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# An Integrated Framework for Interactive and Inclusive Asynchronous Online Learning at Scale: Data Literacy in Higher Education

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## Abstract

Online asynchronous learning offers considerable flexibility but frequently faces challenges in sustaining engagement, interactivity, and inclusivity across diverse learner populations. This study introduces the OPTIMAL framework—an Online, Pedagogy- and Technology-Integrated, Microcurricula Approach for interactive and inclusive Learning—synthesising universal design for learning, active learning, and constructive alignment with technology integration frameworks (TPACK and PICRAT), operationalised through a microcurricula-as-a-service architecture. A three-year longitudinal case study (2022/23 to 2024/25) examined the application of the framework to a data literacy and analytics module serving over 5000 students across more than 15 programs and five faculties at Dublin City University. The module design constructively aligned learning outcomes, content, and technology at three levels to support multiple learning pathways, formative assessment, and transdisciplinary engagement, deliberately fostering transformative uses of technology in a fully asynchronous environment. Mixed-methods evaluation—combining learning analytics, surveys ( $n = 1743$ ), and qualitative feedback—demonstrated sustained positive outcomes across all three years, including 95–99% completion rates, consistently high satisfaction, and longitudinal gains in engagement and pass rates. These findings demonstrate how the deliberate integration of pedagogical theory, technological frameworks, and modular curriculum architecture can deliver scalable, inclusive, and high-engagement online education, offering both a transferable, evidence-based model for educators and curriculum designers and longitudinal empirical validation for researchers.

**Keywords:** inclusive education; universal design for learning; UDL; online asynchronous learning; technology integration; microcurricula; educational technology; transformative learning; active learning; data literacy



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## 1. Introduction

The rapid expansion of online asynchronous learning in higher education has created unprecedented opportunities to reach diverse student populations at scale (Levey, 2023; Varkey et al., 2022). However, this expansion has simultaneously exposed critical challenges in designing learning experiences that are truly interactive, inclusive, and accessible to learners from varied social, cultural, psychological, and economic backgrounds (CAST, 2018; Dean et al., 2017). While educational institutions increasingly serve thousands of students through online platforms, many struggle to move beyond passive content delivery toward transformative learning experiences that accommodate diverse learning needs and

foster meaningful engagement (Emmers et al., 2022; Farrell et al., 2021). This challenge is particularly acute in transdisciplinary modules such as data literacy and analytics, where students from multiple academic programs with heterogeneous prior knowledge and skills must develop technical competencies and critical analytical attitudes (Vuorikari et al., 2022).

The post-pandemic educational landscape has accelerated hybrid and fully online learning, increasing the demand for scalable, inclusive, and effective online education. As data literacy emerges as one of the fundamental 21st-century transversal skills across disciplines (Anderson, 2024; Lund et al., 2026; Vuorikari et al., 2022), universities need to deliver high-quality instruction while ensuring accessibility for diverse learners. Student-centred pedagogies, including universal design for learning (UDL) (Buckland, 2012; CAST, 2018) and active learning strategies such as problem-based learning (Christersson et al., 2019; Eison, 2010), project-based learning (Guo et al., 2020), and inquiry-based learning (Lee, 2012; Spronken-Smith & Walker, 2010), have proven effective in face-to-face contexts, yet their systematic adaptation to large-scale, asynchronous environments remains underexplored.

Despite the proliferation of educational technologies—including learning management systems (LMSs), interactive content tools, adaptive platforms, and AI-based systems (Haleem et al., 2022; Kang, 2021; Mahmud et al., 2022)—integration of pedagogy, technology, and content design to support interactivity and inclusivity at scale remains limited. Many implementations are fragmented, dispersing key functionalities across tools and undermining coherence (Kimmons et al., 2020). While technologies claim alignment with UDL principles (CAST, 2018), evidence of their structured integration in large-scale asynchronous curricula is scarce, limiting potential for inclusive and transformative learning for thousands of diverse students.

This paper presents a comprehensive case study of a data literacy and analytics module that integrates pedagogy, technology, and inclusive curriculum design via a microcurricula-as-a-service model (Abgaz & Dunne, 2023). Microcurricula decompose traditional modules into granular, self-contained units (0.5–1 ECTS) focused on a single learning outcome with complete content, assessment, and instructional activities. This design provides flexibility and personalisation while maintaining coherence and constructive alignment across outcomes, activities, and assessments. The module serves 5220+ first- and second-year students across 15+ programs at Dublin City University, delivered asynchronously over three academic years (2022/23–2024/25).

