



ADAPTTER: Developing a Framework for Teaching Computational Thinking in Second-Level Schools by Design Research

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Abstract

Computational Thinking (CT) is a problem-solving process applicable across all disciplines. It has been defined as a 21st-century skill (Wing, *Communications of the ACM*, 49(3), 33–35, 2006). Unfortunately, little pedagogical research is available to guide teachers and designers when devising a CT course. This study addresses this issue by describing how a framework to teach CT to second-level students evolved. This framework, ADAPTTER, has been shown to result in a high quality, engaging, low threshold, effective, and practical course. A three-phase Educational Design Research study was employed to develop this framework. It involved six schools, eleven teachers, four content experts, and 446 students. Data was gathered using various means: teacher interviews and diaries, students' questionnaires, artefacts, and tests. The ADAPTTER framework is offered as a way for teachers and researchers to design a CT course, understand its components and have conversations around the same.

Keywords Computational thinking · Framework · Teaching · Learning · Second-level education · Educational design research

Introduction

Computational Thinking is a 21st-century skill (Wing, 2006). It can be understood as an approach to problem-solving that applies to many disciplines. It is a thought process that draws on constructs fundamental to Computer Science such as decomposition, abstraction, pattern matching, and algorithmic design (including logical thinking). Linked with these problem-solving skills is the knowledge that we live in a digital world.

Students would benefit from understanding this digital world and how algorithms drive it (Curzon et al., 2019). Unfortunately, CT is not a topic many Irish post-primary teachers formally teach.

This paper describes the development of an instructional framework, ADAPTTER, through Educational Design Research (EDR). ADAPTTER stands for Activities, Demonstrations, Application, Pre-activation, Transparency, Theory, Exemplification, and Reflection. These components resulted in a CT course that is high quality, practical, engaging, effective, and low threshold. This CT course can be used for both the teaching and learning of CT to students (aged fourteen up) and second-level teachers.

This paper describes the iterative design, development, and evaluation of the ADAPTTER framework. This is achieved by first outlining the research question, followed by the EDR methodology employed in this study. A detailed description of the prototype phase of the EDR process is next provided, coupled with how the findings from this process influenced and affected the CT course's design.

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Research Question

This study set out to answer the following research question: What are the characteristics of a high quality, practical, engaging, effective, and low threshold course for both the learning and teaching of Computational Thinking to Irish second-level teachers and students? In answering this

question, two practical outcomes resulted: a CT course, and the ADAPTTER framework. The criteria stated in the research question, and its rationale can be understood as follows.

Low threshold relates to resources and pre-requisite knowledge. The course is designed to be taught using technological resources available in a standard equipped Irish post-primary classroom (for example, a data projector and a teacher computer). The course assumes no pre-requisite Computer Science and programming knowledge. This was important as at the post-primary level, the two formal courses, the Junior Cycle short course Coding, and the Senior Cycle Leaving Certificate Computer Science (LCCS) course are both in the early stages and optional. Coding was first piloted to 22 schools in 2016-2017, and the LCCS was first piloted to 40 schools in 2018-2020 (Fleming & McInerney, 2019; Scanlon & Connolly, 2021). There are 730 post-primary schools in Ireland (Lawlor et al., 2020).

Effectiveness, practicality and quality were chosen, as they are inter-related criteria considered essential for design interventions (Archer, 2019). **Quality** is understood as the completed design intervention meeting the following three criteria: validity, practicality, and effectiveness (Nieveen, 1999). For the course (intervention) to be valid, it must be developed based on state-of-the-art (scientific) knowledge, and be relevant for its context and purpose. (Nieveen, 2010; Plomp, 2013). The course must be **practical**, “usable in the setting for which it has been designed and developed” (Plomp, 2013, p. 29) and effective, i.e. it must attain the desired outcomes (Plomp, 2013). In this instance, **effectiveness** was understood as teachers and students having a positive reaction to the course and students attaining the desired learning outcomes. **Engagement** is defined as a multidimensional facet (Dorph et al., 2016; Fredricks et al., 2011) containing cognitive, behavioural and emotional criteria. Having an engaging course is considered important as it helps students develop an interest in a subject and provides students with a positive experience (Carini et al., 2006; Hidi & Renninger, 2006).

Methodology

Educational Design Research (EDR) differs from other forms of inquiry as it simultaneously focuses on developing practical solutions and theoretical insights (Plomp, 2010). It can be understood as “the systematic study of designing, developing and evaluating educational interventions (such as programs, teaching-learning strategies and materials, products and systems) as solutions for complex problems in educational practice” (Plomp, 2013, p. 13). Design research is understood as a common label assigned to ‘a family of related research’ (Van den Akker *et al.* (2006, p. 4). Other examples include design experiments (Brown, 1992; Collins,

1990), design-based research (The Design-Based Research Collective, 2003) and design studies (Shavelson et al., 2003). EDR is recommended in settings when content knowledge is new, teachers’ knowledge or availability of instructional materials is poor, teaching and pedagogical expertise are unclear, and complicated societal factors exist (Kelly, 2013). All of the above factors were relevant in this study.

Design Research: Three Phases

This EDR study adopted the iterative three-phase approach Plomp (2013) recommended: preliminary, prototype, and summative. An overview of each phase is provided below. This is followed by a detailed description of the prototype phase's process, goals, and findings, and how they contributed to developing the ADAPTTER framework. Figure 1 shows these three phases, together with their particular aims and collaborators.

The preliminary analysis phase was concerned with gaining an insight into ‘the educational problem’ of how best to teach and learn CT, specifically in the Irish context. It comprised of context and needs analysis, literature reviews, and devising a hybrid conjecture map for the design of the intervention. Informal school visits, and an exploratory survey were also performed. Findings from this phase resulted in the development of Version 1 of the CT course and an initial set of local instructional theory, which would eventually become the ADAPTTER framework.

The prototype phase concerned piloting, refining, and evaluating the CT course, and the evolving instructional framework. It contained two iterations: Version 1 and Version 2.

The summative phase is the final assessment phase. Evaluations were carried out to investigate if the course designed using the ADAPTTER framework was effective, engaging, high quality, low threshold and practical.

