycle chemistry, and how awareness of these cognitive processes can influence how they would approach chemistry experiments as

a teacher. I then emphasised the value of student's awareness of cognitive processes related to experimental activity at the submicroscopic level. In addition, the teacher role includes constantly prompting awareness of student cognitive processes related to the chemistry phenomenon at the submicroscopic level to avoid laboratories based on practical skills only. I indicated this can be done by using prompt questions which students can complete during or after the experiments. Prompts questions such as, *What do you think will be the products of the reaction? Why do you think this?; what species at the submicroscopic level do you think combined to give a product?; Draw what you visualise is happening in that conical flask at the submicroscopic level; what is present in that flask at the start, during or after the reaction?; Has your thinking changed in relation to the chemistry taking place, how has it changed?; What underlying concepts explain what you have observed, where have you thought of them previously? etc*

The PSTs, in pairs, were asked to describe an experimental activity document for a teacher on the identification of anions (i.e., chloride, sulphate, sulphite, and nitrate ions), where the aim of this was to promote PSTs awareness of cognitive processes related to the submicroscopic level for experiments. The descriptions were to include how the teacher would conduct the laboratory activity, how they would promote awareness of cognitive processes related to the submicroscopic level, and examples of questions or tasks the teacher could use. A PST then took on the role of the teacher for the laboratory session they had designed, during which they approached another pair of PSTs to demonstrate how they would implement their proposed experimental activity. Following the completion of the activity, the PSTs who acted as the teachers returned to their original pair. The PSTs then discussed and shared their experiences of the experimental activities they had completed.

Workshop 9 - Metacognition, cognitive processes related to linking the macroscopic to the submicroscopic levels

This workshop included metacognitive strategies to enhance the PSTs' awareness of utilising laboratory activities in chemistry to foster student metacognition in relation to the awareness of cognitive processes related to linking the macroscopic and submicroscopic levels of chemistry. An initial episode focused on raising the PSTs' awareness of the opportunities for fostering understanding through a 'practice before theory' approach. I aimed to emphasise the use of chemistry laboratory activities to develop an awareness of cognitive processes in

chemistry based on one's understanding of chemistry at the submicroscopic level, rather than merely confirming theoretical knowledge. The PSTs, in pairs, were required to analyse and modify an experimental activity in a way which would help senior cycle students develop their understanding of the reactivity of the halogens.

In a similar way to the previous workshop, the PSTs swapped their experimental activity with a different pair of PSTs and one of the PSTs in the group acted as the teacher of their experimental activity. Following the completion of the experimental activity each pair of PSTs discussed the activity using prompt questions e.g. *(i) For the experiment itself, what were the results obtained?; what is your thinking in relation to the results where they what you thought they were going to be, did you think about what they might be before the activity. (ii) what do you think is the purpose of the experiment from a teaching perspective, did it increase your awareness of the submicroscopic level of thinking? Did you visualise it at the submicroscopic level? (iii) How was the experiment performed, did it challenge you to think or visualise anything other than at macroscopic level? and then underlying chemical concepts do you think explain these observations (hypotheses and suggestions)? Did you think about underlying concepts during the experiment? (iv) How can teachers use experimental observations to promote awareness of thinking in chemistry?* I emphasised that by explicitly teaching the chemistry of an experiment before carrying it out possibly removes the need for many cognitive processes that would normally come with the student's discovery during experimentation. The purpose of this explanation was to highlight to the PSTs the importance of constantly challenging students to increase awareness of cognitive processes in chemistry. I emphasised that small changes in how teaching strategies are implemented, e.g., the order of tasks, can enhance how much students think and can help students to become more aware of their cognitive processes.

Workshop 10 - Assessment of metacognition in chemistry

In the final workshop, the PSTs' assessment and interpretation of students' cognitive processes in chemistry was discussed, with a focus on in-class assessment through the generation and refinement of representations or visualisations, think aloud protocol, metacognitive modelling, etc.

In an episode at the start of the workshop, the PSTs discussed assessment techniques that they thought were useful strategies for establishing their own cognitive processes in chemistry. The

PSTs then analysed questions from the Leaving Certificate chemistry examination papers, where they discussed if the parts of the question could be answered using recall/memory or if they required understanding. The PSTs then rephrased a part of a question to show it could be enhanced to assess various cognitive processes including understanding. The PSTs then shared their examples with the rest of the group.

In a later episode the PSTs were asked to reflect on the assessment strategies they experienced in senior cycle chemistry. The PSTs then discussed in groups the following prompt questions *(i) why each of the strategies they have described focus either on recall of information or encourage a display of thinking and understanding of concepts in chemistry* *(ii) What is it about certain assessment strategies that encouraged them to think about chemistry and underlying concepts?* The purpose of this episode was to promote awareness of the cognitive processes induced by assessment strategies based on their own experience.

In a subsequent episode, the role of generating representations of cognitive processes related to chemical phenomena as part of assessments was discussed. As part of a workshop task, the PSTs were asked to draw a representation of how they visualise methanol as a liquid, at the macroscopic, submicroscopic, and symbolic levels, and describe their cognitive processes through their representations. The PSTs then exchanged their representations and evaluated each other's work based on the clarity of the cognitive processes conveyed in the representations. I emphasised that the representations of their cognitive processes related to the macroscopic, sub-microscopic, and symbolic levels which chemistry students generate need to be refined by themselves over time improving their metacognition through discussing and prompting an awareness of the evolution and consolidation of their cognitive processes. The PSTs and I discussed the importance of assessment of cognitive processes in chemistry using discussion, metacognitive prompts and the think aloud protocol. The PSTs also engaged in a group discussion on the advantages and disadvantages of assessing students' cognitive processes through the use of representations when compared to word-only based explanations of their cognitive processes. I highlighted the importance of incorporating associated discussions, descriptions and metacognitive prompts to capitalise on opportunities to promote metacognition.

Further episodes in the workshop addressed the types of prompts and questions which encourage awareness of cognitive processes in chemistry. The purpose of these episodes was to develop the PSTs awareness of the variation which can occur in the answers produced when

formulating assessment questions in chemistry. The PSTs suggested metacognitive prompts which they thought could be used in a chemistry class. The PSTs then exchanged their questions with other groups, who answered them. The questions, along with the responses, were subsequently returned to the original authors for review. The PSTs then evaluated the responses to determine whether they reflected the level of understanding of chemistry that the PSTs intended when formulating the questions.

To conclude the workshop, the PSTs were given time to reflect and record what they considered the key "take-home messages" from the module, any recommendations for improvement, and aspects they would have liked to see included or excluded.

Appendix O Metacognitive teaching and learning strategies – Methodology module (AR Cycle 5)

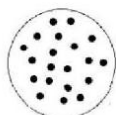
M1 Generation of representations

A metacognitive strategy which was used in the senior cycle study was the generation and refinement of representations in chemistry. The power and domain specific use of this strategy, which provides opportunities for metacognitive experiences was discussed as part of the findings from the senior cycle study in Chapter 4. The generation of the representations aimed to promote PSTs development of metacognitive awareness and the refinement of representations focused on development of metacognitive regulation in chemistry. In one particular assignment given in Workshop 1 the PSTs were asked to answer the following prompt questions:

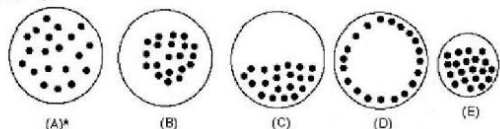
Problems I and III relate to Gas Laws/behaviour, while Problems II and IV relate to Stoichiometry. Considering each pair of problems, discuss the difference between the problems (i.e. I vs III, and II vs IV) and how the type of problem can impact on assessment of student understanding of the topic, in relation to an article from chemistry literature, Concept learning versus problem solving: There is a difference by Nakhleh and Mitchell (1993). To provide context, the problems included in the above article are shown in Figure 6.5.

Problem I.

The following diagram represents a cross-sectional area of a rigid sealed steel tank filled with hydrogen gas at 20 °C and 3 atm pressure. The dots represent the distribution of all the hydrogen molecules in the tank.



Which of the following diagrams illustrate the most probable distribution of molecules of hydrogen gas in the sealed steel tank if the temperature is lowered to -5 °C? The boiling point of hydrogen is -252.8 °C.



Correct answer: (A)

Problem III.

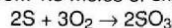
0.100 mole of hydrogen gas occupies 600 mL at 25 °C and 4.08 atm. If the volume is held constant, what will be the pressure of the sample of gas at -5 °C?

- (a) 4.54 atm (b) 3.67 atm (c) 6.00 atm (d) 2.98 atm
(e) 4.08 atm

Correct answer: (b)

Problem II.

Calculate the maximum weight of SO₃ that could be produced from 1.9 moles of oxygen and excess sulfur.

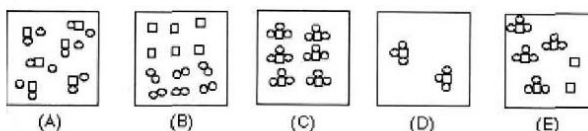


Problem IV.

The equation for a reaction is $2\text{S} + 3\text{O}_2 \rightarrow 2\text{SO}_3$. Consider the mixture of S (□) and O₂ (oo) in a closed container as illustrated below:



Which of the following represents the product mixture?



Correct answer: (E)

Figure M1 An extract used in a workshop reflection task from the article *Concept learning versus problem solving: There is a difference*. (Nakhleh, M.B. & Mitchell, 1993).

The above task was to encourage the PSTs to examine how representations can be used to encourage and challenge students thereby increasing awareness of their own thinking in chemistry. PST responses to this task are discussed in Section 10.2.2.

During the module, as part of an emphasis on the PSTs experiencing metacognitive strategies, the PSTs were given many opportunities to generate and refine their representations of their thinking in relation to chemical phenomena. This was to address PSTs experiencing and using the generation of representations as a metacognitive strategy which provide a domain specific approach to voicing thinking and demonstrating evaluation and consolidation of thinking for oneself and others thereby providing opportunities for increasing metacognitive awareness. For example, in Workshop 1, the PSTs were asked to draw how they visualise H_2O as a gas, a liquid, and a solid, showing any intramolecular and intermolecular bonding (Task 1), with a clear instruction that it was in a supportive environment. I discussed the context of the task before the PSTs began. In this discussion I addressed the important role of a supportive and encouraging atmosphere as part of the culture of a metacognitive approach to teaching chemistry, where students can think freely and express their thinking or difficulties in relation to their understanding in chemistry.

“What I'd like to do now again is to give you a chance to think. I would like you to draw what H_2O is, as a solid liquid and gas with the intermolecular and intramolecular forces. Any sort of an image that you believe represents it in your thinking. What I really want you to do is draw what you imagine them to be. One of the greatest things you can admit, and one of the greatest things you can encourage students to do in your class is admit, that they are not clear on something in chemistry. Even if it's the day before the Leaving Certificate exam and they're able to tell you that they don't know what H_2O is. Then you're in a very good place and you have built up a trusting supportive environment which is an important part of an environment which provides opportunities for personal development in terms of thinking in chemistry” (PR).

M2 Reflective writing and generation of representations

Reflective writing was frequently used as part of workshop assignments/tasks and often overlapped with other metacognitive strategies. The focus of this initial episode is to embed the use of reflective writing and analogies as a teaching and learning strategy into the teaching of Thermochemistry. The focus is to encourage PSTs to independently think about what they know about a topic and to explicitly write down what they thought about and did or did not understand during a chemistry lesson. Reflective writing often took the form of generation of representations based on PSTs' thinking a chemical phenomenon. An example of a reflective

writing prompt used in the workshop in Week 6 of the Methodology module is *Write down or draw representations of five things you think of or visualise when they see chemical equilibrium*. Examples of responses from S5 and S10 are shown in Figure 6.4.

Often following the initial reflective writing task, the PSTs were asked to ‘think aloud’ in relation to their knowledge of a chemical phenomenon. I noted the focus of this task at the start of this episode, and how the use of the PST generated responses would be used as part of a group discussion.

“The PSTs initial task on reflection on what knowledge they had in relation to what they think about or visualise when they see chemical equilibrium gave the students time to construct an initial thinking. Following the completion of the survey three of the PSTs were asked to volunteer what they had indicated they think of and I used this as a way to further introduce the principle of a system at equilibrium. The PSTs highlighted the reversibility of a reaction at equilibrium” (PR Reflection Workshop 6).

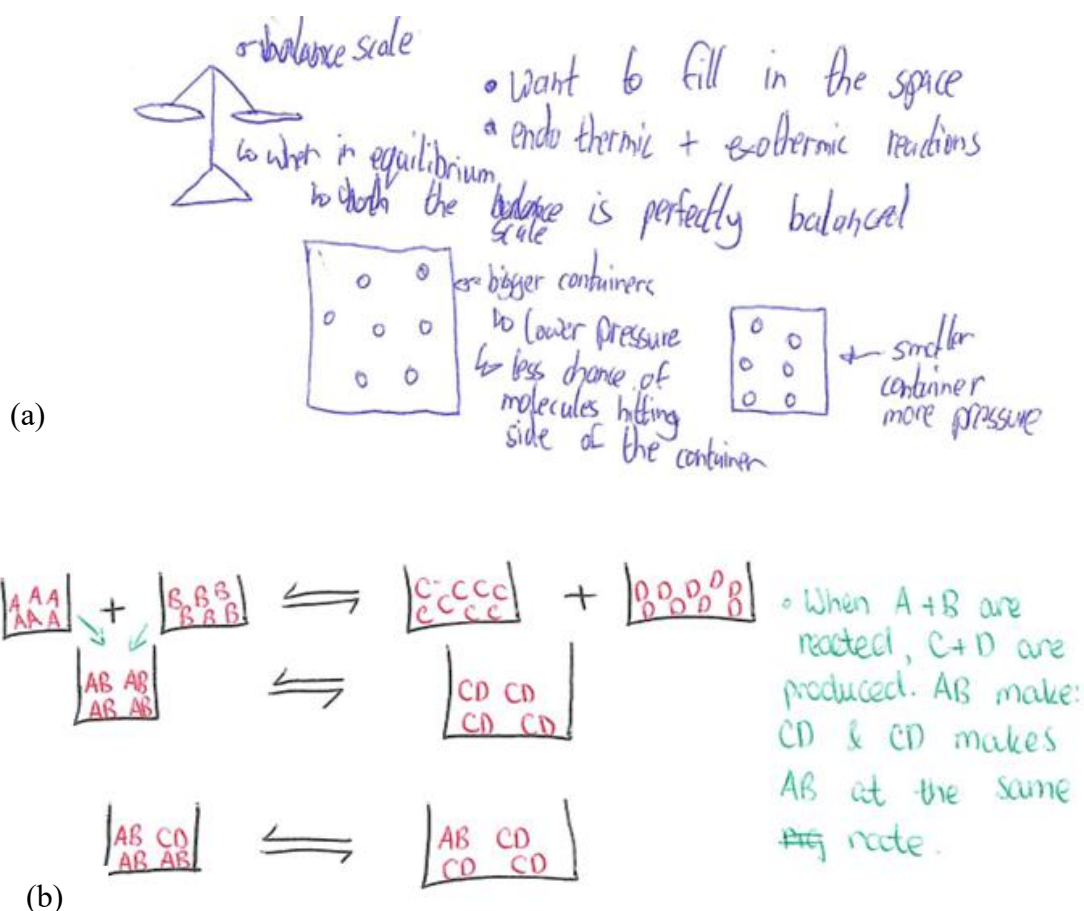


Figure M2 Responses by (a) S5 and (b) S10, to the prompt question: *Write down or draw representations of five things you think of or visualise when they see chemical equilibrium*