The proposed framework is built upon two complementary and interdependent layers of theoretical grounding. The first layer comprises pedagogical theories—UDL, active learning, and constructive alignment—which collectively define what constitutes effective, inclusive, and interactive learning design. The second layer comprises technology integration models—TPACK (Mishra & Koehler, 2006) and PICRAT (Kimmons et al., 2020)—which explain how technology is strategically selected and exploited to operationalise the pedagogical design, as instantiated through the LMS, known institutionally as Loop, and H5P interactive content (Magro, 2021). Critically, these two layers are hierarchical and interdependent rather than additive: the pedagogical theories establish the design principles and intended outcomes, which in turn drive the criteria for technology selection and deployment. Constructive alignment operationalises this integration at three levels: curriculum design, connecting competencies, outcomes, assessments, and learning activities; technology selection, emphasising transformative affordances guided by TPACK and PICRAT; and content development, supporting multiple means of representation, engagement, and expression in accordance with UDL principles. Together, and further operationalised through a microcurricula-as-a-service architecture, these elements constitute what is termed the OPTIMAL framework: an Online, Pedagogy- and Technology-Integrated, Microcurricula Approach for interactive and inclusive Learning.

The study asks the following: “Can the constructive alignment of pedagogy, technology, and content via microcurricula deliver an interactive and inclusive module at scale, enhancing learning for diverse students?” Using mixed-methods research, quantitative performance and survey data are analysed alongside qualitative student feedback collected over three years. The paper makes the following key contributions to the fields of educational technology and inclusive online learning:

- **The OPTIMAL Framework:** Presents an evidence-based framework synthesising all of these theoretical and technological elements into a single coherent, operationalised framework explicitly designed for interactive and inclusive online asynchronous learning at scale.
- **Microcurricula-as-a-Service Model:** Introduces and demonstrates a Microcurricula-as-a-Service model that enables programs to selectively adopt, sequence, and contextualise modular content within their own disciplinary frameworks while maintaining coherent learning pathways for diverse student populations—a level of flexibility and transferability that distinguishes this approach from conventional microcurricula implementations.
- **Systematic Technology Integration:** Documents the strategic selection and exploitation of educational technologies (Moodle/Loop, H5P) guided by explicit integration frameworks, demonstrating how specific technological affordances support UDL principles and active learning strategies in asynchronous environments.
- **Longitudinal Evidence at Scale:** Provides empirical evidence from a three-year implementation serving students across multiple disciplines, demonstrating sustained effectiveness in supporting learning outcomes, engagement, and inclusive practices in large-scale online education.
- **Practical Implementation Guidelines:** Offers transferable insights for educators and curriculum designers seeking to integrate pedagogy, technology, and content in online learning contexts.

It is therefore the integration, contextualisation, and longitudinal empirical validation of these elements collectively that constitutes the unique contribution of this study, rather than any single component in isolation. The OPTIMAL framework offers a replicable, evidence-based blueprint that addresses a gap in the literature, the absence of empirically validated integrated design frameworks for delivering transversal competencies inclusively and effectively to large, diverse student populations in fully asynchronous online environments.

The remainder of the paper is structured as follows: Section 2 establishes the theoretical foundations, technology frameworks, and related online learning approaches that underpin the OPTIMAL framework. Section 3 presents the OPTIMAL framework alongside the case study context, leading to the application of the theoretical propositions. Section 4 details the research design, encompassing data collection and analysis methods, and situates these within the broader empirical investigation. Section 5 reports three years of quantitative and qualitative findings that substantiate the proposed approach. Although the theoretical depth of the earlier sections may initially suggest a purely conceptual contribution, the application of the theoretical propositions to a large sample of participants yields robust empirical findings that complement and convincingly validate the framework. Section 6 interprets the findings, examines implications, and notes limitations of the study. Section 7 summarises the key contributions and outlines directions for future research.

## 2. Background: Theoretical Framework and Related Work

The design of interactive and inclusive online learning experiences requires the systematic integration of pedagogical theories, technology integration frameworks, and educa-

tional content design. This section reviews the theoretical foundations that informed our approach and examines frameworks for technology integration in educational contexts. It explores the capabilities of relevant educational technologies and situates this work within the broader landscape of online learning design research.

### 2.1. Pedagogical Foundations for Inclusive Online Learning

Learning theories provide the foundation for effective curriculum design in higher education. Behaviourism emphasises learning through stimulus and response (Carlile & Jordan, 2005), while cognitivism focuses on mental processes of understanding and memory. Constructivism views learning as an active process where students construct knowledge through experience and reflection (Dewey, 1926, 1938; Piaget, 1970; Vygotsky, 1978). In asynchronous online environments, constructivist approaches are especially valuable as they support learners with diverse backgrounds, allowing them to engage meaningfully, progress at their own pace, and connect new ideas to prior knowledge.