Preliminary Phase

The preliminary phase was conducted over twenty months, from January 2017 to September 2018. Many of the activities occurred in parallel, such as three systematic literature reviews (Kirwan, 2021) five informal school visits, seven informal teacher interviews and an exploratory survey. The survey (n=33) was issued through the Computers in Education Society in Ireland (CESI) mailing list. It was adapted from Yadav et al.’s (2014) Computing Attitude Survey.

Findings from this phase informed the initial development and design of the CT course. Of note, Selby and Woollard’s (2014) definition of CT was the most useful. It included operational characteristics, shared parallels with organisations associated with compulsory education, and was consistent with Irish policy documents, which highlighted the

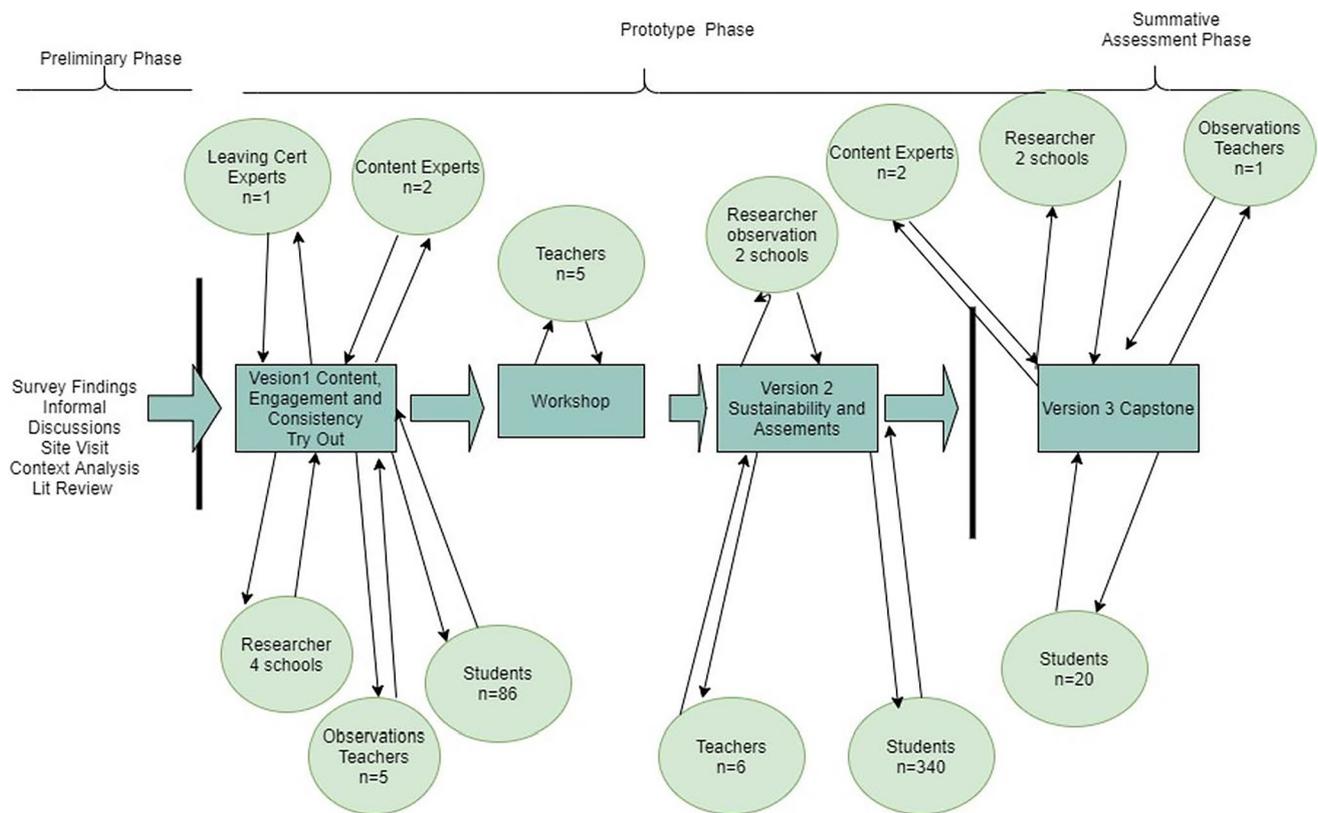


Fig. 1 The Phases and Activities that occurred during the EDR study (Kirwan, 2021). Diagram format was influenced by Mafumiko (2006) and Masole (2011)

importance of CT to both coding and problem-solving. This definition, coupled with the LCCS curriculum, influenced the topics covered by the CT course. The prevalence and importance of collaboration and scaffolding (irrespective of the tool) when teaching CT (Kirwan, 2021) was also noted.

A third finding was in relation to programming languages being the most common tool used to teach CT (Kirwan, 2021), however students ability to tackle real-world problems was noted as being limited by their programming knowledge (Krugel & Hubwieser, 2017). The proposed CT course would therefore need to allow students to tackle complex problems in Computer Science (which relate to real-life) without prerequisite knowledge. The course would also need to have a low threshold. For these reasons, unplugged activities were proposed as a pedagogical tool to teach CT. Unplugged refers to activities that allow students to engage with concepts and ideas from Computer Science without using a computer, for example, games, magic tricks, and storytelling. The activities are typified as collaborative, engaging and simple to implement (Bell et al., 2009). They bridge the gap for teachers who are not adept in Computer Science but are expected to teach it (Rodriguez et al., 2016). Unplugged activities were found to be one of the successful strategies used when teaching computing by British teachers (Sentance & Csizmadia, 2017).

The above findings from the preliminary phase resulted in the following design conjectures being proposed for Version 1 of the course. These conjectures are stated in Table 1.

In short, it was conjectured that the characteristics of low threshold, high quality, effectiveness, practicality and engagement would be observed if certain design elements were initially included or applied. As stated earlier, Version 1 of the course needed to be completed in full before it was piloted. For this reason, the initial design was influenced by Merrill's (2002) First Principles. Merrill's principles are theoretically robust, and are derived from pre-existing theories and models. When used, they result in effective, efficient and engaging learning (J. Gardner & Belland, 2012; J. L. Gardner, 2011; Lo & Hew, 2017; M. D. Merrill, 2002), all components judged important to this study. They revolve around the promotion of learning. They state that learning occurs when 1) students are involved in solving real-world problems, 2) existing knowledge is activated, 3) new knowledge is demonstrated, 4) new knowledge is applied by students and 5) new knowledge is integrated into the student's life. The above design conjectures are captured in a hybrid Conjecture Map (see Fig. 2) that illustrates the design trajectory and salient design features of this EDR study (Sandoval, 2014).