M3‘Think aloud’ protocol

The ‘think aloud’ protocol was frequently used as a means to verbalise thinking and metacognitive experiences for a particular chemical phenomenon. In an episode/task from workshop 5 to rank the compounds *butan-2-ol*, *diethyl ethyl*, *butan-1-ol*, *butane* in order of their boiling point, this involved the PSTs drawing representations of their visualisations and then to ‘think aloud’ through their rationale. An example from one PST:

“What I thought was that, because I was looking at the electronegativity values 3, 2.4, and 2.1. I was just looking at this, in particular, I was just looking at that direction, intermolecular bonds, I take this for example there is a dipole there, I was looking at that direction there, the electronegativity values there. I was like, I think the difference there is 0.9, I can’t think of the exact values off the top of my head. I think that was the highest electronegativity difference, the difference is the reason why butan-2-ol is ahead of butan-1-ol is because the carbons around this will stabilise the charge. I think I remember that from organic chemistry. That’s why it’s ahead of butan-1-ol, and then for that, there is this dipole. I was just looking at the rest of the OH in terms of boiling point you’re not looking to break up the entire molecule; it’s just separate from the water molecule. So, if that was like, linked to another etho group of diethyl ether with the boiling point, you just look at the break this bond intermolecular to spread them out. So spread them out. And I was just considering that electronegativity value. So, the amount of energy has to be put in to break that bond, is it going to be higher or lower than OH bond? So, I thought I said that’s going to be lower and therefore its 3rd, then eventually it was like a very, it’s a molecule that doesn’t really have a dipole, unless they are temporary. Doesn’t have a real electronegativity difference there, it’s like 0.4, its small electronegativity difference. So, you’re going to have another molecule and that’s positively charged negative but again there’s no huge difference there. So, it’s not going to take a lot of energy to break that (intermolecular) bond.” (S3, Workshop 5)

The above example of a ‘*think aloud protocol*’ gave an insight to S3’s thinking, helped S3 to formulate their thinking while also being helpful for the other PSTs. S10 argued the use of the ‘think aloud’ protocol which asks students to explain their thinking would increase student metacognition in chemistry.

“I would first do this by encouraging them to always ‘think aloud’. For example, when solving a stoichiometric problem, the student should say to me, their teacher, “I am going to come up with the mole ratio for these two products”, to which I would always reply “Why?”, until it becomes second nature for a student to ask themselves “Why?” to all of their thinking. In this way, a student can have a deeper understanding of not only their thought process, but also can explore more chemistry topics than just the one being asked” (S10)

S10 goes on to indicate they believe the ‘think aloud’ protocol gives a chance to assess student misconceptions and particular challenges that students may face in relation to chemistry understanding are highlighted. S10 also highlights the effect of failing to address misconceptions has on understanding other topics in chemistry.

“Another benefit to students giving their thought process a voice is that misconceptions are more likely to be addressed and dealt with. Often, students have preconceived ideas that do not align with scientific understanding and when they are thinking aloud, these misconceptions or challenges that they did not know they had come to light. When these problems come to the surface, they can be dealt with before they affect the students' understanding of other topics or hinder them having a deeper understanding of the topic at hand” (S10).

M4 Teacher (Teacher educator) led metacognitive discussions

Creating opportunities for metacognitive experiences was promoted through the use of explicitly discussing metacognition in the context of chemistry. In an example of metacognitive discussion I led, I highlighted how our understanding of the concepts changes as we think more deeply about them or use them in different contexts for a student. In an episode in Workshop 3, the PR began the episode by stating the following:

“Linking underlying concepts in chemistry while also being aware of your thinking in chemistry is a fundamental part of understanding and teaching the subject. Therefore, we need to examine the key concepts that underlie the topic under consideration e.g., the key concepts when we considered states of matter [] related to the particular nature of matter and the intra and intermolecular bonds in water molecules, and the degree of energy in the states of matter, and how these are represented” (PR).

The PSTs looked at how their own thinking has changed to this point in relation to these diagrams. The PR highlights the importance of thinking in chemistry and being aware of exercising mental strategies to address understanding and problem solving in chemistry. An analogy is used to contrast methods of thinking and problem-solving.

“It’s not easy if you have not done it before. The more you do it in this module. These ideas around thinking and chemistry, like the metacognition, is basically to ensure that the students are aware of their own knowledge and thinking, and how they’re thinking when they are having difficulty solving a problem. Thinking about the examples you gave last week in relation to what you do when you are having difficulty. People Google it, Google is like sweets, or sugar. Whereas taking the time to use your own thinking is like porridge. Sugar feels good, and lasts a short length of time. Whereas if you go to the hassle of eating the porridge, and what I mean by that is giving yourself thinking time

and taking the time to think about how you are thinking about a chemistry problem, your thinking will develop and become more transferrable to other chemistry problems. So really, what it comes down to is what we discussed last week, where we want to teach students to fish or develop their own awareness about how they think about chemistry concepts, rather than handing them a fish, or telling them information” (PR).

I highlighted the Hansel and Gretel analogy used in the last episode for being aware of the paths your thinking takes, and the importance of time and reflection on thinking strategies.

“How to get students to describe and become more aware of their own thinking in chemistry, so that they are like Hansel and Gretel, in that they drop breadcrumbs as they are thinking about chemistry. And they can walk that ‘thinking’ path again when they see a concept may apply to another topic” (PR, Workshop 6).

I highlighted the overlapping nature of metacognition, and generation of representations;

“So, we’re constantly explicitly reinforcing and discussing metacognition, concepts, representations and visualisations of chemistry. But the difference in Leaving Cert, while you are constantly reinforcing, but you won’t be explicitly teaching the students those. Does that make sense? You will be teaching them how to demonstrate their thinking, and how to represent their thinking, whether that’s in a diagram or using an underlying concept. For example, you ask students to draw diagrams of a topic, because it represents their thinking, you then use metacognitive prompts to discuss their thinking represented, or ask them to ‘think aloud’ while redrawing their representation in front of the class” (PR)

M5 Teacher explicit metacognitive instruction

Providing the PSTs with opportunities for their own metacognitive experiences, but also having a sound understanding of metacognition in the context of chemistry was embedded within the methodology module. I explicitly addressed metacognition as it applies to chemistry, introducing the concept of metacognition within the module in Workshop 2 using an analogy.

PR: What happens in Gogglebox who are you watching?

S12: You’re watching people watch TV.

PR: Exactly you’re watching people watch TV. If I said this, was you thinking (pointing at an image of a person watching TV). Metacognition is watching yourself watch TV, and regulating what you watch based on watching yourself.

PR: In chemistry, metacognition is being aware of, and influencing the links you create in your thinking about a topic. If you know how you understand something, if you understand that to get your head around this topic you must draw a visual representation or link it to an underlying concept to help you think. That you are ‘watching’ or aware

of what thinking strategy is necessary to get over a problem or to understand the concept, you 'regulate' by thinking of possible alternative ways of thinking about the concept, and reflecting how this topic relates to a way I thought about another topic. When you're not directly thinking about the problem or concept, but rather metacognition is when you're watching, being aware, controlling, monitoring, your own thoughts when learning chemistry".

The above dialogue provides an example of my approach to explicitly addressing metacognition as a concept, the language used through the analogy was to challenge PSTs to think about it, rather than proving a definition such as "thinking about thinking". I noted in my workshop reflection how "*it may be easier to just say its "thinking about thinking", but I think that is very reductionist and that provides a unchallenging interpretation, almost preventing a deeper understanding of metacognition especially in the context of chemistry*".

M6 Metacognitive modelling by the teacher

Similar to the 'think aloud' protocol, modelling metacognition provides further explanation of the concept of metacognition in a personal domain specific way. Metacognitive modelling often took place embedded within other metacognitive strategies such as generation of representations. An example of metacognitive modelling from workshop 6 of the module, I modelled how I reflected on their my thinking in the past while in the car on my journey to the workshop.

"I always thought to myself when I was struggling in chemistry, whether it was an undergraduate level or whatever level, how do I get over my difficulty in understanding this chemical phenomenon? An example of this was for a biochemistry topic when I was in university. I could not understand the very straightforward level of Krebs cycle, the surface level I mean, listing the steps etc. I remember being in the library. The biochemistry exam was in a week's time. I spent the whole day scratching the surface of the Krebs Cycle by trying to remember it. It effectively was cognitive overload, too many bits of information. I then realised it was just a waste of time for my thinking processes. I realised it's not going in, and it's not going to go in, using this strategy. I thought to myself this strategy is just not working for me. I decided to change my approach to learning the Krebs cycle. I spent the next day, reading two textbooks on the Krebs cycle, reading and understanding way above what was required for that biochemistry course, looking at the underlying chemistry. I had actively changed my thinking approach completely, and that had a subsequent effect on how I actually thought about chemistry from that point on. I realised for my thinking, I need to chunk information by linking it to underlying concepts" (PR)

The above example I demonstrated all three subcategories of metacognitive awareness, i.e., MDK (e.g. *I had actively changed my thinking approach completely, and that had a subsequent effect on how I actually thought about chemistry from that point on. I realised for my thinking, I need to chunk information by linking it to underlying concepts*), MPK (*I spent the whole day*

scratching the surface of the Krebs Cycle by trying to remember it. It effectively was cognitive overload, too many bits of information. I then realised it was just a waste of time for my thinking processes. I realised it's not going in, and it's not going to go in, using this strategy.), and also metacognitive regulation in terms of MM (*I always thought to myself when I was struggling in chemistry, whether it was an undergraduate level or whatever level, how do I get over my difficulty in understanding this chemical phenomenon?*).

M7 Metacognitive prompts

In an example of the use of metacognitive prompts, when S3 described their thinking and generated representations on the board as part of the ‘think aloud’ protocol in relation to electronegativity and polarity for the molecules, I used some prompts to promote metacognition. Examples included “*Was there a different way to think about it?*” “*What does that line [in a representation] mean?*” “*Where did you learn to think about the molecules that way first?*”, “*Did you think about another topic like states of matter or chemical bonding in a similar way?*”. Other examples include during the generation of representations of an acid base theory, the metacognitive prompts included “*write down your thinking, explain your thinking*” “*Is there an alternative way to think about this topic?*” “*Can you make links to how you think about redox reactions, is there a similar thinking process related to the loss and gain of protons as there is to the loss and gain of electrons even though they are completely separate chemical processes, can you think about them in a similar way?*”. Metacognitive prompts were widely used throughout the module and were embedded in the other metacognitive strategies, to both promote opportunities for metacognitive experiences for the PSTs and to model their use in teaching.

Appendix P PST methodology module MOLES-S survey data (AR Cycle 5)

Table N1 Mean PST score for each item within the subcategories of the MOLES-S survey

MOLES Subcategory	MOLES Question	Mean Score (1-5)
Metacognitive demands	Students are asked by the teacher to think about how they learn chemistry.	4.9
	Students are asked by the teacher to explain how they solve chemistry problems.	5.0
	Students are asked by the teacher to think about their difficulties in learning chemistry.	4.7
	Students are asked by the teacher to think about how they could become better learners of chemistry.	4.7
	Students are asked by the teacher to try new ways of learning chemistry.	4.7
Student-student discourse	Students discuss with each other about how they learn chemistry.	3.8
	Students discuss with each other about how they think when they learn chemistry.	3.8
	Students discuss with each other about different ways of learning chemistry.	3.5
	Students discuss with each other about how well they are learning chemistry.	3.4
	Students discuss with each other about how they can improve their learning about chemistry.	3.6
Student-teacher discourse	Students discuss with the teacher how they learn chemistry.	4.4
	Students discuss with the teacher about how they think when they learn chemistry.	4.8
	Students discuss with the teacher about different ways of learning chemistry.	4.4
	Students discuss with the teacher about how well they are learning chemistry.	3.8
	Students discuss with the teacher about how they can improve their learning of chemistry	4.3
Student voice	It is OK for students to tell the teacher when they don't understand chemistry.	4.8
	It is OK for students to ask the teacher why they have to do a certain activity.	4.1
	It is OK for students to suggest alternative chemistry learning activities to those proposed by their teacher.	3.9
	It is OK for students to speak out about activities that are confusing	4.5
	It is OK for students to speak out about anything that prevents them from learning.	4.5
Distributed control	Students help the teacher plan what needs to be learned.	3.2
	Students help the teacher decide which activities they do.	2.8
	Students help the teacher to decide which activities are best for them.	2.9
	Students help the teacher decide how much time they spend on activities.	2.7
	Students help decide when it is time to begin a new topic.	2.5
Teacher encouragement and support	The teacher encourages students to try to improve how they learn chemistry.	4.7
	The teacher encourages students to try different ways to learn chemistry.	4.7
	The teacher supports students who try to improve their chemistry learning.	4.7
	The teacher supports students who try new ways of learning chemistry.	4.5
	The teacher encourages students to talk with each other about how they learn chemistry.	4.6
Emotional support	Students are treated fairly.	4.9
	Students' efforts are valued.	4.9
	Students' ideas are respected.	4.9
	Students' individual differences are respected.	4.9
	Students and the teacher trust each other.	4.9