#### 2.1.1. Active Learning Strategies

Active learning shifts the focus from passive reception to active engagement, where students construct understanding through doing (Christersson et al., 2019). Strategies such as problem-based learning (PBL) encourage inquiry and collaboration around authentic problems (Eison, 2010; Ryan, 2022; Trullàs et al., 2022), while project-based learning (PjBL) extends this through sustained work that produces real outcomes (Guo et al., 2020; Schneider & Preckel, 2017). Inquiry-based learning (IBL) nurtures curiosity and independence (Lee, 2012; Spronken-Smith & Walker, 2010), and mastery learning emphasises gradual progress through feedback and scaffolding (Bloom, 1968; Guskey, 2007; Krathwohl, 2002). When supported by educational technology, these strategies transform online learning into an interactive, reflective, and learner-centred experience.

#### 2.1.2. Universal Design for Learning

Universal design for learning (UDL) provides a proactive framework for creating inclusive learning environments that serve all students from the outset (CAST, 2018). It is built on three principles—multiple means of representation (MMR), multiple means of engagement (MME), and multiple means of action and expression (MMAE) (Buckland, 2012; Levey, 2023; Rose et al., 2013). These encourage varied content formats, flexible learning pathways, and multiple ways for students to demonstrate understanding. In large-scale online settings, applying UDL principles ensures accessibility, fosters autonomy, and enhances motivation. Achieving this requires thoughtful technology design that combines flexibility with clear structure, creating experiences that accommodate differences without compromising coherence.

#### 2.1.3. Constructive Alignment

Constructive alignment ensures that learning outcomes, activities, and assessments work together coherently to achieve educational goals (Biggs, 2003; Biggs & Tang, 2011). In online contexts, it extends to technology selection—tools must serve learning purposes rather than novelty. Well-aligned designs help students understand what is expected, how to achieve it, and how their progress is assessed. When applied effectively, constructive alignment brings together pedagogy, technology, and assessment into a unified structure that supports purposeful, transparent, and engaging online learning.

### 2.2. Technology Integration Frameworks

While pedagogical theories provide foundations for learning design, systematic integration of educational technologies requires explicit frameworks that guide selection

and implementation decisions. Two complementary frameworks—TPACK and PICRAT—inform our approach to technology integration in this work.

2.2.1. Technological Pedagogical Content Knowledge (TPACK)

The TPACK framework extends Shulman’s concept of pedagogical content knowledge (PCK) (Shulman, 1986, 1987) by explicitly incorporating technological knowledge as a key dimension of effective teaching in digital environments (Koehler & Mishra, 2016; Koehler et al., 2013). It highlights the interplay of content, pedagogy, and technology, emphasising their intersections: PCK concerns how to teach specific content; TCK focuses on how technology reshapes content representation; and TPK examines how teaching evolves with technology. The integrated TPACK (See Figure 1a) domain represents knowledge required to teach specific content using appropriate technologies in pedagogically sound ways. Although criticised for unclear boundaries (Kimmons et al., 2020) and limited adaptability to rapid technological change (Tseng et al., 2020), TPACK provides a framework guiding technology selection and implementation grounded in pedagogical and content relevance.