However, the map is 'hybrid' as it also shows the intersection of the EDR process with the design trajectory. By

Table 1 A summary of the criteria and related design guidelines (Kirwan, 2021)

Criteria	Design guidelines
Engagement	Curriculum designed based on Merrill's (2002) principles of instruction. Unplugged Activities
Effectiveness	Curriculum designed based on Merrill's (2002) principles of Instruction.
Low Threshold	Unplugged Activities
Quality	Content Validity (Content reviewed by experts) Content Consistency (Content reviewed by teachers) Practicality (Piloted by teachers in School) Effectiveness (Curriculum designed based on Merrill's (2002) principles of Instruction.)

showing the roles and actions of participants during the EDR study, the map also serves as an articulation of the EDR process and also design trajectory for this study. The map can be understood as follows. High-level conjectures, such as unplugged activities, Merrill's principles, and group work, are reified within an embodiment, such as tools, materials, and participant structures. These embodiments generate specific mediating processes in the participants (which relate to Merrill's principles), such as collaboration, reflection and engagement with puzzles and unplugged activities. In this instance, these mediating processes should result in the desired outcome, a high quality, engaging, effective course.

The 'Theories, Models and Processes' box was added to highlight the theoretical influence on the created tools, materials and instruments used in this study. For example, similar to Fauzan's (2002; Fauzan et al., 2013) work, four of Guskey's (2002) five levels of data were collected to evaluate an EDR intervention's effectiveness. They were students and teachers' reactions, teacher's use of knowledge and student learning outcomes. Other modifications to the map were to the 'participant structures' box and the addition of the instrument box. The 'participant structures' box includes the roles played by the research participants. The instrument box details the research tools used to evaluate if the mediating processes produced the desired outcomes.

Prototype Phase

The design of Version 1 of the course had its origin in a fusion of collaborative unplugged activities. These activities were placed in a structured framework, influenced by Merrill's First Principles of Instruction (2002). Each lesson contained the following elements: 1) unplugged activities, 2) activation of prior learning, 3) demonstration, application and reflection of knowledge, and 4) collaboration.

The unplugged activities were selected or devised to relate to real-world problems. A teacher's guide was developed that captured the contents of the course. The guide contained lesson plans, design layout of each lesson, screenshots of slides, lecture notes on same, background information on CT and instructions on how to use the unplugged activities.

Version 1 was prototyped from Jan 2019 to May 2019 to eighty-six students, five teachers, and involved four second-level schools. It was taught by the researcher, with the classroom teachers observing. The goal was to evaluate the effectiveness and engagement of the course in its current design, and to assess the content of the course in respect to its validity and relevancy (quality). Details of the schools, teachers and students and how they were recruited are provided in Table 2. The schools were all public state schools, and represented the variety of schools available in Ireland.

The guide from Version 1 was also issued to two content experts, who were carefully selected due to their Computer Science (CS) expertise and their experience with the LCCS subject or CT. These experts came from two different Irish Universities (from authors) and answered questions related to the relevancy of the course topics to CT and its potential for developing students' understanding of same.

The course consisted of five units taught over four to five weeks. The piloting of the course occurred in parallel (in the different schools (see Fig. 3)); thus, micro-cycles occurred within Version 1.

Kennedy-Clark (2013) specifies a micro-cycle in design research as a stand-alone study that focuses on fine-tuning a specific aspect of the research. For this study, the term micro-cycle was applied to a lesson. Figure 3 shows a Gantt Chart that illustrates the lessons, which are represented as a bar on the chart, with the continuous bar representing the full (macro) cycle (which is the course). The timeline allowed for lessons' content and delivery methods to be reviewed and modified between piloting a 'micro-cycle'/ lesson in different participating schools. These micro-cycles informed the emerging local instructional theory. If a lesson or part of a lesson was unsuccessful in one school, i.e. it was not engaging or effective, it was changed when piloted in the next school. This process shares parallels with lesson studies (Lewis et al., 2006). The data used to facilitate these changes were researcher notes, teachers' observations and student engagement questionnaires.

Table 3 illustrates the various means used to gather data in this study. For Version 1, in particular, students were issued with an engagement questionnaire, adapted from the