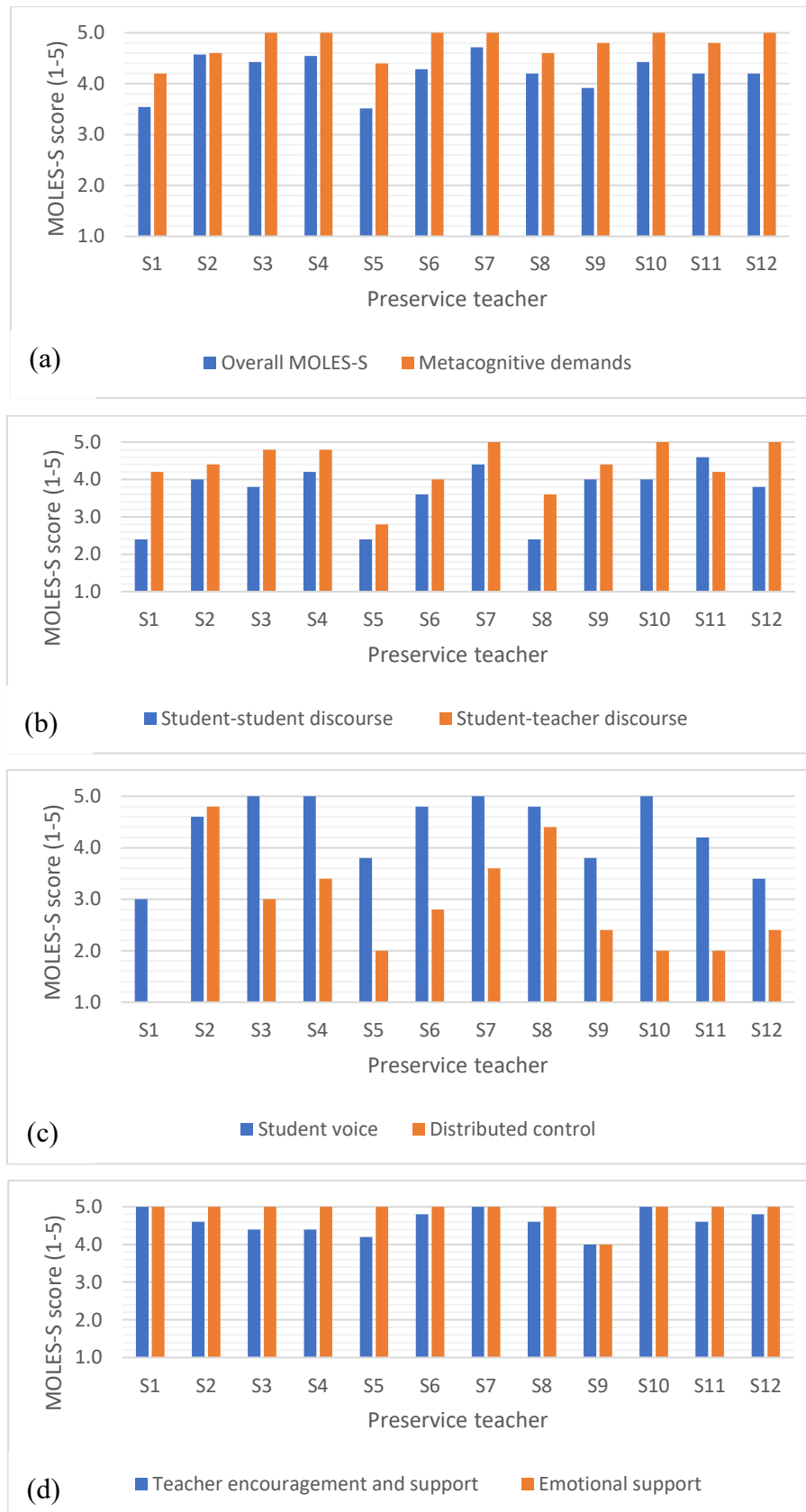


Figure N1 Individual scores for MOLES-S and subcategories based on Methodology module experience. (a) *Overall mean and metacognitive demands*; (b) *Student-student discourse, and Student-teacher discourse*; (c) *Student voice and distributed control* (d) *Teacher encouragement and support, and Emotional support*

Appendix Q PST methodology module MAI survey data (AR Cycle 5)

Table Q1 Mean PST scores for individual MAI items of *metacognitive awareness*

MAI Subcategory	Item	Pre (1-5)	Post (1-5)	Change
Declarative knowledge	I understand my intellectual strengths and weaknesses.	3.5	4.1	0.6
	I know what kind of information is most important to learn.	3.8	4.0	0.3
	I am good at organising information.	3.9	3.8	-0.1
	I know what the teacher expects me to learn.	2.9	3.4	0.5
	I am good at remembering information.	3.7	4.0	0.3
	I have control over how well I learn.	4.0	3.9	-0.1
	I am a good judge of how well I understand something.	3.5	4.0	0.5
	I learn more when I am interested in the topic.	4.9	4.8	-0.1
Procedural knowledge	I try to use strategies that have worked in the past.	4.5	4.6	0.1
	I have a specific purpose for each strategy I use.	2.9	3.9	1.0
	I am aware of what strategies I use when I study.	3.4	3.6	0.2
	I find myself using helpful learning strategies automatically.	3.2	3.9	0.8
Conditional knowledge	I learn best when I know something about the topic.	4.6	4.7	0.1
	I use different learning strategies depending on the situation.	2.8	4.1	1.3
	I can motivate myself to learn when I need to	3.6	3.3	-0.3
	I use my intellectual strengths to compensate for my weaknesses.	3.5	3.7	0.2
	I know when each strategy I use will be most effective.	2.8	3.5	0.7

Table Q2 Mean PST scores for individual MAI items of *metacognitive regulation*

Subcategory	Question	Pre (1-5)	Post (1-5)	Change
Planning	I pace myself while learning in order to have enough time.	3.2	3.3	0.2
	I think about what I really need to learn before I begin a task	3.2	4.0	0.8
	I set specific goals before I begin a task.	2.8	3.3	0.5
	I ask myself questions about the material before I begin.	2.2	3.0	0.8
	I think of several ways to solve a problem and choose the best one.	2.4	3.4	1.0
	I read instructions carefully before I begin a task.	4.0	4.2	0.2
	I organise my time to best accomplish my goals.	2.8	3.5	0.7
Information management strategies	I slow down when I encounter important information.	4.3	4.5	0.2
	I consciously focus my attention on important information.	3.2	4.1	0.9
	I focus on the meaning and significance of new information.	3.4	4.0	0.6
	I create my own examples to make information more meaningful.	3.0	3.7	0.7
	I draw pictures or diagrams to help me understand while learning.	3.7	4.3	0.5
	I try to translate new information into my own words.	3.7	3.8	0.2
	I use the organisational structure of the text to help me learn.	3.3	3.3	0.0
	I ask myself if what I'm reading is related to what I already know.	3.4	3.8	0.4
	I try to break studying down into smaller steps.	3.9	4.2	0.3
	I focus on overall meaning rather than specifics.	2.9	3.7	0.8
Comprehension monitoring	I ask myself periodically if I am meeting my goals.	3.0	4.0	1.0
	I consider several alternatives to a problem before I answer.	2.5	3.8	1.3
	I ask myself if I have considered all options when solving a problem.	2.8	3.6	0.8
	I periodically review to help me understand important relationships.	2.4	3.4	1.0
	I find myself analysing the usefulness of strategies while I study.	2.6	3.2	0.6
	I find myself pausing regularly to check my comprehension.	3.8	3.5	-0.3
	I ask myself questions about how well I am doing while I am learning something new.	2.8	3.6	0.8
Debugging strategies	I ask others for help when I don't understand something.	4.7	4.7	0.0
	I change strategies when I fail to understand.	3.4	3.7	0.3
	I re-evaluate my assumptions when I get confused.	3.5	3.8	0.3
	I stop and go back over new information that is not clear.	3.9	4.2	0.3
	I stop and reread when I get confused.	4.4	4.4	0.0
Evaluation	I know how well I did once I finish a test.	3.7	3.7	0.0
	I ask myself if there was an easier way to do things after I finish a task.	2.8	3.5	0.7
	I summarise what I've learned after I finish.	3.5	3.8	0.3
	I ask myself how well I accomplish my goals once I'm finished.	2.8	3.3	0.4
	I ask myself if I have considered all options after I solve a problem.	2.2	3.2	1.0
	I ask myself if I learned as much as I could have once I finish a task.	2.7	3.3	0.6

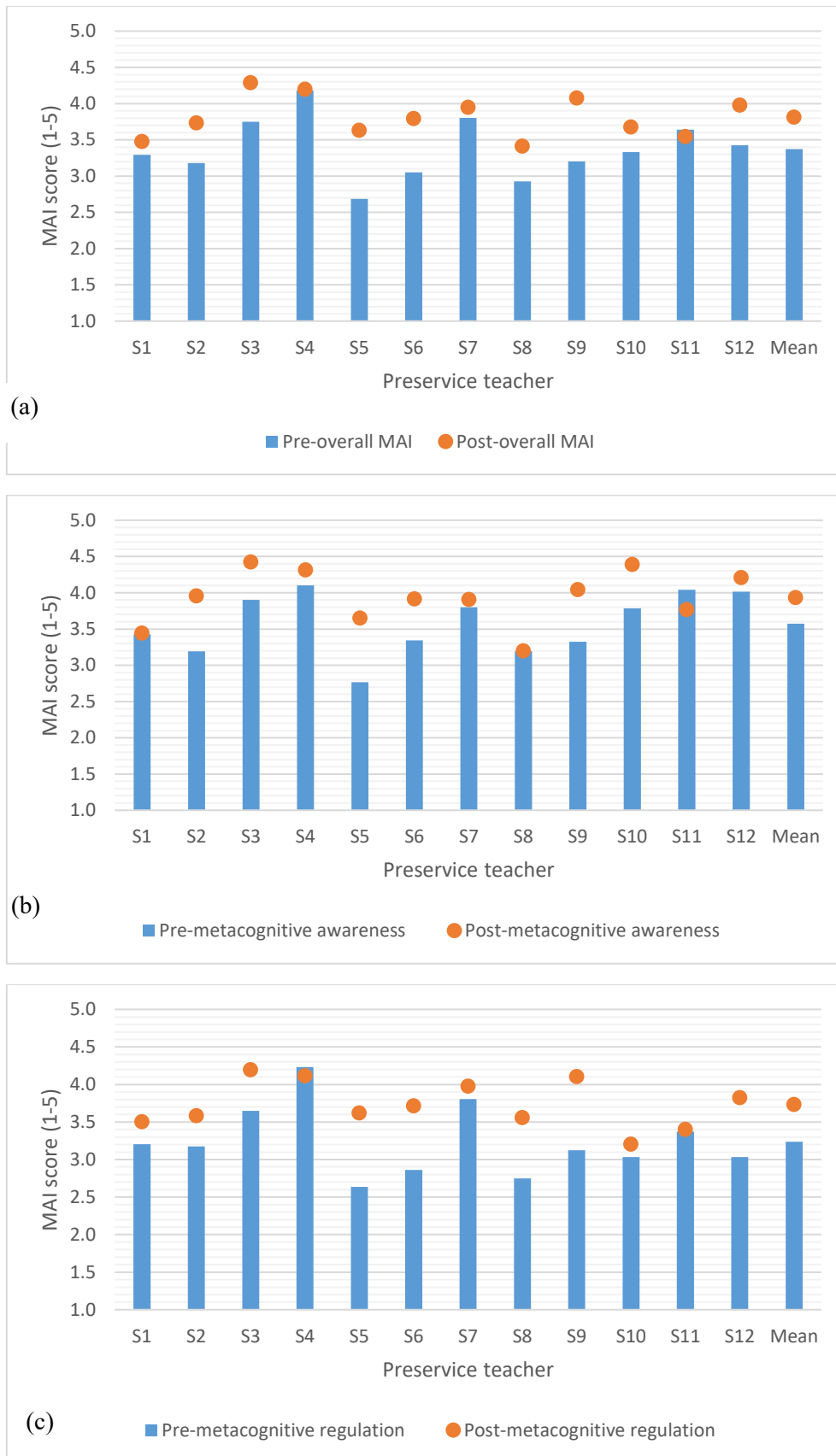


Figure Q1 MAI scores pre and post module mean scores. (a) *overall* (b) *metacognitive awareness* and (c) *metacognitive regulation*. The bar chart indicates the initial score at the beginning of the module, the orange dot indicates the score at the end of module

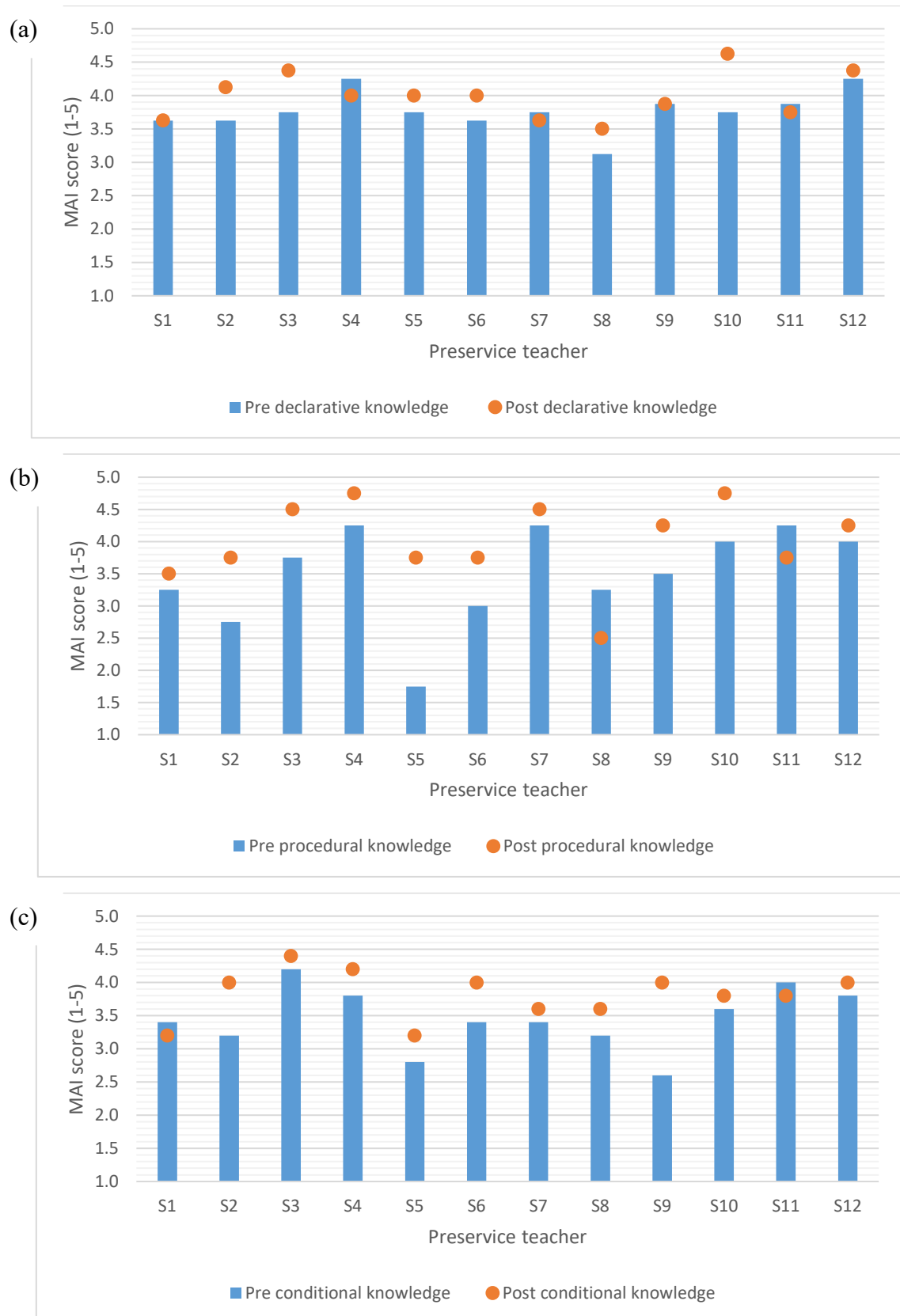


Figure Q2 Metacognitive awareness and subcategories - individual PST scores. (a) *declarative knowledge* (b) *procedural knowledge* (c) *conditional knowledge*. The bar chart indicates the initial score at the beginning of the module, the orange dot indicates the score at the end of methodology module