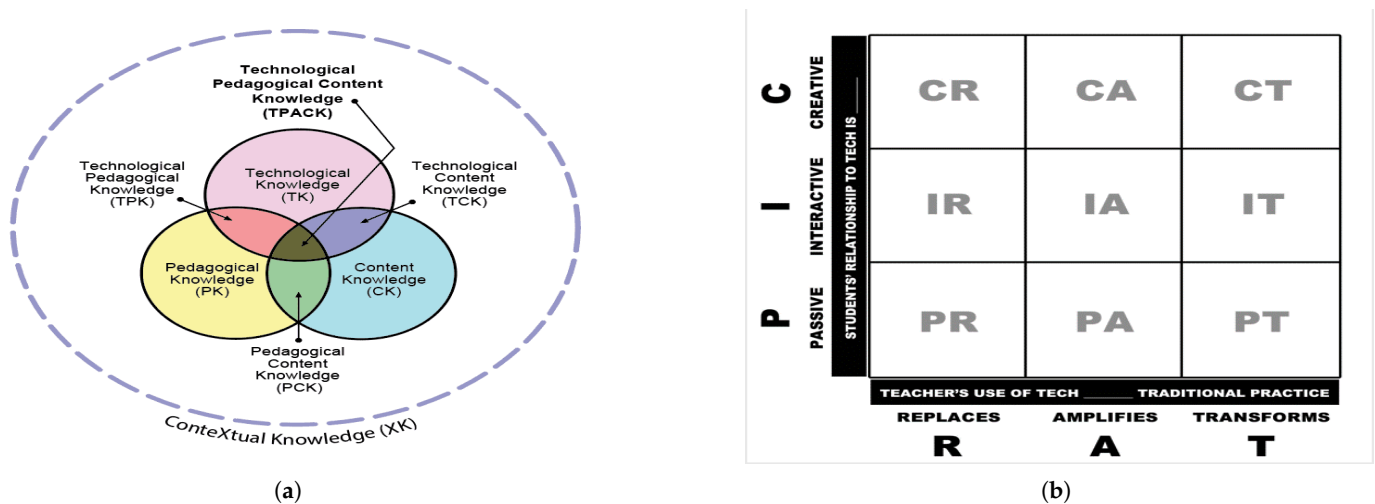


Figure 1. Technology integration models: (a) TPACK model (Warr & Mishra, 2022). (b) PICRAT model (Kimmons et al., 2020). Both diagrams are published with written permission from the authors via CC-BY licence.

2.2.2. Passive, Interactive, Creative and Replace, Amplify, Transform (PICRAT)

While TPACK guides the knowledge required for integrating technology, the PICRAT framework (See Figure 1b) evaluates its impact on student engagement and learning transformation (Kimmons et al., 2020). It combines two dimensions: the PIC model—categorising student interaction as passive (consuming content), interactive (manipulating or responding), or creative (producing new artefacts)—and the RAT model, which assesses technology’s pedagogical function as replacement, amplification, or transformation. Replacement substitutes traditional tools, amplification enhances efficiency or accessibility, and transformation enables novel learning experiences. Kimmons et al. (2020) emphasise that true transformation occurs when technology facilitates otherwise impossible learning activities. The combined PICRAT matrix thus guides educators toward interactive and creative–transformative applications that maximise technology’s potential, particularly in online asynchronous environments.

Together, TPACK and PICRAT provide complementary frameworks: TPACK guides the integration of technological, pedagogical, and content knowledge, while PICRAT offers criteria for evaluating whether specific implementations effectively engage students and

transform learning experiences. Both frameworks informed the technology selection and implementation decisions in this work.

### 2.3. Educational Technologies for Online Learning

The educational technology landscape has evolved rapidly, encompassing LMS platforms, interactive tools, adaptive systems, and emerging AI-based solutions (Haleem et al., 2022; Kang, 2021; Mahmud et al., 2022). Yet, many remain resource-intensive or untested at scale. This study focuses on two mature, accessible technologies—Moodle-based LMS and H5P interactive content—that effectively operationalise UDL and active learning at scale in online asynchronous environments.

#### 2.3.1. Learning Management Systems: Moodle/Loop

LMSs form the foundation of online and blended learning by centralising course delivery, communication, and assessment (Gamage et al., 2022). Moodle/Loop provides modular course structures, multi-format content, discussion tools, assessment systems, analytics, and integration capabilities supporting inclusive, student-centred learning. These affordances align with UDL principles and enable flexible, scalable course designs. While LMS platforms provide structure and analytics, achieving higher interactivity and creativity requires complementary tools that move practice from passive-replace toward the interactive-amplify or creative-transform dimensions within the PICRAT framework.

#### 2.3.2. H5P: Interactive Content Creation and Delivery

H5P is an open-source framework that integrates with LMS platforms to create engaging, interactive HTML5 content (Magro, 2021). Offering over 50 activity types—from interactive presentations and multimedia enhancements to embedded assessments—H5P supports multiple means of representation, engagement, and expression. Its integration with Moodle transforms static materials into dynamic learning experiences while preserving analytics and feedback. This synergy enables sustainable, scalable, and transformative online learning, fostering active engagement and measurable learning gains.

### 2.4. Related Work and Research Gap

While educational technology integration in higher education has been widely studied, key gaps persist that this work addresses. Studies on UDL (Emmers et al., 2022), active learning (Eison, 2010), or educational technologies (Gamage et al., 2022; Magro, 2021) often examine isolated dimensions—pedagogy, technology, or content—without demonstrating their systematic alignment. This fragmentation limits practitioners' ability to translate theory into coherent, scalable learning designs. Further, existing research draws on small-scale pilots or single-semester implementations (Md Osman, 2022; Yang & Romero-Hall, 2024). Few studies evaluate inclusive online learning across large cohorts or multiple programs, leaving questions about scalability, sustainability, and long-term impact unanswered.