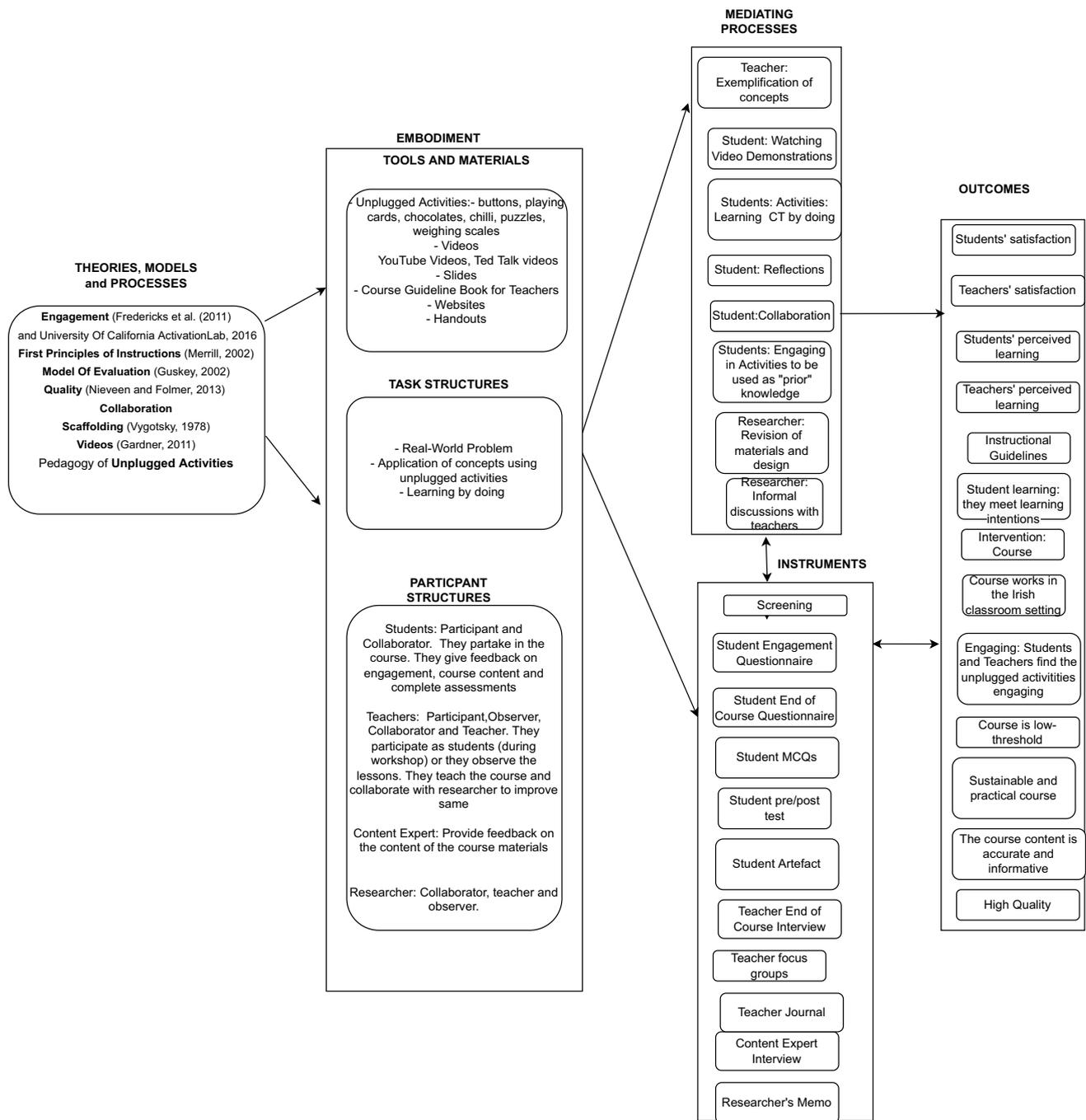


Fig. 2 Hybrid Map that illustrates the design trajectory of the study and pertinent EDR activities (Kirwan, 2021)

University of California’s Activation Lab (2016) Engagement Survey, after each lesson. It had eight items and a five-point Likert scale. It served two purposes: to provide the student voice during the piloting of each lesson and to be triangulated with engagement data captured at the end of the course. The mode and median values for each of the eight items were captured. Students were also issued with an end of course questionnaire, whose items were influenced from

Frick et al.’s (2009) Teaching and Learning Quality instrument for higher education students. The questionnaire had twenty-one items, a five-point Likert scale, and three open-ended questions (related to 1) strength of the course 2) recommendations and 3) perceived learning). The questionnaire collected data on unplugged activities, Merrill’s five principles of instructions, the course effectiveness, in particular two of Guskey’s four levels of data, i.e. student learning

Table 2 A summary of the schools and participants involved in the piloting of Version 1 of the intervention (Kirwan, 2021)

School type	Teacher recruitment	Student selection	Student class	Student numbers
School 1: All boy	School purposely selected (2 teachers, both female). Both teachers had no CS experience or qualification.	Students self selected into course	Transition Year (TY) (aged 15-16)	16
School 2: All boy	CESI Mailing List, (1 teacher, male) Teacher was studying for a CS qualification. No CS teaching experience	Students self selected into course	Transition Year (aged 15-16)	28
School 3: All girl	CESI Mailing List.: (1 teacher, male). Teacher had qualification in CS Teacher had CS teaching experience	Students took course as part of a compulsory timetabled TY computer class	Transition Year (aged 15-16)	30
School 4: Mixed DEIS (Delivering Equality of opportunity In Schools) School	CESI Mailing List. 1 teacher female. Teacher was studying for a CS qualification. No CS teaching experience	Students took course as part of a compulsory timetabled TY computer class	Transition Year (aged 15-16)	25 (12 consented for data)

outcomes and student reactions. Students also completed pre and post-tests which consisted of six open-ended questions. This provided a baseline on students' initial CT knowledge, as this was previously unknown, provided feedback on the course's instructional design by highlighting misconceptions or instructional difficulties and provided data related to students' learning outcomes (see effectiveness). The teacher's observations were captured in a journal, weekly emails, or informal discussions that the researcher documented and validated with the same teacher at interview. All teachers

were interviewed (semi-structured) post-course to ascertain their views on the course's engagement, low threshold, and content.

Data analysis occurred in three stages, after each lesson 'on the fly' (Bakker & van Eerde, 2015) and during a two-stage 'retrospective analysis' process: after each version, and at the end of the whole EDR process. The following section focuses on the analysis that resulted in changes or validations to the design model and not the course content and/or materials.

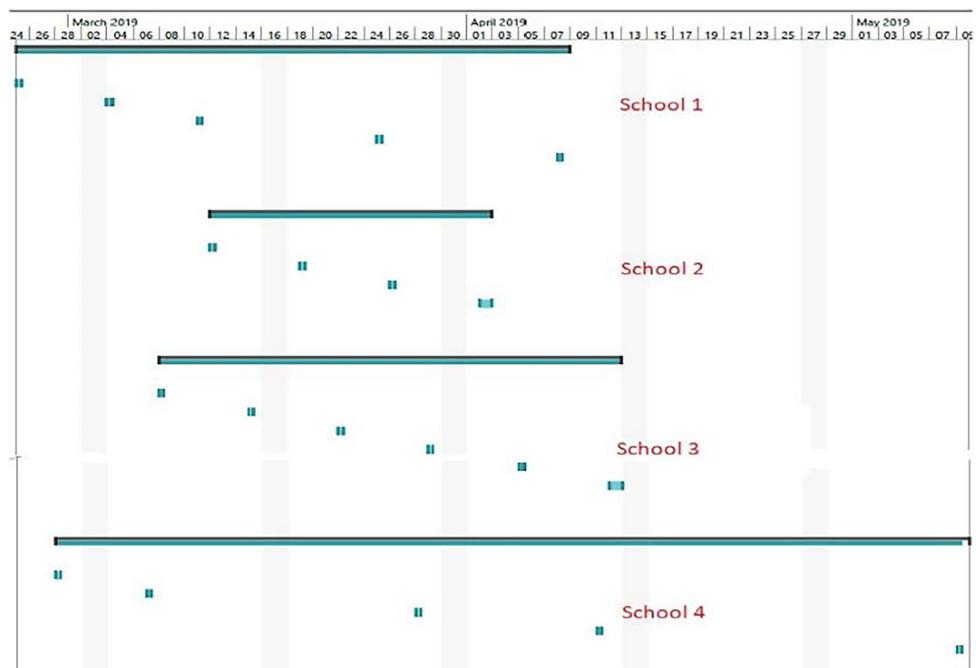
Fig. 3 Gantt Chart showing the timeline of the lessons (micro cycles) (Kirwan, 2021)