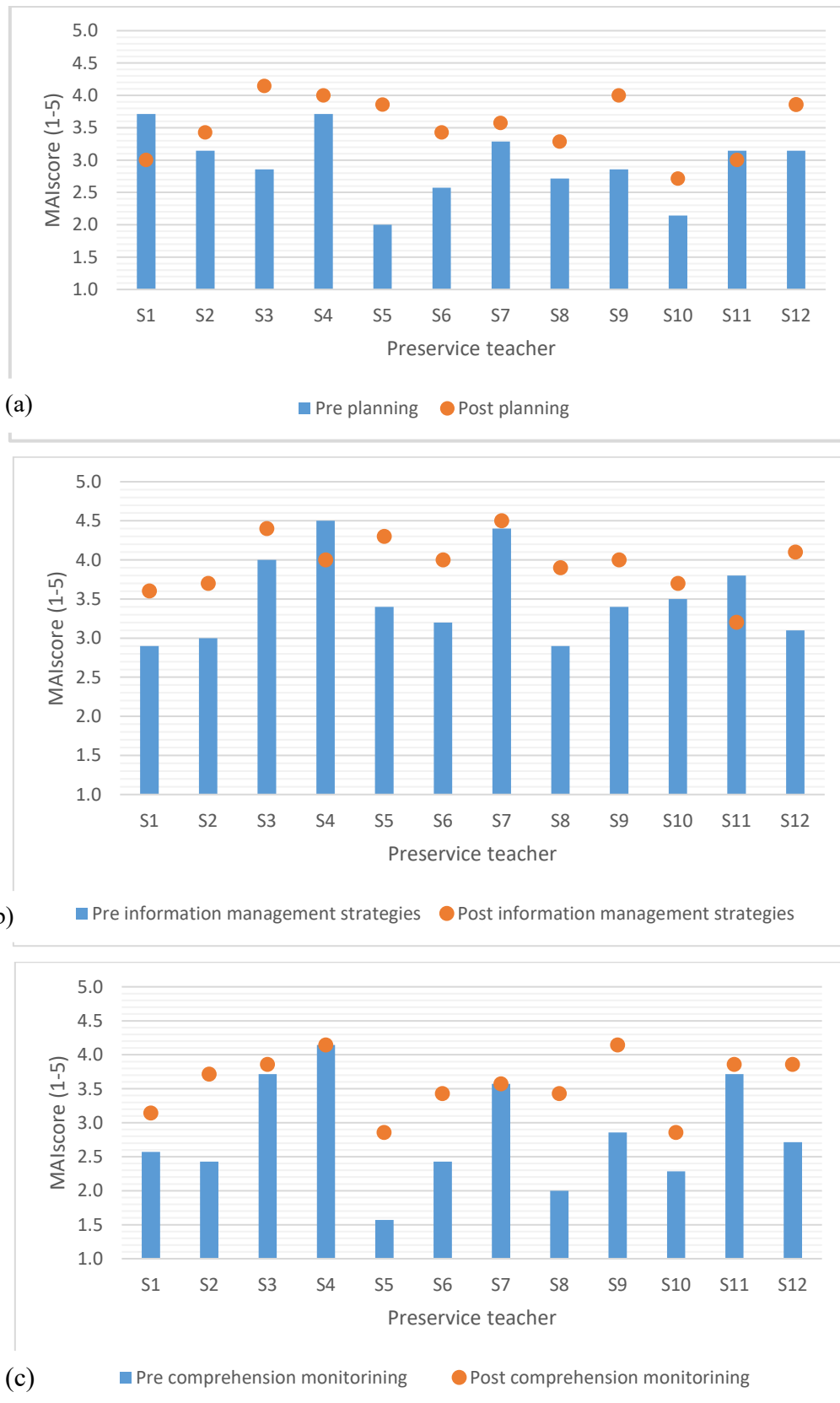


Figure Q3 Metacognitive regulation and subcategories - individual PST scores (1-5). The bar chart indicates the initial score at the beginning of the module, the orange dot indicates the score at the end of module.

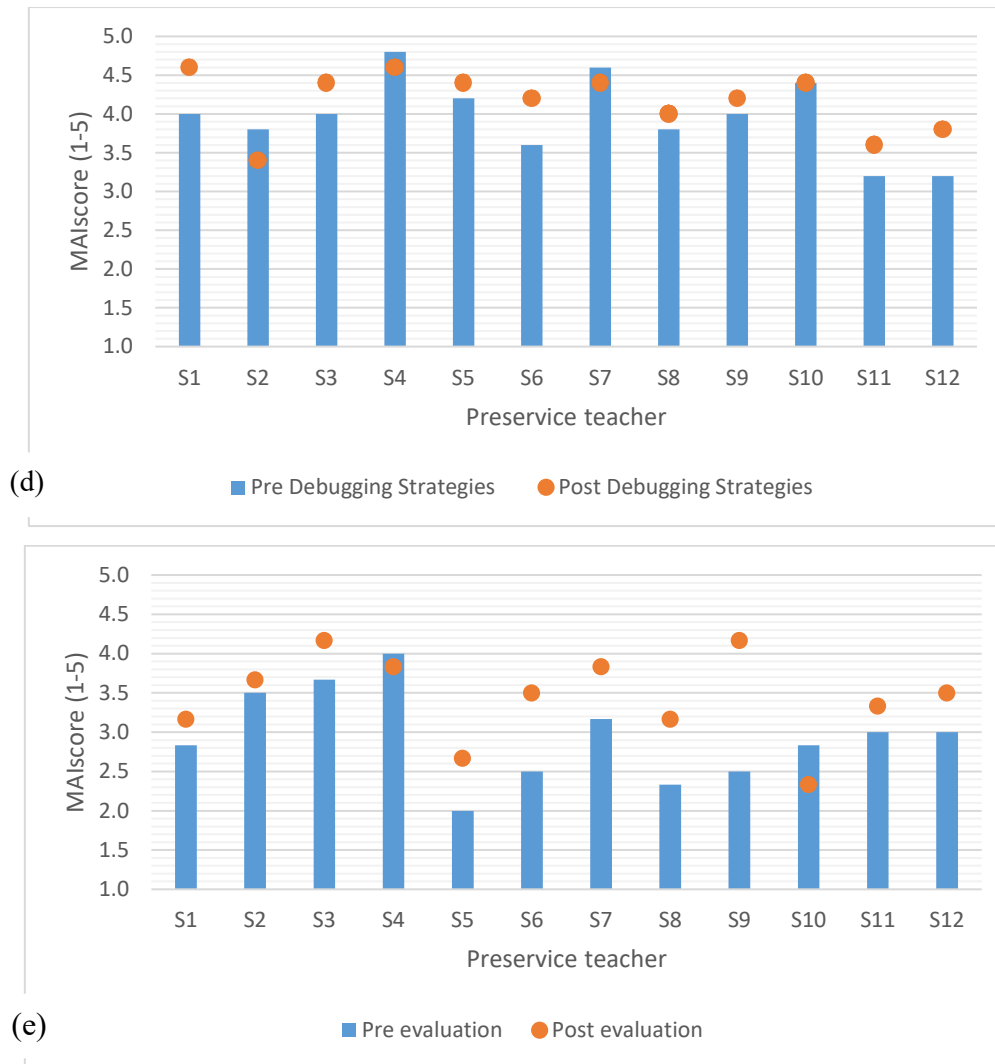


Figure Q3 Continued Metacognitive regulation and subcategories - individual PST scores (1-5). The bar chart indicates the initial score at the beginning of the module, the orange dot indicates the score at the end of module.

Appendix R PST Case Studies – Methodology Module (AR Cycle 5)

R.1 The Case of S12

R.1.1 S12's experience and knowledge of metacognition in chemistry

Based on S12's responses to the items in the MOLES-S, it can be interpreted that their perception of their senior cycle experience was not particularly metacognitively orientated. Therefore, it is important they experience metacognitive strategies before they implement them as teachers (Kallio et al., 2021). S12's scores for the various subcategories in the MOLES-S are shown in Figure 11.1.

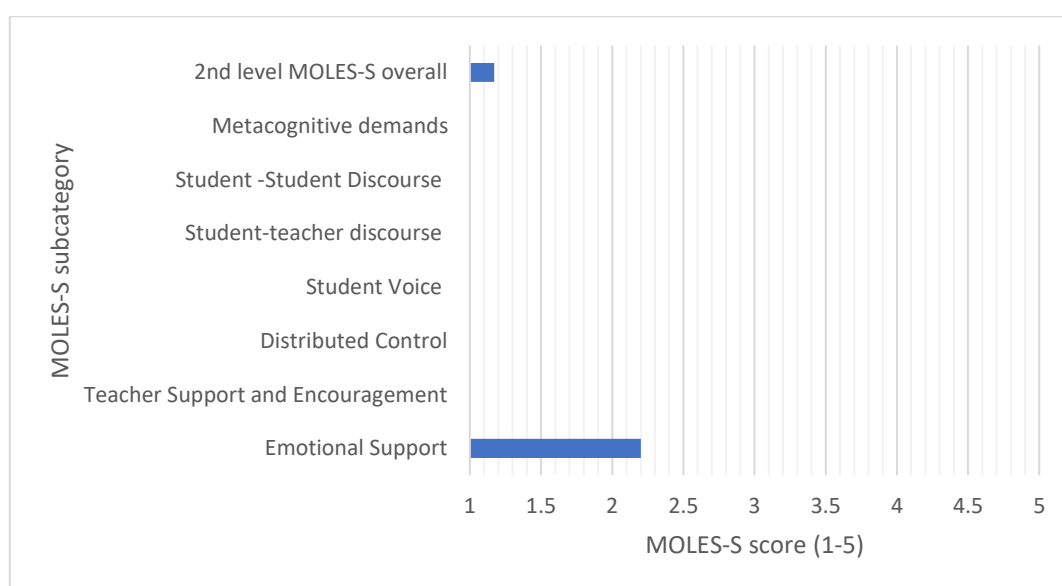


Figure R.1 Scores in subcategories of the MOLES-S survey for S12 in relation to their experience in senior cycle chemistry

Reflecting on their senior cycle chemistry experience, S12 perceived it to be based on “*memorisation, and learning off definitions*”. They also described doing “*calculations all the time but never understanding what they meant*”. When asked how they could become better learners of chemistry at senior cycle, S12 indicated how they would have attempted “*to understand the topics instead of just learning them off*”. This description of their senior cycle experience is similar to experiences described in previous literature where there can be a focus on rote learning in preparation for high stakes examinations such as the Irish Leaving Certificate examinations (Nuthall, 2005; Banks & Smyth, 2015).

S12 scores for the subcategories of the MOLES-S in relation to the methodology module are shown in Figure R.2. Interpreting S12's responses for the subcategories of MOLES-S for the

methodology module, it can be argued they found the methodology module metacognitively demanding, and that the environment in the workshops was metacognitively orientated. This is reflective of the metacognitive culture I aimed to embed in the workshops and is in agreement with my reflections (See section R.4).

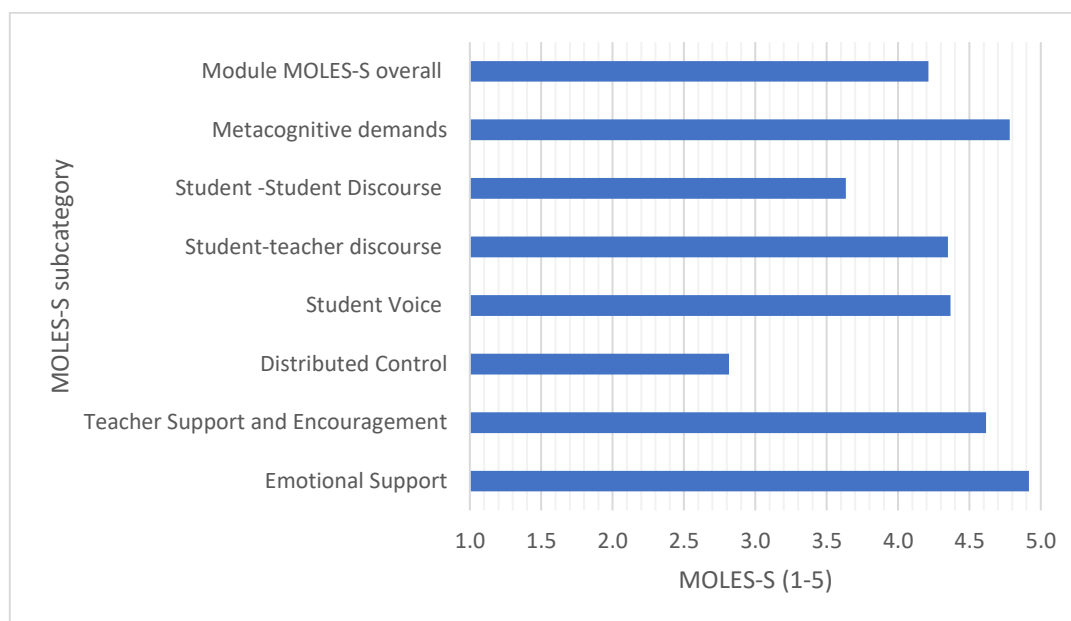


Figure R.2 Scores in subcategories of the MOLES-S survey in relation to S12's experience in the methodology module

S12 demonstrated growth in their interpretation of metacognition throughout the duration of the module. For example, S12 described metacognition as “*a thinking process in which students look internally and monitor and assess their own comprehension and thinking of a given topic*”. This description focuses on metacognitive regulation.

S12's descriptions included ME, for example they reflected on their own cognitive processes in senior cycle and now as a PST in relation to the topic of radioactivity.

“One example of this that I have discussed before is the Beta decay reaction in the radioactivity chapter. When I was doing my leaving certificate, I just learnt the general formula for a beta reaction and that was all I did for the exam. It wasn't until I had to practice teaching the topic in a workshop [when] I started to use metacognition and evaluate my own thinking of the reaction. I had no idea how to explain why the atom lost an electron but somehow gained a proton and moved up on the periodic table. I thought deeper about one type of reaction on the course. I evaluated my own thinking and revealed that what I really knew about it, was just some general formula and definition that I memorised. Through this, I developed my own understanding of the process which I can share with my students and help develop their understanding of it too. I also asked myself loads of questions as to why does the beta decay reaction do that?” (S12).

The above example demonstrates S12's metacognition in terms of MDK (e.g. *I had no idea how to explain why the atom lost an electron but somehow gained a proton and moved up on the periodic table*) MPK related to how they think (e.g. *"I just learnt the general formula"*) and ME (e.g. *"I evaluated my own thinking and revealed that what I really knew about it, was just some general formula and definition that I memorised"*). S12 also demonstrates their awareness of the evolution of their cognitive processes *"I developed my own understanding of the process which I can share with my students and help develop their understanding of it too. I also asked myself loads of questions as to why does the beta decay reaction do that?"*. The above description is an example of metacognition in chemistry where one is aware of the cognitive processes induced by constantly probing and testing the robustness of knowledge (See Fleming, et al., 2012). S12 demonstrated MPK and ME while reflecting on their senior cycle experience and its potential impact on their teaching practice during a discussion in the final workshop of the module. *"I would like to spend more time on the mole concept, that was such a huge misunderstanding that I had in senior cycle. I would like to spend more time on how to introduce this to a class"*.