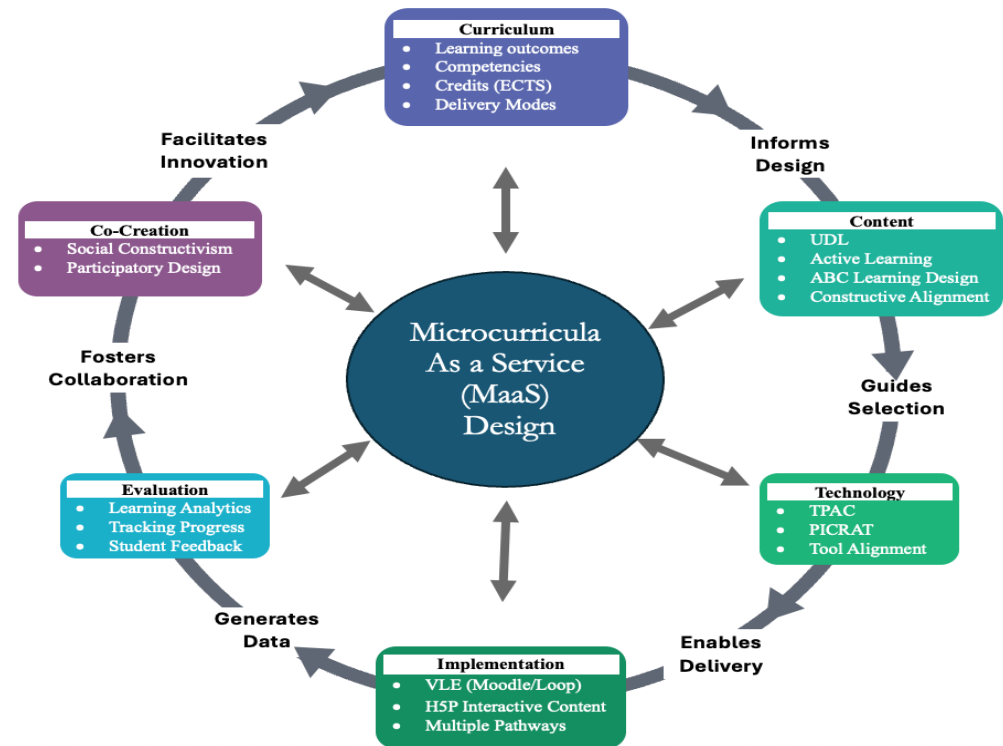
Considering theory and practice, frameworks such as TPACK and PICRAT (Kimmons et al., 2020; Koehler & Mishra, 2016) are conceptually appropriate but rarely operationalised in real-world course design or evaluation, making their practical implications and transferability unclear. Although competency-based microcredential approaches are growing (Vuorikari et al., 2022), limited research explores how modular “microcurricula” structures can balance flexibility, coherence, and accessibility in asynchronous environments. Finally, data literacy research remains discipline-specific (Vuorikari et al., 2022), with little focus on transdisciplinary designs that support diverse learners across academic programs. Understanding how to maintain coherence and relevance across such breadth remains a critical research need.

### 3. The OPTIMAL Framework and Case Study Implementation

This section presents the OPTIMAL framework that synthesises pedagogical foundations, technology integration models, and content design from Section 2, followed by its application in a large-scale data literacy and analytics module.

#### 3.1. The OPTIMAL Framework

The OPTIMAL framework (Figure 2) integrates four interconnected dimensions that enable interactive and inclusive online learning at scale: (1) competency-driven curriculum design, (2) microcurricula as a service architecture, (3) pedagogical integration, and (4) systematic technology selection and evaluation.



**Figure 2.** The OPTIMAL framework representing the core components, transitions, and steps for interactive and inclusive design. The arrows indicate continuous interaction and improvement between components of the framework.

#### 3.1.1. Competency-Driven Design and Microcurricula Architecture

The framework begins with systematic identification of learning competencies using established frameworks (e.g., DigComp 2.2 for data literacy (Vuorikari et al., 2022)), stakeholder input, and alignment with program requirements. These competencies are then structured into microcurricula as a service (MaaS) (Abgaz & Dunne, 2023; Abgaz et al., 2023)—a modular architecture that decomposes monolithic modules into granular, self-contained learning units (0.5–1.0 ECTS each).