Table 3 A summary of the evaluations conducted and how they related to the course criteria and theory (Kirwan, 2021)

Version	Criteria	Model/Theory	Evaluation
1, 3	Engagement	Engagement is considered a multidimensional facet, containing cognitive, behavioural and emotional elements. (Fredricks et al., 2011)	1. Screening (researcher) 2. Student engagement questionnaire 3. Teacher Interview 4. Teacher observations in journal 5. Researcher observations
1, 2, 3	Effectiveness	Guskey (2002) Participants Reactions Participants Learning Participants' Use of New Knowledge and Skills Student Learning Outcomes	1. Student end of course questionnaire 2. Student Portfolios 3. Teacher interviews 4. Teacher observations in journal
1, 2, 3	Low Threshold		Interview (teachers) Students end of course questionnaire
2, 3	Assessment		Pre and post tests for Students Teacher interviews
1,2,3	Quality	Nieveen(1999) Validity Practicality Effectiveness	Interview (teacher) Interview (content expert) Teacher journals Researcher journal

'On the Fly' analysis and the Evolving Design

The design model for Version 1 originated in a fusion of collaborative unplugged activities placed in a structured framework, influenced by Merrill's First Principles of Instruction (2002). The first 'On the Fly' analysis conducted during the piloting of Version 1, highlighted problems with the "activation" step. Students did not have a common knowledge base connected to CT concepts. This finding was also validated during the analysis of the results of the pre-tests. A pre-activation step, was thus introduced during the prototype of Version 1, and trialled in all subsequent lessons. This consisted of one or two short, simple, memorable, and fun activities performed at the start of each lesson. Pre-activation is the name coined in this study for a memorable activity that established a baseline of knowledge, which could be activated later to build on new knowledge, in the same lesson. For example, in unit 1, students were asked to sort buttons, at the start of the lesson. This task was referred back to when the CT components of decomposition, pattern matching and abstraction were explained. These activities were considered different from the unplugged activities used to apply new knowledge.

"That was incredible yeah. Sorting the buttons like and they see the difference in how they were going about size and shape you know like number of holes and stuff like that". (Teacher 2, interview)

Retrospective Analysis

Data from the student 'end of course' questionnaire was analysed to validate the current design model. Its quantitative

data was inputted into the SPSS software, and descriptive statistics were gathered to collect the mode and median values for each of its item per school. The qualitative data from the open-ended questions were analysed (per school) using a deductive content analysis approach. This was driven by the three open-ended questions (Fereday & Muir-Cochrane, 2006), and provided both descriptive and quantifiable information (Sabharwal et al., 2016; Vaismoradi et al., 2013) (see Table 4). Data from the semi-structured teacher interviews and content experts were analysed using Thematic Analysis (Braun & Clarke, 2006).

Findings from the analysis of the collected data validated the following design components, i.e. unplugged activities, demonstration and application of knowledge. The collected data also confirmed that the course was engaging and effective. Of note, the mode and median value for each item on the end of course questionnaire was either 4 or 5. This corresponds to Agree or Strongly Agree. A sample of some of these items are provided below:

- I am dissatisfied with the activities used in this course. (reversed)
- I engaged in activities that helped me learn ideas or skills that were new and unfamiliar to me.
- In this course, I was able to connect the activities to new ideas and skills I was learning.
- The activities helped increase my knowledge and skills in Computational Thinking.
- Overall, I would recommend this course to other students.
- This course was a waste of time. (reversed)

Table 4 Results from the analysis of the open-ended question: What are the strengths of this course? (N=26, School 3) (Kirwan, 2021)

Content	Description	Example	Frequency Column	
			Mentions	By Person
Pedagogy	Answers related to activities and the way the course was taught, i.e. interactive, collaborative and using demonstrations	<p>“easy to stay focused as there was a lot of activities” (Student S12)</p> <p>“the activities were the strength, they got everyone involved”(Student S13)</p> <p>“activities ... really helped me to understand and learn more”(Student S21)</p> <p>“very interactive.. it put the learning into real-life situation”(Student S17)</p> <p>“I love the group work”(Student S20)</p> <p>“We were shown examples of what we were being told about” (Student S10)</p>	23 (activities) 54	21 26
Teacher	Answers identified the teacher as a strength	<p>“teacher is really nice, friendly and helpful” (Student S2)</p> <p>“Colette was very engaging and fun to learn from” (Student S17)</p>	7	7
Content	Answers related to the Course Content	<p>“Personally I really enjoyed the algorithms and ethics section of the course” (Student S4)</p> <p>“I also think the content of the classes was another strength as we learnt so many new things every week without all the information being too much to take in” (Student S6)</p>	9	7
Other	Answers were mixed. They ranged from the course cheered them up, to the fact they enjoyed it	<p>“Sometimes when I was fed up or in a sad mood, this course always cheered me up & I looked forward to it each week” (Student S26)</p> <p>“Different use to teacher and PowerPoint ... this course ... involved ... use our brains” (Student S4)</p>	4	4

- Media used in this course (e.g. videos, websites, slides) were helpful in learning.
- My teacher gave examples of concepts that I was expected to learn.