Further evidence of S12's development in metacognition during the module is reflected in an increase in their overall mean score on the MAI survey. This increase was primarily attributed to an improvement in the subcomponent of metacognitive regulation, rather than metacognitive awareness as shown in Figure R.3. The relatively high mean score for metacognitive awareness at the start of the module helps explain this trend.

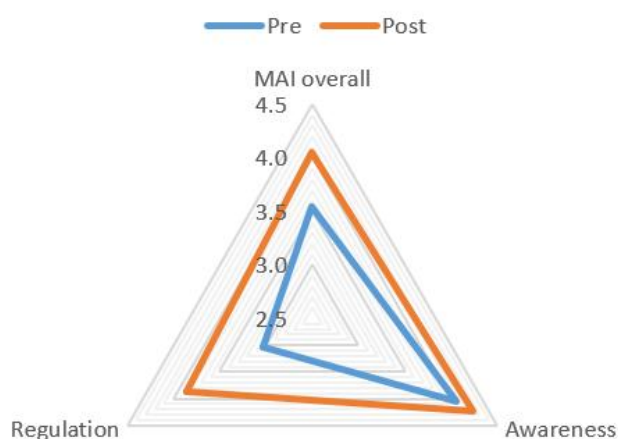


Figure R.3 MAI mean scores for S12 – for overall MAI, metacognitive awareness and metacognitive regulation - pre and post the methodology module

S12's showed a relatively large increase in the subcategories of MCK and MPK in the MAI subcomponent of metacognitive awareness, while their MDK was the highest of the subcomponents of metacognitive awareness both at the start, and at the end of the module (Figure R.4).

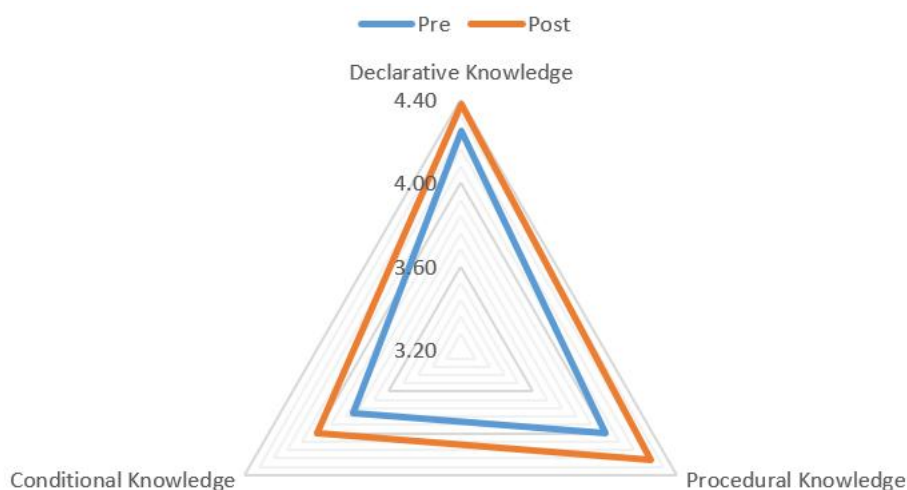


Figure R.4 Subcategories of metacognitive awareness - mean S12 scores- pre and post the methodology module

S12 demonstrated MDK when reflecting on their cognitive processes in relation to endothermic and exothermic reactions in senior cycle education where they described how they are now aware they “*learnt a bunch of definitions and formulas with no real deeper understanding going on*”. S12 indicates they now believe had they taken a metacognitive approach they would have “*been able to evaluate this method of learning and realise that it was not efficient at all*”. S12 indicated the relevance of visualisation and generating representations as part of increasing metacognitive awareness, where they indicated they have realised “*a much more beneficial way of thinking about this topic is through visualisation. Drawing of bonds breaking, and bond making, and the energy going in and out of the system would have provided a greater level of understanding*”. While visualisations and understanding are cognitive processes, the metacognitive aspect here is S12’s awareness of their understanding and visualisations in chemistry. S12 highlighted how incorporating metacognition (MDK and ME) is important at senior cycle chemistry as it “*gives students time to think and reflect on why they are struggling to come to terms with grasping a chemistry topic and for them to identify new methods to help them achieve their learning goals*”. S12’s emphasis on metacognitive regulation in the examples above, are reflected in their MAI scores where there was a relatively large increase ($\geq 10\%$) in all subcategories of metacognitive regulation as shown in Figure R.5.



Figure R.5 Subcategories of metacognitive regulation - mean S12 scores- pre and post the methodology module

The relatively large increases in S12's mean MAI scores for metacognitive regulation when compared with metacognitive awareness could also be explained through S12's initial MAI data indicating a relatively low mean MAI score metacognitive regulation. The MAI data and comments made by S12 suggest their experience in the methodology module helped develop their metacognition in chemistry.

R.1.2 S12's generation of representations

In a task in Workshop 1, S12 was asked to represent how they visualise H_2O as a gas, a liquid, and a solid in any representation they wished, showing any intramolecular and intermolecular bonding (Task W1)

S12's representations, shown in Figure R.6, give rise to several areas of discussion in relation to what the various parts of the representations mean. For example, S12's representation of the liquid and the gas contain no indications of motion of molecules, also in terms of the length of the (assumed) $H-O$ bonds, there is an unexplained difference in representations underneath and above the wavy line.

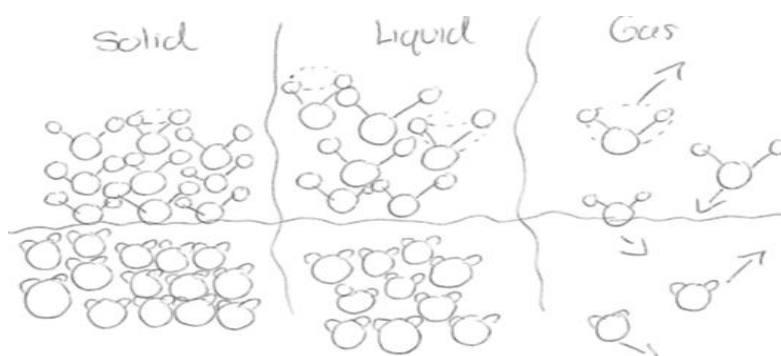


Figure R.6 S12's response to Task W1 in the first workshop; *Draw how you visualise H_2O as a gas, a liquid, and a solid in any representation you wish, showing any intramolecular and intermolecular bonding?*

In the third workshop, following group discussions and reviews of the PSTs representations, S12 regenerated their representation (Task W3). S12's representation shows a much greater level of detail of their visualisation in comparison to their earlier representation (Figure R.7). They have indicated the "pull" on the electrons towards the oxygen giving rise to the polarity of the water molecule, they have shown the bonding taking place in the molecule of water through the use of Bohr diagrams for hydrogen and oxygen and the possible vibrating of solid molecules, rolling nature of liquid molecules and the motion displayed by the gaseous H_2O . The orientation of the H_2O molecules which was noted as a possible error in their earlier representation appears to be addressed, e.g., they have represented the specific orientation of two molecules at the bottom of the representation for the solid.

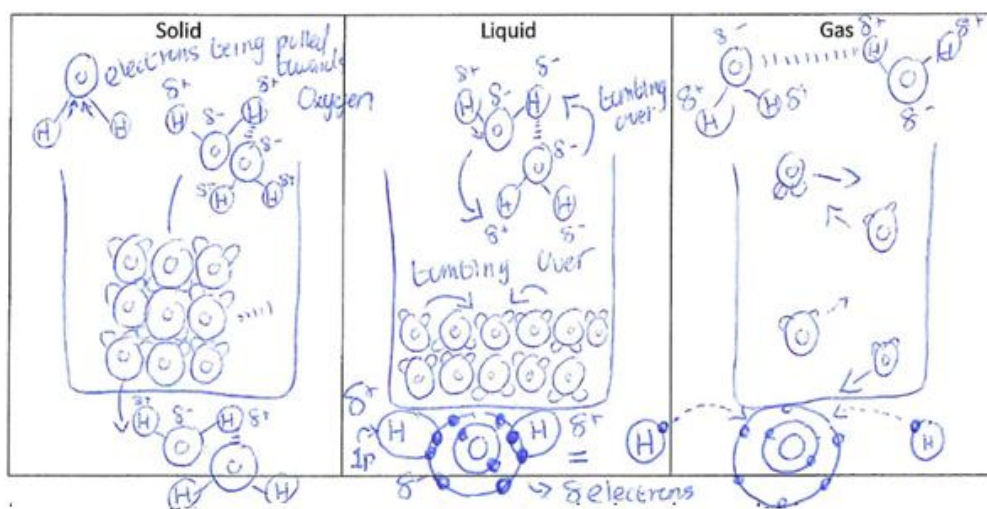


Figure R.7 S12's response to Task W3 in the third workshop; *Draw your representations of how you visualise H_2O as a gas, a liquid, and a solid in any representation you wish, showing any intramolecular and intermolecular bonding?*

The design of the module where the PSTs experience the metacognitive strategies was an integral part of addressing metacognition in the module design. For example, throughout the process of generating, reflecting on, discussing, and revising representations during the first three workshops, S12's descriptions of their cognitive processes became increasingly detailed. They demonstrated a growing awareness of the voice, evolution and consolidation of their cognitive processes. S12 demonstrated ME, providing evidence of their awareness of the evolution of their cognitive processes through the use of representations in the workshops. This was particularly evident in their representations of H_2O and their understanding of the underlying concept of electronegativity, along with the cognitive processes activated by these representations, as indicated in the following description.

"I didn't think much about the molecules when it came to the first time doing representations. Now, I think about the motion of the molecules and their attraction towards each other in all three states. I went from understanding very little and not being able to recall a lot to being able to draw and represent intramolecular and intermolecular forces for all states of matter. I used to think that intramolecular forces were different between all three states. I think more about the underlying concepts such as motion, electronegativity, in terms of developing a more realistic diagram of what I think is going on at this level" (S12)

This exemplifies how incorporating descriptions of cognitive processes related to the generation of representations in the module serves as a domain-specific approach to incorporating metacognition in chemistry, offering a better indication of the cognitive processes compared to a solely word-based approach. Another example of the power of representations in providing opportunities for metacognition in chemistry, S12's representation of their cognitive processes related to chemical equilibrium through the example of ammonia in Part 1 of their final assignment (see Table 9.4) is shown in Figure R.8. An interesting observation to note in relation to this example is that at the end of the fifth workshop of the module, when I asked the PSTs to generate a representation of how they visualise chemical equilibrium, S12 was able to write the equation and associated formula for the equilibrium constant (K_c). However, when asked, they were unable to depict any representation of how they visualise chemical equilibrium at the submicroscopic level within the five-minute timeframe I provided. In my reflections, I noted this as an observation across the group of PSTs in that workshop: *"They [PSTs] are well able to write the K_c formula and the associated generic equation, but they are unable to represent what chemical equilibrium looks like at the submicroscopic level."* This aligns with previous research suggesting that chemistry students

are often proficient in calculations but may struggle with cognitive processes related to the submicroscopic level (e.g., Harrison & Treagust, 2002).

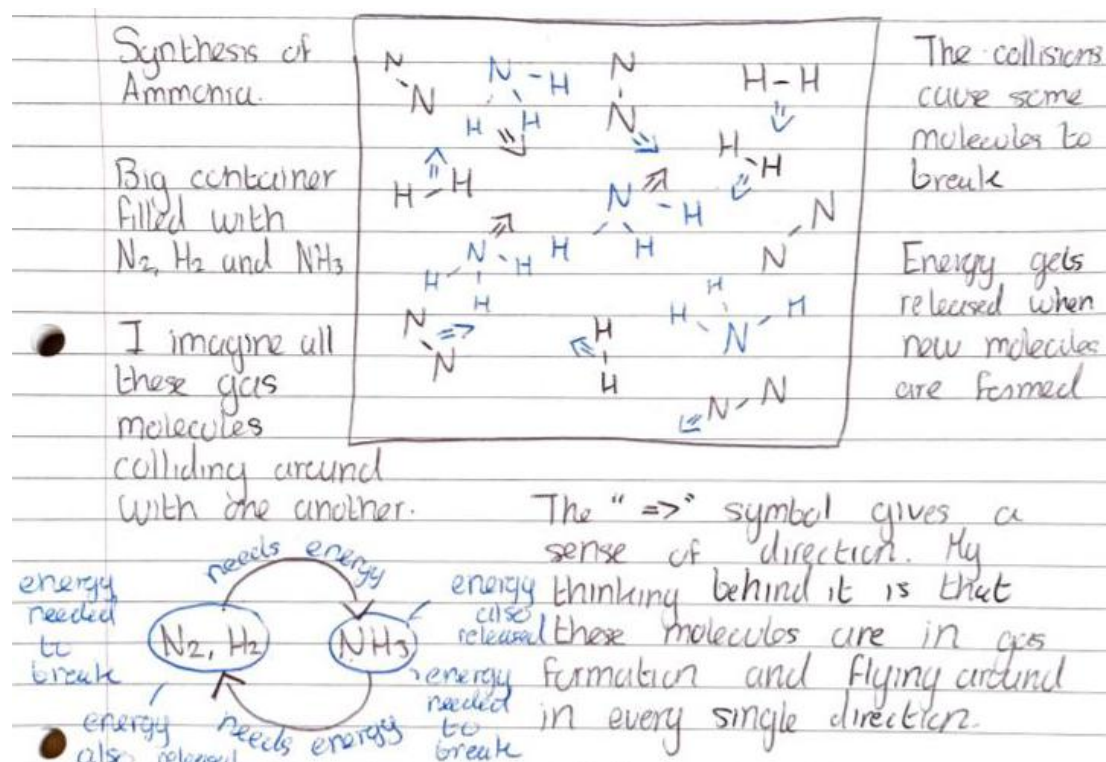


Figure R.8 Representation by S12 of energy in a reaction at equilibrium

S12's associated explanation of their cognitive processes related to their representation of chemical equilibrium provides evidence of their awareness of their own MDK in terms of their cognitive processes related to submicroscopic level of the chemistry.

"This is a representation of my thinking when it comes to energy involved surrounding the synthesis of ammonia. I drew a big container filled with nitrogen, hydrogen and ammonia gases. I imagine that they are all crashing into each other at high speeds. My thinking behind this process is that the energy is in a cycle. Energy is needed to break the ammonia (NH_3) molecule and released when hydrogen (H_2) and nitrogen (N_2) are formed. This is the endothermic reaction as more energy is needed to break the ammonia molecule compared to the energy released when hydrogen and nitrogen molecules are formed. The reaction of hydrogen and nitrogen forming ammonia is the exothermic reaction. This means that more energy is released when ammonia is formed in comparison to the energy required to break the bonds in hydrogen and nitrogen. This reaction is in equilibrium as soon as reaction breaking NH_3 occurs at the same time the reaction forming NH_3 occurs somewhere else in the container. That is why I imagine the energy is the system flowing as a cycle. It is constantly being needed and released as reactions keep on occurring".