Each microcurriculum functions as an independent service with: (1) specific learning outcome(s) aligned with competencies, (2) complete instructional content and activities, (3) an aligned assessment measuring outcome achievement, (4) a dedicated delivery infrastructure (LMS course page), and (5) independent progress tracking. This architecture, derived from software engineering principles (i.e., microservices and service-oriented architecture (Abgaz et al., 2023)) through analogical reasoning (Dong et al., 2017; O'Donoghue et al., 2014), enables multiple forms of flexibility: structural (combining into varied module sizes or embedding across programs), temporal (asynchronous year-round access), path-

way (multiple tool/context implementations), and pedagogical (personalised sequences, mastery-based progression).

The MaaS approach directly supports UDL principles: multiple means of engagement through learner choice and pacing, multiple means of representation through varied pathway implementations, and multiple means of action and expression through diverse assessment approaches across microcurricula. This modular architecture is essential for delivering personalised, inclusive learning at scale while maintaining coherence and constructive alignment.

### 3.1.2. Pedagogical Integration

The OPTIMAL framework systematically integrates UDL, active learning, and constructive alignment through structured design processes. UDL's three principles are embedded from inception: content designed multimodally (MMR), modular structure enabling choice and autonomy (MME), and varied assessment formats (MMAE). Active learning is operationalised through ABC Learning Design (Gormley et al., 2022; Ó Súilleabháin et al., 2024), which structures experiences across six learning types: acquisition, investigation, practice, discussion, collaboration, and production. Each microcurriculum explicitly plans activities across these types, ensuring students move beyond passive consumption toward investigation, application, and creation.

Constructive alignment extends beyond traditional outcome-activity-assessment alignment to encompass technology selection (with technologies chosen for their capacity to support planned activities) and content design (with formats that enable intended interactions). The granular microcurricula structure inherently supports mastery learning—students demonstrate achievement before progressing, with formative feedback informing readiness and enabling targeted support.

### 3.1.3. Systematic Technology Selection and Evaluation

The framework employs TPACK to guide technology selection, ensuring choices emerge from the intersection of pedagogical requirements, content characteristics, and learning contexts rather than from feature lists or popularity. Technologies are selected by asking the following: “Does this support our pedagogical strategies?”, “Can it represent content effectively?”, “Is it accessible for diverse learners?”, and “Does it integrate with institutional infrastructure?”

PICRAT serves dual purposes: as a design tool guiding decisions toward interactive and creative uses with amplification or transformation effects, and as an evaluation tool assessing implemented designs. During design, PICRAT prompts: Will students interact passively, actively, or creatively? Does technology merely replace, amplify, or transform practices? These questions deliberately move designs away from Passive-Replacement toward higher-impact quadrants. During evaluation, PICRAT provides structured analysis of actual student engagement and technology effects, informing iterative refinements.

### 3.1.4. Implementation Process

The typical design process proceeds: (1) define competencies using frameworks and stakeholder input, (2) structure competencies into focused microcurricula, (3) apply UDL and design experiences across ABC learning types ensuring constructive alignment, (4) select technologies using TPACK criteria, (5) design implementations using PICRAT to maximise interactivity and transformation, and (6) evaluate and iterate based on evidence. This systematic approach, adaptable to diverse contexts, is demonstrated in the following case study.

### 3.2. Case Study: Data Literacy and Analytics Module

The OPTIMAL framework was applied in the design and delivery of a data literacy and analytics module at Dublin City University, delivered entirely in an online asynchronous environment. Data literacy and analytics represent critical transversal competencies that cut across multiple disciplines, equipping students with the essential skills required for effective navigation of an increasingly data-intensive twenty-first-century landscape (Anderson, 2024; Atenas et al., 2023; Coners et al., 2025; Kim et al., 2024).

The microcurricula-as-a-service architecture is particularly well-suited to data literacy and analytics precisely because of its transversal nature. As a competency that spans multiple disciplines, data literacy and analytics cannot effectively be delivered through a one-size-fits-all approach—different disciplines demand different levels of depth, emphasis, and tooling. Some programs require only foundational conceptual understanding, while others necessitate advanced technical proficiency or discipline-specific tool selection.

The microcurricula architecture directly addresses this heterogeneity by offering discrete microcurricula that enable programs to select, sequence, and contextualise topics appropriate to their specific disciplinary requirements and student profiles. Furthermore, the modular design supports a highly flexible, progressive competency development—programs can embed foundational microcurricula into existing modules, building incrementally from introductory through intermediate to advanced topics, and extending into discipline-specific applications where required. This level of flexibility and personalisation is structurally impossible within a conventional monolithic module, where all students are required to engage with the full content regardless of their disciplinary context or prior competency level.