The majority of students expressed a positive reaction to the course. They did not find it a waste of time, would recommend it to others, and were satisfied with both the content and activities used in the course. These results were triangulated with qualitative data from the open-ended question “What are the strengths of this course” and with data from the teachers’ and content experts’ interviews. Analysis of students’ answers categorised four strengths of the course: ‘Activities’, ‘Pedagogy’, ‘Learning’ and ‘Course Content’. Table 4 presents an example of how the content analysis results were displayed for School 3.

Students considered ‘Activities’ as a strength for a variety of reasons. These reasons included answers corresponding to the three facets of engagement: emotional, cognitive and behavioural (Fredricks et al., 2011). Activities were described as: “fun and interactive” (student A12), “engaging” (students A1, A8), “peaked my interest” (student A1). “made the course more enjoyable” (Student S3). Several students linked this fun element to learning “I really enjoyed

the practical games and explanations that we got to do before the theory as I felt it helped to explain the theory and information we were given. I found it made the course more enjoyable” (Student A3).

Students also enjoyed the collaborative element of the activities, with Student A13 and Student N20 highlighting the inclusive element of the activities. “the activities were the strengths, getting everyone involved, and teaching us how to do the activities really helped instead of just having a powerpoint. Even if you didn’t enjoy it, you could still get involved” (Student A13).

Changes to Design

Analysis of interview data from teachers and content experts saw ‘clarity’ emerging as an important instructional element. It was linked to both the quality of the course and student engagement. Both content experts referred to items captured under the theme of clarity, such as definitions, course layout, information, position on definitions, and language. Of note, Expert 1 highlighted how clarity was needed on whether the course considered CT as knowledge or skill. The course considers both as being equally important. Expert 2 highlighted clarity with respect to the evolving instructional model, he

recommended that the instructional model of the course should be highlighted in conjunction with the content. Gooder et al. (2012, p. 48) concur with Expert 2, emphasising the “inseparable link between curriculum and instruction”. Gooder et al. highlight how the American ‘Exploring Computer Science’ course’s instructional paradigm was as crucial as the selected content. Expert 1 highlighted the importance of clarity in language, particularly where the word had a specific meaning in Computer Science. This concern was in relation to two words: sorting and abstraction. During the piloting of Version 1 of the course, one of the ‘pre-activation’ activities consisted of sorting buttons.

Expert 1 questioned the word ‘sorting’, as the activity resulted in students ‘sorting’ based on colour and the number of holes in the buttons. In Computer Science, the word sort means “rearranging information into ascending or descending order by means of sortkeys” (A. B. Butterfield et al., 2016, para 1). The word ‘sorting’ was changed to categorising. Clarity was also needed concerning the course definition of abstraction. The course defines it as identifying and capturing essential details, thus highlighting the reductionist and modelling aspects of abstraction as Wing (2009) specified. In Computer Science, there are two types of abstraction: modelling and encapsulation (The Open University, 2019). The course emphasises the modelling approach, i.e. ignoring detail that is not of interest. Clarification on why the encapsulation approach (information hiding) was not used (most students had not programmed, and the cognitive load was judged to be too high) was documented in the teachers’ handbook.

Clarity in relation to activities was also captured during the ‘On the Fly’ analysis. Teachers reported that student engagement increased when instructions were clear.

Students were also most engaged when the task at hand was very clear to them. The spell checker activity caused confusion for some but was introduced excellently with the spelling test. More scaffolding here to help students approach the problem with a strategy would help. (Teacher 2, Email, 12th March 2019)

Prototype Phase (Version 2)

Version 2 of the course was piloted over four months, from August 2019 to December 2019. It involved three hundred and forty students, six teachers, and two schools. Details of the school and students are provided in Table 5.

The goal of this version of the prototype was to explore the practicality and usability of the course and how best to assess the content. Unlike Version 1, the participating teachers taught Version 2. As student assessment is outside the scope of this paper, the data discussed here relates to the teachers’ perspectives from the piloting of Version 2, in particular their perspectives on its practicality, usability and effectiveness. Data was collected using the following methods: individual and group interviews and teacher diaries. The data was analysed using thematic analysis. Four key themes were generated: ‘Teachers’ Experiences’, ‘Students’ Experiences’, ‘Learning Environment’, and ‘Course Design’. This paper is concerned with the data gathered under ‘Course Design’ and ‘Teachers’ Experiences’, which influenced the design model.

With reference to the ‘evolving design model’, teachers’ data validated the use of unplugged activities, both those used for pre-activation of knowledge and activities used to apply knowledge. They also validated that the activities were engaging and thought-provoking for both teachers and students. The teachers reported finding them memorable, which aided the linkage of CT to other subjects and computer programming. Analysis of teachers’ interview data also emphasised the success of short videos (3/4 minutes) as both a demonstration tool and a means of setting up an unplugged activity, i.e. as a hook. Knowledge demonstrated first to students before they applied it was shown to aid clarity and engagement.

Evolving Design Model

Analysis of teachers’ data resulted in three changes to the current design model: the addition of theory and

Table 5 A summary of the schools and participants involved in the piloting of Version 2 of the intervention (Kirwan, 2021)

School type	Teacher recruitment	Student selection	Student class	Student numbers
School 2: All boy	CESI Mailing List, Teacher self selected: (1 teacher, male). Teacher was studying for a CS qualification. No CS teaching experience. Teacher was also part of pilot of Version 1	Students took course as part of a compulsory timetabled computer class twice a week	Transition Year (aged 15-16)	35
School 5: All boy	CESI Mailing List. self selected: (5 teachers: 2 male, 3 female). Three had CS qualifications, 2 did not	Students took course as part of a compulsory timetabled computer class twice a week	1 st Year (age 12-13) 4 classes 2nd Year (age 13-14) 4 classes 3rd Year (age 14-15) 4 classes TY (age 15-16) 1 class	305

exemplifications as essential components and a change in how reflections of new knowledge were conducted.

Theory

The design component of ‘Theory’ emerged to prominence during this phase. Teachers relayed how knowing and understanding the components of CT facilitated their articulation of problem-solving in their other teaching subjects. For example, Teacher 6 (Interview) and Teacher 7 (Interview) stated they used the word abstraction when modelling trigonometry. Teacher 10 confirmed how he linked logic to English writing to verify conclusions (Interview). Teacher 9 (Email, 8th October 2019) explained how her students said they would use the idea of decomposition and abstraction in their Art class when drawing an image. Teachers 6 and 7 explored this topic further by stating that the course had given them an articulation grammar.