While possible errors in understanding are evident in S12's representations shown in this section, the process of generating and refining these representations, alongside the associated discussions and descriptions, was part of incorporating and modelling metacognition in the workshops. This process enabled their cognitive processes related to the chemical phenomena to be voiced, evolved, and consolidated more effectively than through a word-only approach. The importance as part of a metacognitive strategy, is where the individual is the generator of the representations rather than the interpreter as discussed in previous literature in other contexts (e.g. Tytler, et al., 2013).

R.1.3 S12's incorporation of metacognition in their teaching

Incorporation of metacognitive strategies and explicitly discussing them in a domain specific manner in the module, provided opportunities for the PSTs to develop their pedagogical knowledge in the context of teaching metacognition (Zohar & Barzilai, 2013). S12 displayed their understanding of this aspect of the module. For example, on completion of the module, when asked to reflect on the central take away messages following their experience in the module, S12 indicated they now think about "*getting students to draw diagrams and to include descriptions or discussions of their thinking about their diagrams*" and "*as a teacher, to talk through your own thinking of a topic with students*". These comments in relation to the module are supported by S12's relatively high overall score of 4.2 out of 5 for the MOLES-S in relation to the methodology module, while within that survey, S12 scored 4.8 out of 5 for the subcategory *metacognitive demands* (Figure R.2).

In S12's description of a lesson on how they would teach the chemical phenomenon of exothermic and endothermic, S12 focused on representations of student cognitive processes. S12 described tasks embedded in lessons which encourage students to generate their own representations of cognitive processes in chemistry, as a means to encourage students to become aware of their cognitive processes in relation to knowledge as applied to a chemical phenomenon. For example, S12 indicated they want students to come up with their own descriptions using representations of both endothermic and exothermic based on the chemistry that they already know. and "*how the purpose behind this [representations of student thinking] is to address their metacognition awareness*" as they want students to "*become more aware of how they can come up with their own terms and more aware of how they can think for themselves*". This is interesting as this is one of the findings of the senior cycle study incorporated into the design of the methodology module, where the benefit of student generated

As part of the teaching of this chemical reaction (Figure R.9), S12 described how they would ask students to visualise this reaction in a beaker and used this to encourage students to think about the effect that an increase in temperature would have. S12 indicates that *“students will have to think about what side the reaction will be shifted to and what colour the beaker will become after this change, and this will encourage students to think about the reasons why this change occurs and why the equilibrium changed in the direction that they predicted”*. The task is described by S12 as providing students with the opportunity to become aware of cognitive processes in chemistry where they *“use visualisations and draw out [represent] what they expect to happen on the sub-microscopic, macroscopic and symbolic levels”*. As part of a task in the last workshop S12 discussed how they would promote opportunities for metacognition in the classroom, though *“by not giving students the answer straight away. Letting them think about certain concepts and build their own understanding. By getting students to draw diagrams and include their thinking they will become more aware of how they think”*.

This approach by S12 focuses on the productive use of student’s own representations for learning (Tytler et al., 2013), while it is in agreement with Gilbert (2005) who argues to be metacognitively capable in respect of visualisations, students should know the conventions of macroscopic, symbolic and submicroscopic representations that they generate or observe.

As part of S12’s planning for the incorporation of metacognitive strategies in their teaching, S12 demonstrates their metacognitive awareness including ME and MDK when they described themselves as a rote learner when in senior cycle chemistry, contrasting this with how they would like their students to learn.

“I want them to be aware of and use metacognition when it comes to these activities and not just receive answers and definitions from me. So many students just learn these things off when it comes to Leaving Certificate Chemistry. I was one of these students. There is no element of understanding in that. I want them to really think about it before I give them any formal definitions, or I explain any concepts to them” (S12 Assignment, P2).

In part three of their final assignment (see Table 9.4), S12 made an audiovisual recording of the implementation of a part of a lesson which represents an aspect of how they would teach the sub-topic of ‘Exothermic and Endothermic reactions in relation to equilibrium’. Notably, S12’s teaching reflected the metacognitive goals of their plan. S12 focused on asking students to represent their visualisations and began by asking a student to talk through their representation and thinking *“Talk me through your thinking- why you have visualised it the way you have”*. The student articulated their thinking regarding the absorption of heat from the

environment, demonstrating the implementation of the ‘think-aloud’ protocol. This approach was applied in the context of using representations to explore the chemistry of exothermic and endothermic reactions. S12 also modelled their cognitive processes while generating their own representations and provided examples of representations of their own cognitive processes related to the submicroscopic level. The benefit of teachers modelling their cognitive processes to increase student metacognitive awareness has been described in literature (e.g. Zohar & Barzilai, 2013; Brown, et al., 1984; Tishman, et al., 1995; Veenman et al., 2006; Zohar & Ben-David, 2008). While S12 does not indicate the use of discussion or prompt questions in this description, they do indicate the teacher should “*talk through your thinking of a topic to students. You don’t want your students to see you as the teacher who has all this knowledge of chemistry and not explain your thinking*”. In an example of teacher metacognitive modelling, S12 also described their own thinking each time following the student’s explanation in their audiovisual recording. S12 generated a representation, where they modelled their thinking (shown in Figure R.10). They describe the diagrams as representations at the macroscopic level and the submicroscopic level.

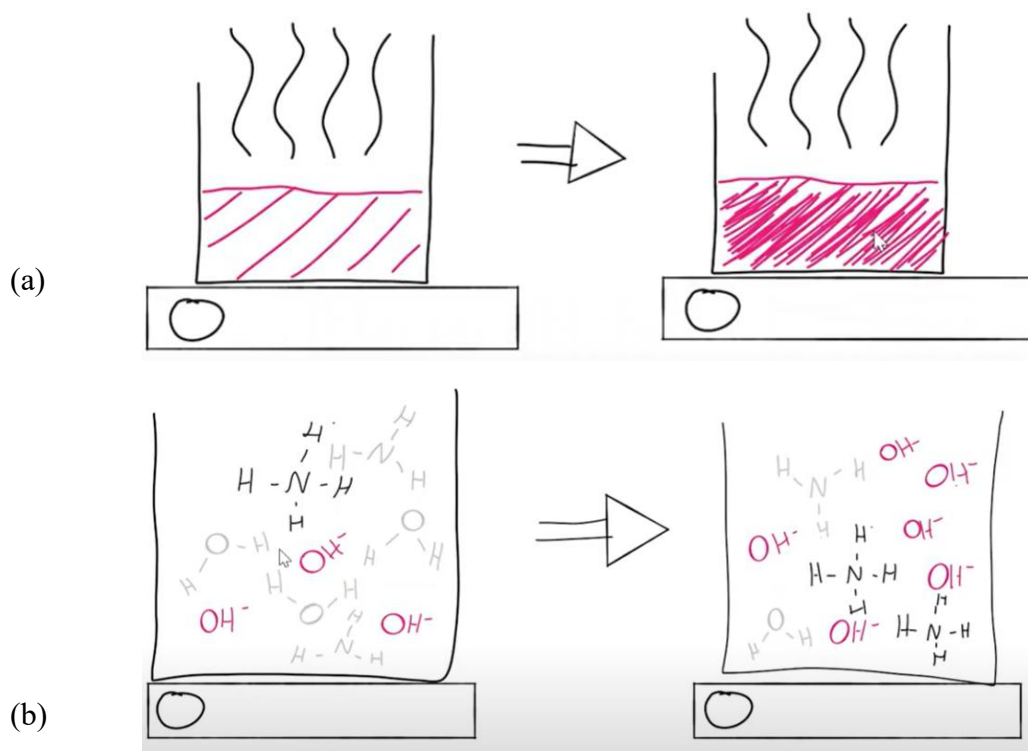


Figure R.10 A representation used by S12 as part of modelling their own thinking at the (a) “macroscopic level” and (b) “submicroscopic level” for “what would happen if the temperature was increased in the beaker” in the equilibrium reaction of aqueous ammonia and water. The pink colour is generated due to the presence of an indicator

The representations S12 uses to model their own cognitive processes in Figure R.10 are accompanied with the explanation “Initially a light pink I can imagine, and if we heat it up, the reaction favours the reaction which forms OH^- ions rather than the reaction that forms the NH_4^+ ions and so we have more OH^- ions in solution, and it gets more pink”. A possible misconception indicated by S12’s representation and modelling of their thinking, is that S12 thinks the species which produces the pink colour is the OH^- ions and not the indicator ions. This emphasises the value of discussions and metacognitive prompts in relation to the generation of the representations of visualisations in chemistry.

S12’s lesson implementation reflects their awareness of their own metacognition and the embedding of strategies to promote student metacognition through ‘think aloud’ protocols, generation of representations and teacher metacognitive modelling. Their execution of the lesson as evidence in their audiovisual recording was aligned with the metacognitive goals indicated in their plan (see Table 9.4). Notably, the metacognitive approach taken in their lesson contrasts with their perception of their own experience in second-level chemistry, which they characterised as being based on memorisation.

S12’s journey, as evidenced by the data they generated, highlights the shift in approach a PST aims to adopt in their teaching of chemistry compared to their own experiences in senior cycle chemistry. S12’s approach to incorporating metacognition in the descriptions of their own cognitive processes and teaching in chemistry highlights the benefit of PSTs experiencing these strategies firsthand in the methodology module I designed. I noted in a reflection how this approach “enhances their pedagogical knowledge in implementing metacognitive strategies and helps PSTs appreciate their value”. It is notable that an observation I made in the fifth-year study (AR Cycle 3) which became part of the design of the methodology module was evident in S12’s work, where they indicated the premise of not giving the students explicit teaching on a topic before asking students to generate their representations based on their current cognitive processes (e.g. understanding, visualisations). The evidence from S12’s description of their teaching of chemistry following their experience in the module indicates that they have reflected on themselves as a learner in senior cycle and they have demonstrated aspects of how they would incorporate metacognition in their teaching of chemistry.

R.2 The case of S3

R.2.1 S3's experience and knowledge of metacognition in chemistry

Reflecting on their experience of senior cycle chemistry as part of a discussion in the first workshop, S3 indicated that their chemistry lessons in senior cycle were focused on memorisation.

“We learnt chemistry through memorisation, learning of definitions and not fully understanding why or what relevance certain concepts have or how they relate to everyday life applications. There was certainly an emphasis on memorisation to get full marks, something that we picked up and something we were trained to do, and there was certainly an emphasis on exams in every chapter” (S3)

S3's MOLES-S overall score for their perception of their experience in senior cycle chemistry was close to the average for the group of PSTs. However, the scores for the subcategories of *Teacher encouragement and support* and *Emotional support* and *Student Voice* were particularly high relative to the other subcategories while they had a relatively low MOLES-S score in the subcategory of *metacognitive demands* for their senior cycle chemistry experience (Figure R.11).

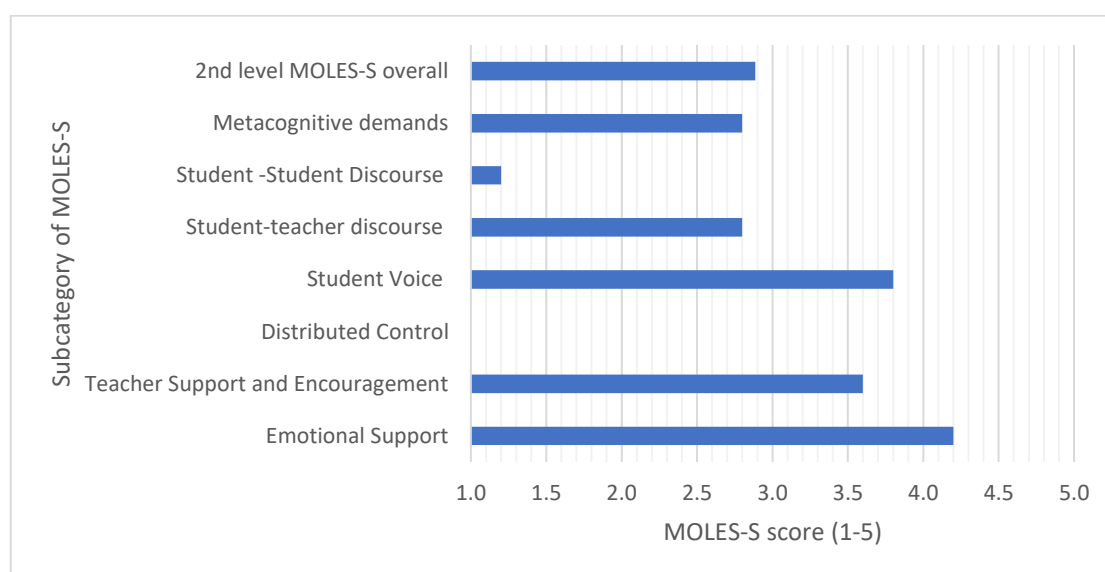


Figure R.11 Subcategory scores for the MOLES-S survey in relation to S3's experience in senior cycle chemistry

In agreement with S12, S3's MOLES-S scores for the methodology module reflect an environment which was metacognitively orientated and particularly metacognitive demanding. S3's scores for the subcategories of the MOLES-S are shown in Figure R.12.

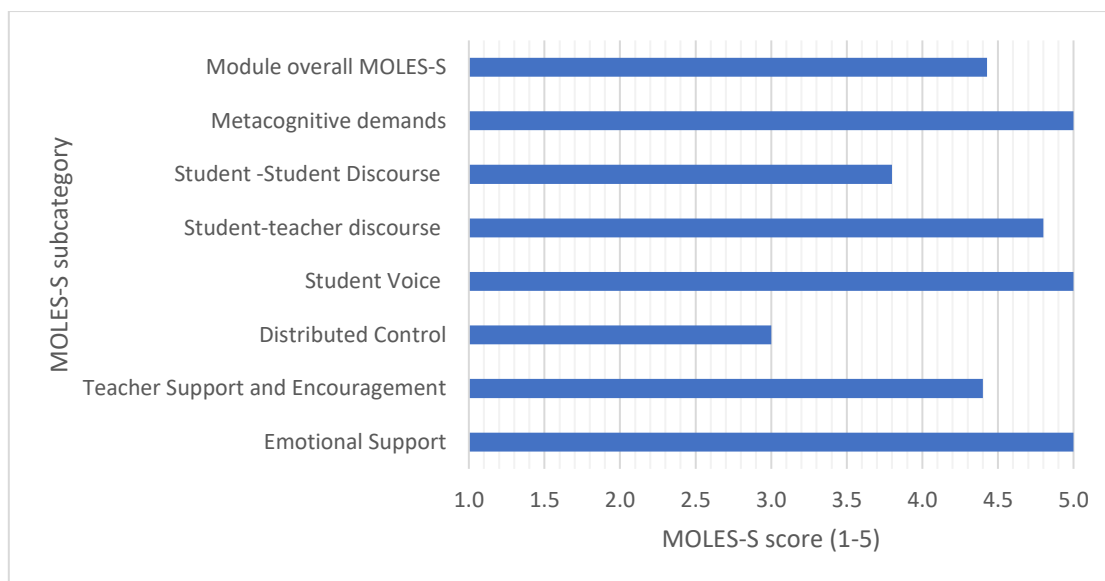


Figure R.12 Subcategory scores for the MOLES-S survey in relation to S3's experience in the methodology module

As part of a metacognitive discussion, when the PSTs were asked how they could become better learners of chemistry at senior cycle, S3 indicated that learning would have been more effective if they aimed *“to understand topics and have less emphasis on memorisation or recall”* (S3 Workshop 1).