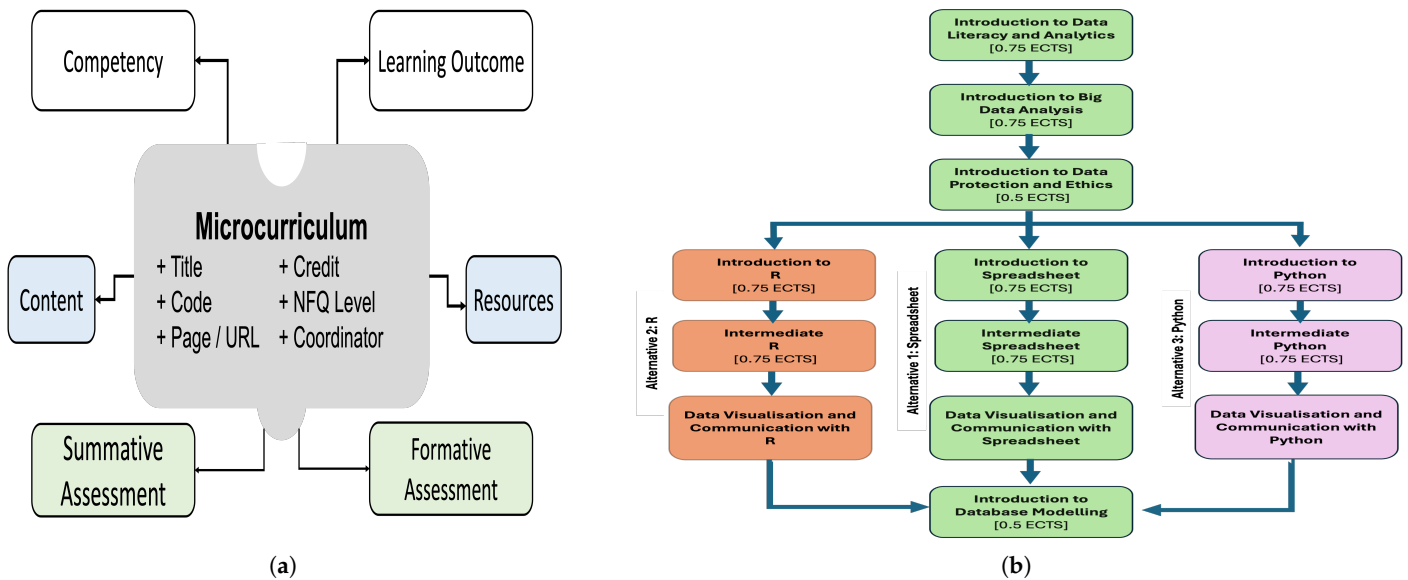
#### 3.2.1. Module Structure and Competency Mapping

The competencies underpinning the seven core topics are derived from multiple complementary sources. First, design-thinking workshops with eight program chairs across ten programs spanning science, engineering and computing, humanities, social sciences, and business faculties, alongside industry partners, data literacy expert panels, and students, informed the identification of relevant competency areas and levels. Second, the competencies were benchmarked against state-of-the-art literature (Huang et al., 2020; Inverarity et al., 2022) and established best practices (Ridsdale et al., 2015). Third, and most critically, the competencies are formally grounded in two widely recognised frameworks: the EU-wide DigComp 2.2 digital competence framework (Vuorikari et al., 2022) and the data literacy conceptual framework (Gummer & Mandinach, 2015), which together provide the explicit structure for differentiating between low-, intermediate-, and high-level data literacy competencies.

Drawing on these sources, seven core topics (Figure 3b) were organised into four knowledge- and attitude-related topics—data literacy and analytics, big data analytics, data protection and ethics, and database modelling—and three skill-related topics—Introductory Spreadsheet/R/Python, Intermediate Spreadsheet/R/Python, and Data Visualisation and Communication with Spreadsheet/R/Python—all explicitly mapped to DigComp 2.2 competency levels.

Each data literacy and analytics topic (DLAT) is implemented as an independent microcurriculum with a dedicated Moodle/Loop page, content, assessment, and progress tracking (Figure 3b). Skill-related topics are delivered through three tool pathways—Spreadsheets, R, and Python—with identical learning outcomes but different implementation tools, resulting in nine distinct microcurricula accommodating diverse program requirements while supporting the context-dependent nature of data literacy and analytics (Lund et al., 2026). The MaaS model flexibly combines microcurricula into 5.0, 7.5,

or 10.0 ECTS stand-alone modules or embeds them individually in other program-specific modules. Around 26 module coordinators have embedded one or more microcurricula in their module without recreating the resources or the assessment.