[Teacher 7] And particularly giving me the language to use the word abstraction.

[Teacher 6] Abstraction and decomposition.

[Teacher 7] Like before, as I said, we did a bit of it last year, I never used the words outside of those two classes. But now I can see myself using it for lots of different classes, like maths

[Teacher 6] Yeah, in Maths. (Group Interview, 4th Dec 2019)

Exemplification

Exemplifications emerged as a valuable design component during this phase. Exemplification has its origins with Merrill’s (2002) principles of demonstration and real-world examples. However, teachers reported that localised, context-specific examples of CT components were essential to CT’s effective teaching and learning. Using real-world examples was not sufficient as students could not relate to them.

Reflection

This design component has its foundations in Merrill’s integration principle (Merrill, 2002). Most teachers confirmed the prominence of the copybook and writing in their approach to teaching: “copy work, backed up with theory, backed up with copy work” (Teacher 9, Interview). Writing was an essential feature of their teaching style, especially for classroom management and ensuring all students’ participation. The pre-activation activities such as the button categorising and the 30 seconds game (an abstraction game) caused classroom management issues for half of the participating teachers. The students were reported as being over-excited after these activities,

making the class harder to control. Writing was suggested as a classroom management technique to calm students. It was also offered as an alternative to verbal reflections. Verbal reflections were used in Version 1, reflecting the researcher’s own preferred medium. Therefore, it is recommended that teacher preference be considered concerning their preferred type of reflections, be it verbal or written.

Summative Phase

The summative phase was conducted in two schools (School 1, School 6) from November 6th to 17th Dec 2019. School 6 was purposely selected, as it was an all-girl school. This phase overlapped with Version 2 of the prototype, which took ten weeks rather than five to complete. Qualitative and quantitative data were captured in this phase (see Table 1) using the same instruments as Version 1 and Version 2. The content experts were selected from two ‘new’ different universities (1 Irish, 1 English). The data analysis confirmed that the course and its design model resulted in an engaging, low threshold, effective, practical and high-quality course.

ADAPTTER Framework: Findings and Recommendations

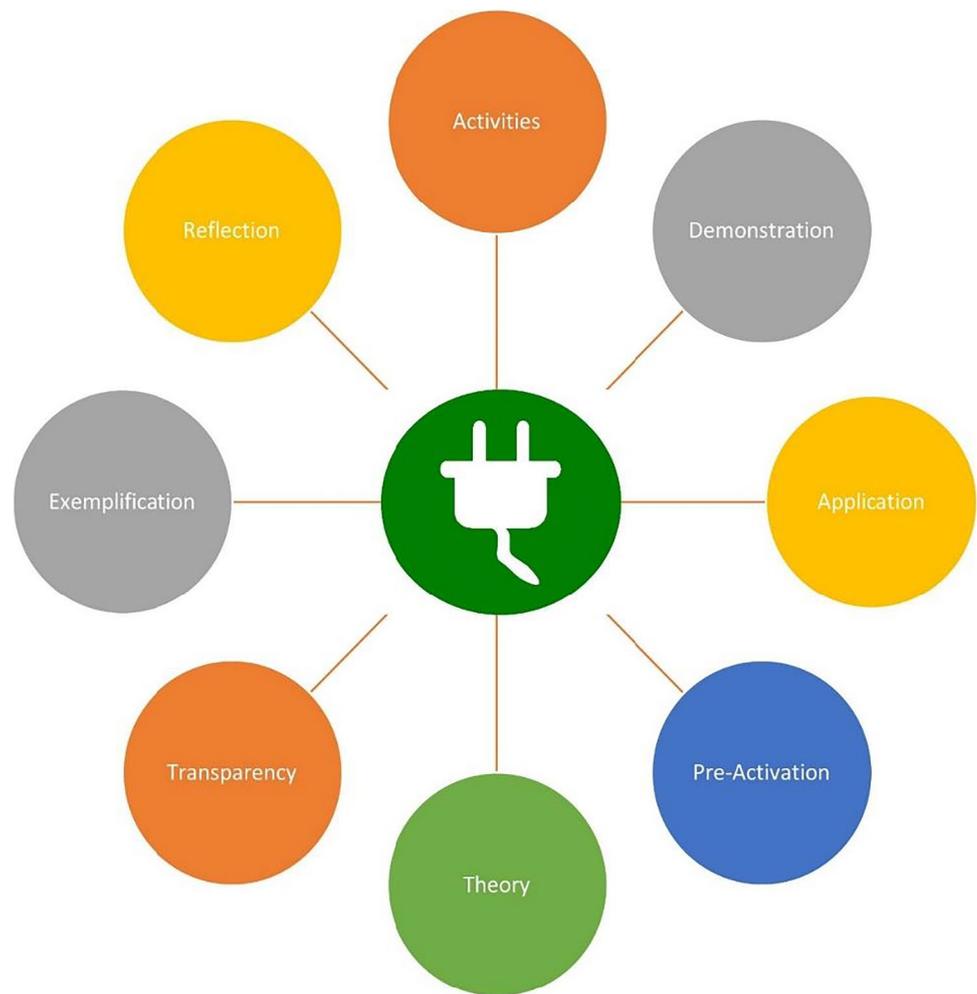
Activities, Demonstrations, Application, Pre-activation, Transparency, Theory, Exemplification, and Reflection (ADAPTTER) are the characteristics of a high quality, practical, engaging, effective, and low threshold course for both the learning and teaching of CT to Irish second-level teachers and students. Each lesson was designed to start with a pre-activation puzzle, followed by theory, then a demonstration and application of knowledge, followed by reflection. The following section discusses and highlights the findings and recommendations of this study (Fig. 4).

Activities

Unplugged activities are credited in their origin to Timothy Bell (Bell, 2018). This study demonstrated that unplugged activities are an important component for the teaching and learning of CT. For clarity, this study makes a distinction between activities used to establish a baseline of knowledge (see pre-activation) and activities that were ‘applied’ after a demonstration. The activities used to develop a baseline of expertise were characterised as being memorable. They took the form of a puzzle or game. These occurred at the start of a lesson or new topic and thus were not demonstrated first.