S3 specifically described their understanding of metacognition in chemistry through awareness of thinking at the sub-microscopic, the macroscopic, and the symbolic levels and argues that by having an awareness of these *“three ways about thinking about an idea the concept itself becomes easier to understand”*. S3 describes how they see the value of metacognition as switching between *“thinking modes and trying to visualise ideas in different ways to understand it”*. They go on to demonstrate ME and MDK in relation to their own cognitive processes in chemistry.

“One of the main issues I had when I was a student was the fact that the only way I was taught to visualise the reaction, was to consider the symbolic level. Without the sub-micro level, that is molecules and atoms colliding, there was a gap in my understanding which became more evident when tackling problems such as reaction mechanisms” (S3, Assignment P1).

In the above example S3 displays metacognitive awareness related to representations and cognitive processes at the submicroscopic symbolic and macroscopic levels, where they place a particular emphasis at the submicroscopic level. As discussed in Chapter 2, this viewpoint has been described in literature where it has been argued that visualisation acts as a background for cognitive processes in chemistry if we consider that mostly all

phenomena in chemistry education are related with imagination and visualisations particularly due to the submicroscopic level of chemistry reactions (Locatelli, et al., 2010; Gilbert, 2008). S3 displayed a relatively large increase in their overall MAI score, MAI metacognitive awareness and MAI metacognitive regulation pre and post the methodology module as shown in Figure R.13.

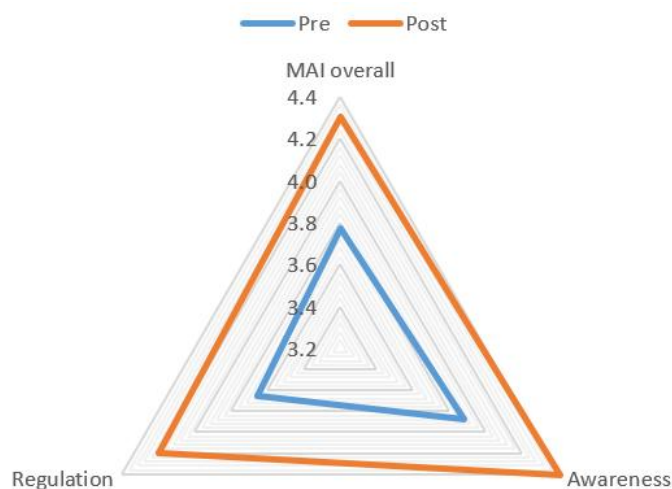


Figure R.13 MAI mean scores for S3 – for *overall MAI, metacognitive awareness and metacognitive regulation* - pre and post the methodology module

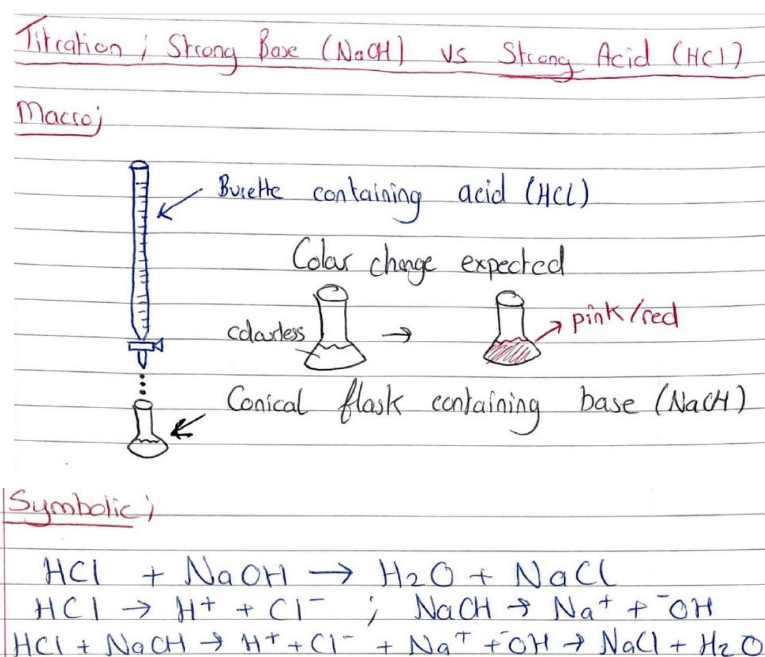
S3 displayed development in terms of MDK over the course of the methodology module. For example, S3 describes experiments in chemistry as an example of where “*many students conduct experiments at the macro level and understand very little about what exactly is occurring in the reaction vessel*”. S3 describes a titration experiment as an example “*of a topic that is sometimes taught to only target the symbolic and macro levels of thinking*”. S3 describes the reaction between sodium hydroxide and hydrochloric acid “*to emphasise the importance of employing all three ways of thinking in terms of macro, sub-micro and symbolic levels when trying to convey a concept or idea*” (Figure R.14). It is interesting that S3 uses the word thinking at the three levels, as opposed to only referencing them as levels representations or visualisations which emphasises the relevance of the metacognition to the study of these levels. (See section 2.4). As discussed in Chapter 2, research suggests a full understanding of a chemical phenomenon involves the ability to move cognitive processes (e.g. thinking, visualising, understanding, learning) between the macroscopic, the submicroscopic, and the symbolic levels (Johnstone, 1991; Gabel, 1999; Treagust & Chittleborough, 2001).

S3’s representations (Figure R.14) of the macroscopic and the symbolic levels are similar to that of what would be expected as per Johnstone’s triangle of representations, however the

submicroscopic representation given by S3 has aspects of the symbolic (e.g., the Na symbol rather than a sketch of the sodium atom). S3 demonstrates an MDK and MPK that merging cognitive processes in relation to each of the three levels provides a more comprehensive understanding of a chemical phenomenon.

For example, S3 argues that all three levels are combined, students get the ‘full picture’ of what is happening when conducting a titration. S3 elaborated on this in their final assignment.

“If students were only shown the macro and symbolic levels, they would not be able to visualise effectively the molecules colliding and the idea that ions are being produced in solution, which form new products. If only the symbolic and sub micro are used, then the students struggle to visualise what is happening at the level at which they can see. Finally, when the students only see the macro and sub micro, they do not see the ratios of the molecules which react with each other, e.g $2A + 3B \rightarrow 4C + D$. Students can see the droplets and colour change at the macro level, they can see the ratio at which molecules will react together and they can represent the molecules colliding in diagrams (sub-micro)” (S3 assignment P1)



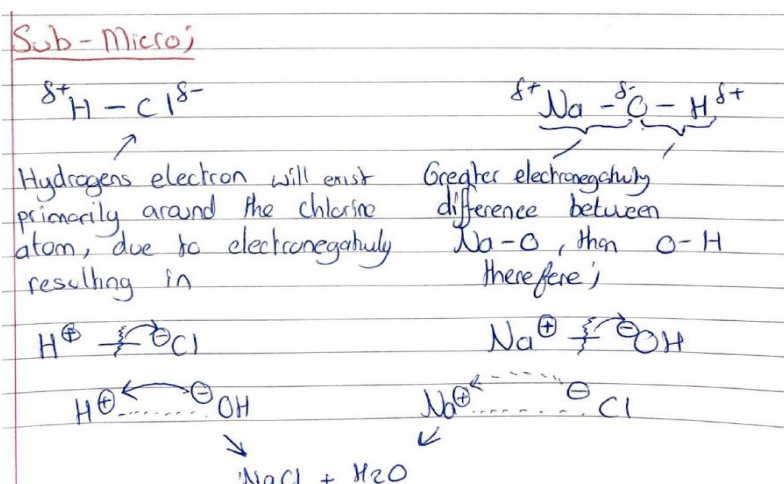


Figure R.14 Representation of the (a) macroscopic level (b) the symbolic level (c) the sub-microscopic level by S3, of the titration involving the reaction of sodium hydroxide (NaOH) and hydrochloric acid (HCl)

In Figure R.14, S3 demonstrates the drawing of the apparatus for the titration, while representations at the macroscopic level may appear the simplest type of representation, its role should not be overlooked. Bodner (2003) argues that drawing an annotated diagram with relevant information can play an important role in solving novel problems.

S3's development in terms of metacognitive awareness is further evidenced within the MAI component of metacognitive knowledge, where S3 showed a relatively large increase in both MAI declarative knowledge and MAI procedural knowledge, while they had a relatively high initial MAI conditional knowledge score (Figure R.15).

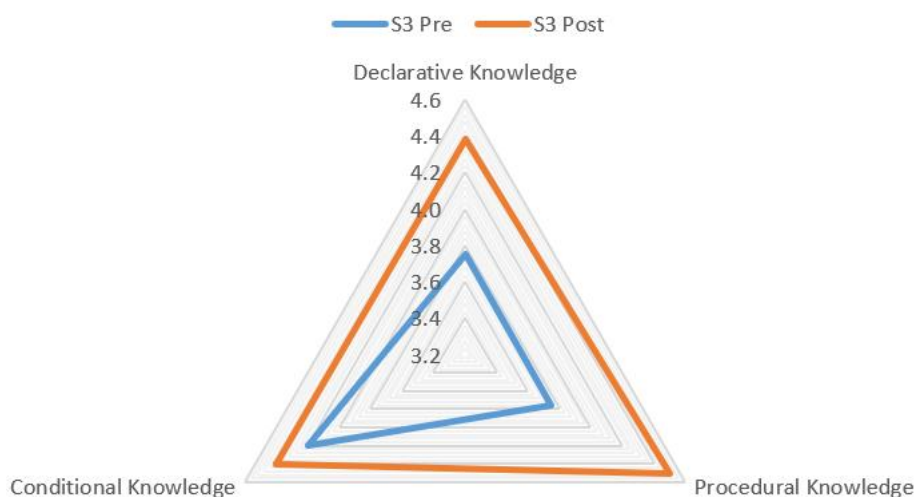


Figure R.15 Subcategories of *Metacognitive awareness* - mean S3 MAI scores- pre and post the methodology module

S3 MAI scores indicate a relatively large increase ($\geq 10\%$) in *planning*, *information management strategies*, *debugging strategies* and *evaluation* (Figure R.16). S3's metacognitive regulation was evident in the descriptions of their thinking. For example, ME was evident in their reflection on their senior cycle experience, for example, “*One of the main issues I had when I was a student was the fact that the only other way, I was taught to visualise the reaction, was to consider the symbolic level*”.

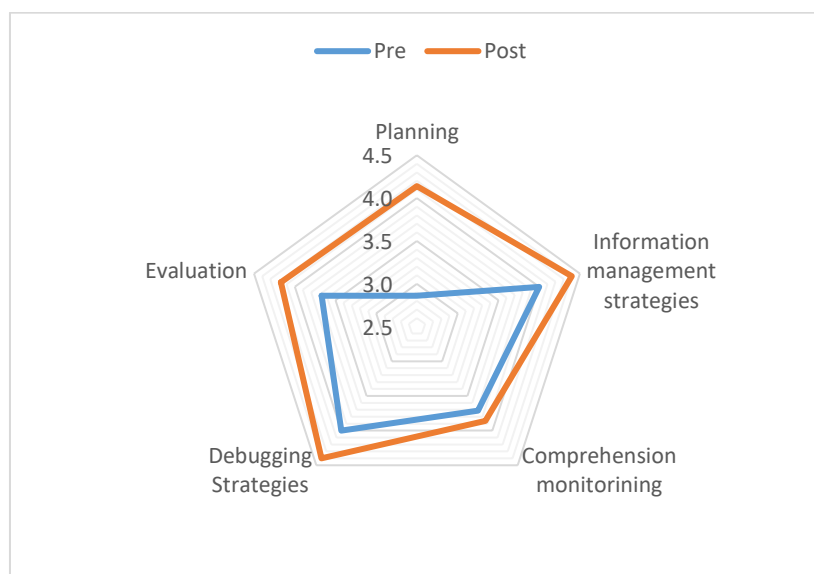


Figure R.16 Subcategories of *Metacognitive regulation* - mean S3 MAI scores- pre and post the methodology module

An analysis of the quantitative and qualitative data discussed in this section suggests that S3's experience in the module facilitated the development of their awareness of metacognition within a chemistry context. S3 demonstrated a particular focus on the importance of being aware of cognitive processes across the submicroscopic, macroscopic, and symbolic levels in chemistry.

R.2.2 S3's generation of representations

S3's representations and associated descriptions provide an insight into their awareness of cognitive processes in chemistry. For example, in the first workshop of the module when the PSTs were asked in task W1 to represent how they visualise H₂O (Figure R.17), S3 placed what appears to be full charges on the oxygen and hydrogen atoms in a water molecule, which may represent a misconception on their part or a lack of focus on the specifics of representations in the first workshop.

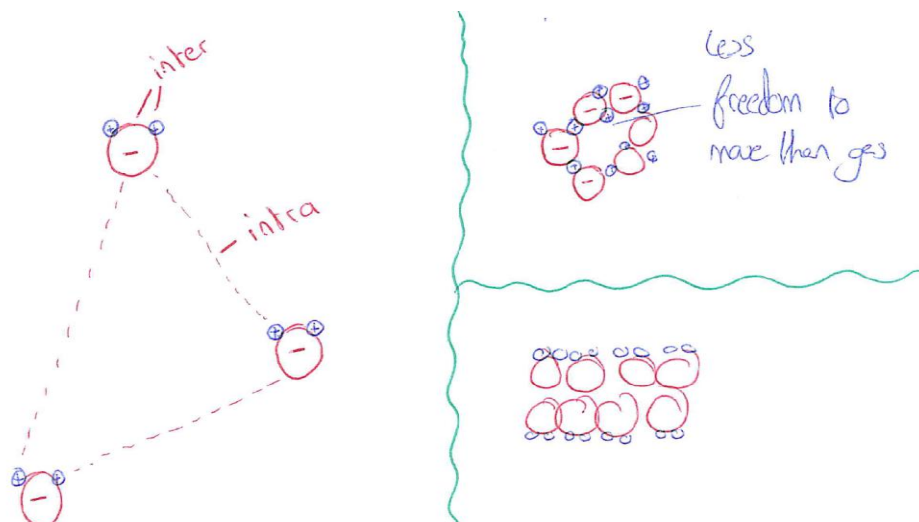


Figure R.17 S3's response to Task W1 in the first workshop; *Draw how you visualise H_2O as a gas, a liquid, and a solid in any representation you wish, showing any intramolecular and intermolecular bonding*

Assuming the red circles represent the oxygen atoms, and the blue circles represent the hydrogen atoms, the arrangement of atoms in the representations show S3's thinking in relation to the polarity and repulsion between the water molecules. The motion of molecules in the states of matter has not been indicated in any of the representations, except to note "less freedom to move than gas" in the liquid representation. The level of detail increased in their representations when the task was repeated in workshop 3, task W3, as shown in Figure R.18. For example, the atoms are labelled, the polarity of the water molecules are included, the shape occupied by each of the states and the motion of the molecules is included. In addition, S3 included the hexagonal arrangement of the H_2O molecules when it is in the solid state, with dash lines between the molecules which presumably indicate intermolecular interactions; however, the nature of these interactions is not indicated on the representations. There is also no indication of why the water molecules behave differently in the three states of matter.