Activities applied after a demonstration (of new knowledge) were always collaborative (Vygotsky, 1978) and related to either Computer Science or ‘real-life’. Where

Fig. 4 The ADAPTTER framework for developing a high quality, effective, low threshold, engaging, and practical course for teaching Computational Thinking (Kirwan, 2021)



appropriate, these group activities should be playfully competitive, accompanied by clear instructions. The findings from this study can be added to the relatively few empirical studies conducted on unplugged approaches in a regular classroom as confirmed by Bell and Vahrenhold (2018) and Curzon et al. (2019).

Demonstrations

The ‘Demonstration’ design component has its origin in Merrill’s (2002) First Principles of Instruction. This study found that demonstrations promoted learning and engagement. They facilitated students approaching a problem with a base of knowledge, and clarity to the task at hand. This study recommends using short, relevant videos or websites to demonstrate CT concepts.

Application

‘Application’ of knowledge has its origin with Merrill (2002). This study found that unplugged activities provided students with the opportunity to practice and apply their knowledge of CT components. This study recommends using everyday items, including peer collaborations, and considering students’ Computer Science knowledge (Sentance & Csizmadia, 2017, p. 479).

Pre-activation

This design component has its foundations in Merrill’s ‘Activation’ principle of instruction, where “Learning is promoted when learners activate existing knowledge and skills as a foundation for new skills” (Merrill, 2013, p. 21). A lack of a common baseline of knowledge associated with CT concepts was evident in Irish second-level students, and

teachers. This finding draws comparisons with Izu et al.'s (2017) study, which found that concepts key to CT are unfamiliar to many K12 teachers. This study recommends a 'pre-activation' activity. This is a simple, short, memorable, and fun activity. It is performed at the start of a lesson or topic, with no explanations or teachings preceding its implementation. The knowledge gained from this activity is 'activated' later in the lesson, to provide the foundation for more complex knowledge. Another activity is then later 'applied' to practice this more 'complex' knowledge. This study recommends that 'explicit teaching' of theoretical concepts follow the 'pre-activation' activities. The 'pre-activation' activity concerns the same concept.

Transparency

This study found that clarity is a crucial design characteristic, ensuring content quality and student engagement. The word transparency is used in its stead to highlight the importance of making this clarity visible. Instructional communication research validates this design component, stating that teacher clarity is essential to teaching effectiveness and learning (Zhang & Huang, 2008). Rosenshine and Furst (1971) are credited with first identifying clarity as one of the top five variables associated with effective teaching. This study advocates that teachers and curriculum designers state clearly their concept definitions and provide clarity to their layout of course materials, concepts and instructional design. Of note, a recent study that systematically analysed conceptual and operational definitions of abstraction highlighted the many varying definitions and interpretations of same (Ezeamuzie et al., 2021).

Theory

Unplugged activities were the main pedagogical tool used for teaching CT, however, this approach was supplemented with theory. A body of studies exists that recommends explicit teaching in Computer Science (Waite, 2017). Of note, Meerbaum-Salant et al. (2011) study questions the use of exploratory learning with Scratch, they posit teaching students the " 'right way' from the beginning" (pg 172). Mayer (2004) and Sweller et al. (2007) advise against minimally guided teaching techniques, asserting that complex concepts must be explicitly taught. The initial design of this CT course trialled explicit teaching to students, based on cognitive load theory (Sweller, 1988). However, as the study progressed, it was found that the explicit teaching of concepts needed to be placed in a framework. This study recommends that for students with no baseline of CT knowledge, that explicit teaching be placed in a framework that incorporates pre-activation activities, 'explicit teaching', demonstration and application of knowledge. This recommendation

shares similarities with Grover et al.'s (2015) view that deep learning (of CT) is fostered with a combination of guided discovery and instruction rather than pure discovery. It also shares similarities with Mooney et al.'s (2014) study findings. In their CT course for Irish post-primary, students "found the material challenging, and both students and teachers reported that a less theoretical and more practical approach might have been more helpful for introducing key concepts" (2014, p. 11).

Exemplification

This design characteristic has its origins with Merrill's Principles of Instructions, specifically demonstrations and real-world examples. Findings for this study recommend that these examples be context-specific and localised. Examples need to be relatable to students, being 'shown rather than told'. It is recommended (once a baseline of knowledge is achieved) that students themselves contribute examples.

Reflection

This design component has its foundations in Merrill's integration principle (M. D. Merrill, 2002). This study recommends that students are allowed to reflect and share their learning. However, teacher preference should be considered in its form, verbal or written.

Conclusion

This paper outlined the evolution of the ADAPTTTER framework, describing its synthesis into a framework that can be successfully used to design a high quality, engaging, practical, effective, and low threshold course. This study validated the use of unplugged activities as a tool for teaching CT. Thus, adding to the relatively few empirical studies conducted using unplugged activities in the classroom (Bell & Vahrenhold, 2018).

The findings from this study have implications for educational policy, initial teacher education, second-level curricula, and second-level teaching practice in Ireland and beyond. More educational systems worldwide are recognising the value of CS education, and thus its importance is expanding (Vegas & Fowler, 2020). This study revealed how the language of CT facilitated the transfer of CT concepts to other subjects. Teachers and students now had common words and terms to articulate their thinking. This finding has implications for new and current teachers.

Using unplugged activities provided a low-threshold (including low cost) way to teach CT successfully. It also allowed for a planned progression of CT concepts. This was shown to reduce the cognitive load of CT, and facilitate its concepts being introduced before programming. Finally, the

ADAPTTER framework is offered as a way for teachers and researchers to integrate all of its components and concepts, and thus have design conversations around them.

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Declarations

Ethics Approval This paper involved human participants. Ethical permission was obtained from Dublin City University Research Ethics Committee (reference number DCUREC/2018/201). Written consent was obtained from all participants (teachers, content experts, students and their guardians). This consent was for both participation and for publication (maintaining anonymity).

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Author Roles This work is based on a finished PhD thesis. The principal author Dr. Colette Kirwan was the research student. Dr. Enda Donlon and Dr. Eamon Costello were her co principal supervisors.

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