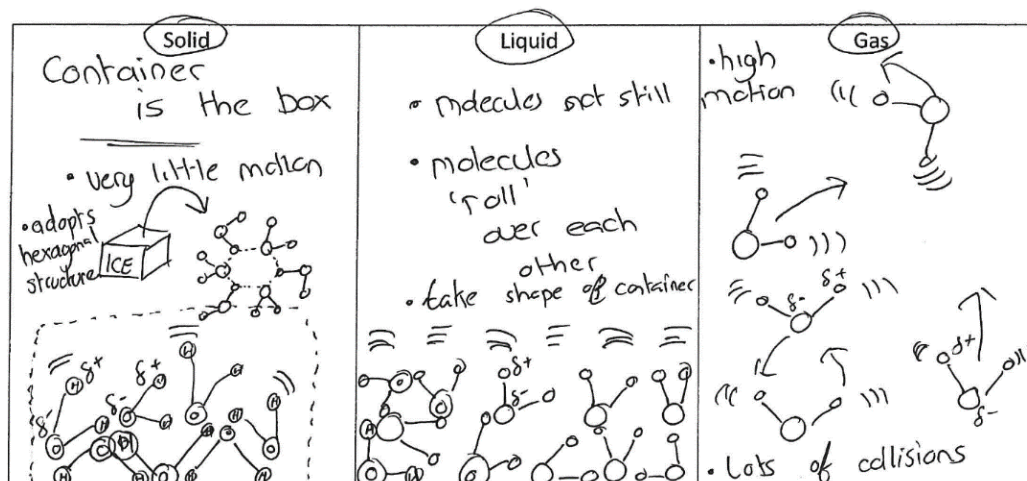


Figure R.18 S3's response to Task W3 in the third workshop; *Draw your representations of how you visualise H₂O as a gas, a liquid, and a solid in any representation you wish, showing any intramolecular and intermolecular bonding*

S3 described how their cognitive processes in relation to the generation of the representations evolved between task W1 to task W3 following their experience in the workshops.

"I now know water solid forms a hexagonal structure with other molecules and vibrates, I always imagined solids with no motion whatsoever. Charge can describe so much when considering inter and intramolecular bonding in terms of structure. Water molecules rolling around each other, I used to think they were fixed. Water molecules are never more/less attracted to each other- only the motion changes when analysing different states of matter. I now understanding, higher energy in terms of motion means that it is more difficult for the molecules to bind together or form intermolecular bonds."

The above description of their thinking displays ME in terms of an awareness of how their thinking has evolved (e.g. *"I used to think they were fixed"*) and MDK in terms of the knowledge they now have related to the use of electrostatic charge for intramolecular and intermolecular forces and MCK related when they should use charge as part of inter and intramolecular bonding. The generation of representations by the PSTs, along with how they discussed, reflected on, and refined these representations during the module workshops, provided rich opportunities for them to engage in domain-specific reflection and analysis of their own cognitive processes.

S3's generated representations also provide evidence of their cognitive processes beyond what would be captured in a purely text-based reflection. For example, while describing the polarity of water, if one reads only S3's text indicating *"The oxygen is more electronegative; Hydrogen is electron deficient. Oxygen becomes negatively charged. Hydrogen becomes positively charged"* one could interpret this as a misconception on the part of S3 where they believe ions were formed. However, when accompanied by the representation (Figure R.19) one can see the delta symbol (normally meaning partial) with the electron (e-) being pulled toward the oxygen atom one can see that S3 means partial negative and positive charges on the atoms generating a polar molecule and not full charges as could be interpreted from S3's accompanying notes. This comparison between what S3 is writing in words and what they draw in their representation of the chemistry provides a greater insight into cognitive processes.

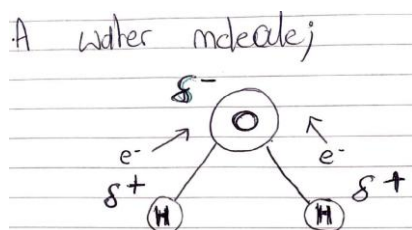


Figure R.19 An ‘exemplar representation’ by S3 of what they would expect students to draw for water molecules at the submicroscopic level

At the end of the sixth workshop, S3’s representation of chemical equilibrium included a symbolic representation accompanied with representations of molecules (Figure R.20). The word “balance” beside the two arrows at the reversible reaction symbol implies they mean the forward reaction is taking place at the same rate as the reverse reaction, however it could also be interpreted as a balance of concentration. A representation indicating possible collisions with notes including referencing the rates of the reactions taking place would have clarified important aspects of chemical equilibrium.

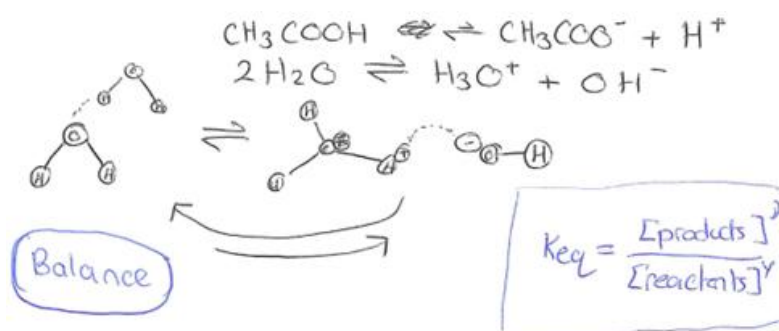


Figure R.20 Representations by S3 in relation to the task of *Write down or draw representations of five things you think or visualise when you see chemical equilibrium?*

This representation provided an opportunity for me to prompt S3’s awareness of their cognitive processes in relation to their understanding of the chemistry involved in the reaction:

PR: What do you think of when you hear chemical equilibrium?

S3: I think of the reaction with two water molecules, and they are in equilibrium with H_3O^+ and OH^-

PR: What's the name given to the reaction?

S3: Water self-ionisation

PR: How would you describe chemical equilibrium?

S3: Well, it has to be a reaction where reactants are constantly becoming products and products are constantly breaking down to the reactants and at the same rate.

While the generation of representations provides opportunities for the PSTs to reflect on their cognitive processes in relation to a chemical phenomenon, my follow up questions provide further evidence of the PSTs understanding. As the questions were part of a group discussion, they did not specifically address S3's generated representation, however this would have provided opportunities for metacognitive prompts such as *"what is your thinking behind the arrows you have shown? What do you mean by the word balance, are there other uses for the word balance in describing how one thinks about this equation?"* I reflected on this episode following this particular workshop and I noted *"An important point is that teacher educator must be aware of potential metacognitive opportunities when designing and implementing tasks, as opportunities for metacognitive prompts can be easily lost"*. I noted in my reflection that *"expanding the students' or PSTs' awareness of their thinking requires the use of representations, descriptions, and discussions to triangulate their thinking, visualising and understanding for both themselves and others"*. This reflection aligns with my experiences during the implementation of the second-level study (AR Cycles 1-3).

S3's representations further demonstrate how generating and describing representations in chemistry created opportunities to enhance their awareness of cognitive processes and provides a platform for questioning and reflecting on these processes.

R.2.3 S3's incorporation of metacognition in their teaching

S3 stated they believe it is important for teachers to model cognitive processes for students through representations of thinking and visualisations, for example they stated, *"It is so important for teachers to demonstrate concepts using all three ways [Submicroscopic, symbolic and macroscopic] of thinking, as it will broaden the range of understanding for students"*.

S3's lesson planning in the final assignment (see Table 9.4) provides opportunities for students to draw the chemistry taking place through the three levels of representation, but there is a focus at the submicroscopic level. For example, S3 indicated they would ask students to represent how they visualise water (liquid state) at the submicroscopic level as part of increasing students' awareness of cognitive processes at that level. S3 provides an exemplar representation (Figure R.21), and they indicate what they would expect to see including *"multiple water molecules, polarity within (intramolecular forces), interaction*

between water molecules (intermolecular interaction)". S3 does not include the relative strengths of the interactions, and a larger number of molecules would have provided more clarity for students in terms of their understanding of the intermolecular and intramolecular bonds.

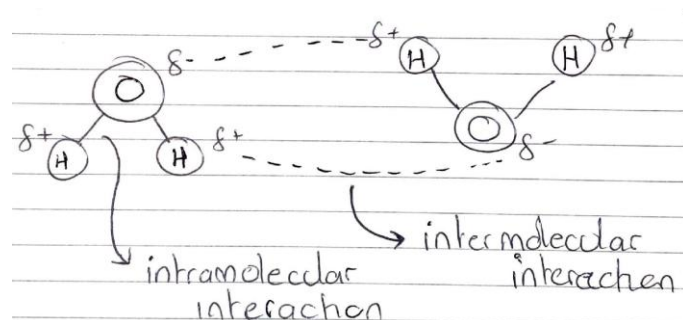


Figure R.21 Exemplar representation by S3 of their thinking in relation to the interaction between two water molecules

S3 demonstrates how as a teacher they would be conscious of being aware of students' cognitive processes, for example they predict that *"some students may forget to include delta negative and delta positive symbols, which would potentially make it more difficult to explain what happens when two water molecules collide"*. S3 discusses how representations of visualisations can act as a springboard for follow up questions, indicating the teacher should use prompts such as *"what happens if two molecules collide, how do you think about or visualise this?"* and they would *"share the students' ideas with the class and attempt to refine the most accurate ones down to the reaction mechanism for $(2\text{H}_2\text{O} \rightarrow \text{H}_3\text{O}^+ + \text{OH}^-)$ "*. It is interesting that S3 indicates that they would focus on refinement of the "most accurate" ideas and provides opportunities for students to become aware of the evaluation of their cognitive processes and as part of the consolidation of student understanding in chemistry.

In their final assignment, S3 made an audiovisual recording of a lesson episode on the self-ionisation of water, in which they focussed on student generation of representations. S3 asked a student in the lesson to 'think aloud' while describing their thinking at the submicroscopic level. This focus on the sub-microscopic representations is an important aspect of understanding chemistry (Wu & Shah, 2004). The tasks in the audiovisual recording of the lesson were aligned to what S3 described in the written form of the lesson rationale they provided in the assignment (see Table 9.4).

S3 demonstrated how they would use metacognitive modelling as a teacher at a number of points in the lesson e.g. *“I was thinking back to... I am going to show you what I am thinking...”*. In a further example of S3 demonstrating that they place value in student’s representations of their thinking and the ‘think aloud’ protocol, S3 indicated they would like students in the class to go up and represent and explain their thinking on the board. S3 also described how they would prompt students *“Why do you think that?”* multiple times during the students’ ‘think aloud’ episodes to encourage reflection on their cognitive processes. However in their audiovisual recording, following a task where students were asked to represent *“what they think might happen if two water molecules collide- or if something will happen?”*, S3 provides the explanation of what happens, rather than asking the student to explain their thinking on the task. Reflecting on S3’s descriptions I noted *“S3’s description of their lesson also highlights the challenge of going beyond the cognitive - students using cognitive processes—to the metacognitive, which involves awareness of cognitive processes, as well as why and when they use different cognitive processes when studying a chemical phenomenon”*.

The domain specific approach to incorporating metacognitive awareness in chemistry through representations can be interpreted from S3’s reflections. For example, as part of a reflection task in the final workshop of the module, S3 indicated that they now see the purpose of *“drawing as much as possible, as it is useful to get all of the information on the page”*. S3 indicated that they use representations as part of voicing both student thinking and teachers’ thinking. S3 described how following the module that they see that part of the role of a chemistry teacher is

“to say you’re not some chemistry wizards here. It’s sharing your thinking with them and it’s a group effort, and it’s also individual. I think bring it down to these key concepts and show your thinking” (S3)

S3 went on to describe how following the completion of the module they aimed to include different ways of representing thinking in their teaching and how they would place an importance on students *“awareness of switching between symbolic, sub-micro and macroscopic levels of thinking in chemistry”*.

S3 participated in an interview following their school placement in the semester following the Methodology module. In this interview, S3 I asked *“What would you say are the skills in chemistry that you were emphasising with them [their students on placement]?”* S3 responded by stating they *“tried to use visualisations and underlying concepts for thinking about topics*

in particular. To visualise, I thought that was done very well in the module. I said, can you just draw what you think? So, this was after we'd done that, just a bit on the atom and like molecules and compounds.”. S3 went on to indicate that in class they would ask students, “Can you just draw what you think water might look like? The three levels that we had to look at. And there was some interest. We had a lot of time to discuss some of the ones that may have varied, like people had a few different ways of representing. I thought that was brilliant. In my own lessons the students discussed it and I got someone to draw on the board. And it was very interesting”. The above comments by S3 demonstrated an awareness of the cognitive processes in their own thinking of chemistry and their awareness of these in their own teaching while on placement.

S3 also indicated in the interview that they used representations as the basis for discussions about cognitive processes in chemistry in their lessons.

“We had a discussion about it and it wasn't so much so that we just said, here's the definition now let's have a talk about it. We did it the opposite way around. So, let's draw what we think, have a discussion about it. And then say, right, well, let's narrow it down to this. After discussion and after visualising, they really enjoyed it as well”.

S3 displayed metacognitive awareness of their own cognitive processes and how it is brought into their teaching in the post placement interview. For example, in the passage below S3 indicates awareness of their own cognitive processes (in particular MDK and MPK) in relation to electronegativity in senior cycle chemistry, and how they approached it as a teacher.

“But it [Electronegativity] was always one that I struggled to get my head around. I know it's very important in chemistry, but it was something that I always struggled with. The reason I struggled was because it was like definition first and then we had a chat about it, that was the way I was taught. So, I was actually struggling to remember what the definition was, a very word for word definition of electronegativity. I feel as if I could explain it now, but I wouldn't be able to give the definition of electronegativity word for word or pretty formal. That was one that made me think and say what actually is electronegativity if you're looking at a particular molecule, represent it, and then it explains polar covalent bonds or whatever polarity is in molecules. So has this a knock-on effect, just by stripping it down to its basic charge, and mentioning charge, I think it's very important there. But that was one that stood out to me. I think that really helped to deepen their [students'] understanding and just to help them visualise, to break down the barriers of, like I said, we're working with atoms here.” (S3, post placement interview)

Overall, S3 demonstrates an awareness of their own cognitive processes, student cognitive processes as well as an ability to incorporate metacognitive strategies as part of their teaching on school placement. For example, they indicated that they use the generation of representations to provide opportunities for metacognitive prompts and discussions, and as part of their own metacognitive modelling in lessons.