**Figure 3.** Microcurriculum implementation of data literacy and analytics: (a) Structure of a microcurriculum as a self-contained unit that provides the blueprint. (b) Individual microcurricula topics that can be delivered independently or composed together to make a bigger credit module.

Students access content asynchronously throughout the semester or the academic year according to their program preference, progress at their own pace, and attempt assessments upon completion. Students taking a 5-ECTS module are required to pass each microcurriculum successfully to pass the module. This structure provides student agency, supports mastery learning, and accommodates diverse circumstances—critical for full-time and part-time students, those with caring responsibilities, and international students managing time zones.

### 3.2.2. Content Development and Pedagogical Implementation

Content within each microcurriculum applies UDL principles and ABC Learning Design, incorporating all six learning types: Acquisition (H5P interactive books with multimodal content), investigation (formative questions, interactive videos), practice (peer-learning activities, case studies), discussion (open-ended forum questions), collaboration (peer-learning activities), and production (assignments creating artefacts). Table 1 maps learning types to technologies, UDL principles, strategies, and rationales.

UDL implementation includes: multimodal content (text, video, audio, interactive elements) for MMR; learner choice in pathways/pacing and varied activities for MME; and diverse assessment formats (quizzes, projects, discussions, peer activities) for MMAE. With continuous design and integration, 350 FACcTS—formative assessments co-created with students—provide extensive low-stakes practice with immediate feedback, supporting mastery learning and reducing assessment anxiety.

**Table 1.** Learning types mapped to selected content, technology, UDL principles, strategies, and rationale.

| Learning Type | Content                                  | Technology                       | UDL            | Strategy                        | Rationale  |
|---------------|--|----------------------------------|----------------|---------------------------------|--|
| Acquisition   | Lecture notes and references             | H5P books, interactive videos    | MMR, MME       | Active, Mastery                 | Consume multimodal content with embedded interactivity         |
| Investigation | Knowledge checks, case studies           | H5P quizzes, games, case studies | MME, MMAE      | IBL, PBL,                       | Encourage inquiry of core concepts and self-directed learning  |
| Practice      | Projects, homework                       | Loop boards, forums              | MME, MMAE      | PjBL, PBL                       | Apply learned knowledge practically in one's discipline        |
| Discussion    | Open-ended questions, experience sharing | Loop forums, boards              | MMR, MME       | IBL, PBL, Social Constructivism | Share practical experience and perspectives across disciplines |
| Collaboration | Peer learning activities                 | Loop forums                      | MME, MMAE      | PjBL, Social Constructivism     | Co-construct understanding and peer feedback                   |
| Production    | Assignments, design projects             | Loop, H5P quizzes, boards        | MME, MMR, MMAE | Student-centred                 | Create and share various artefacts with scaffolded guidance    |

### 3.2.3. Technology Integration: PICRAT Analysis

The systematic application of PICRAT during design ensured that technology use genuinely enhanced learning.

**Passive Dimension:** Technology replaces print media with accessible digital content (Figure 4a), amplifies through multimodal organisation (Figure 4b) and expert interviews, and transforms via comprehensive analytics enabling instant individual progress tracking and instructor insights at scale (Figure 4c).

**Interactive Dimension:** Digital formats replace traditional assessments with immediate feedback (Figure 5a). Amplification occurs through detailed, customised feedback linking to content sections, interactive videos requiring active engagement, and automated guidance for thousands of practice attempts (Figure 5b). Transformation emerges through transdisciplinary peer discussions where students from 15+ programs contribute diverse perspectives, peer-learning activities enabling scaled collaboration and adaptive scaffolding. This provides personalised support based on individual responses—coordination at this scale is impossible without the use of technology.

**Creative Dimension:** Students create digital artefacts (datasets, visualisations, ER diagrams) demonstrating authentic application (Figure 6a,b). Sharing via Loop boards amplifies learning—students see diverse design approaches from peers, raising quality standards and expanding understanding of possibilities. Transformation occurs through integrated competency projects requiring data collection, analysis, visualisation, and communication with iterative peer refinement (Figure 6c,d), and through student co-creation of 350+ formative questions (FACCtS), shifting from consumers to co-creators—cyclical improvement enabled by technology at scale.

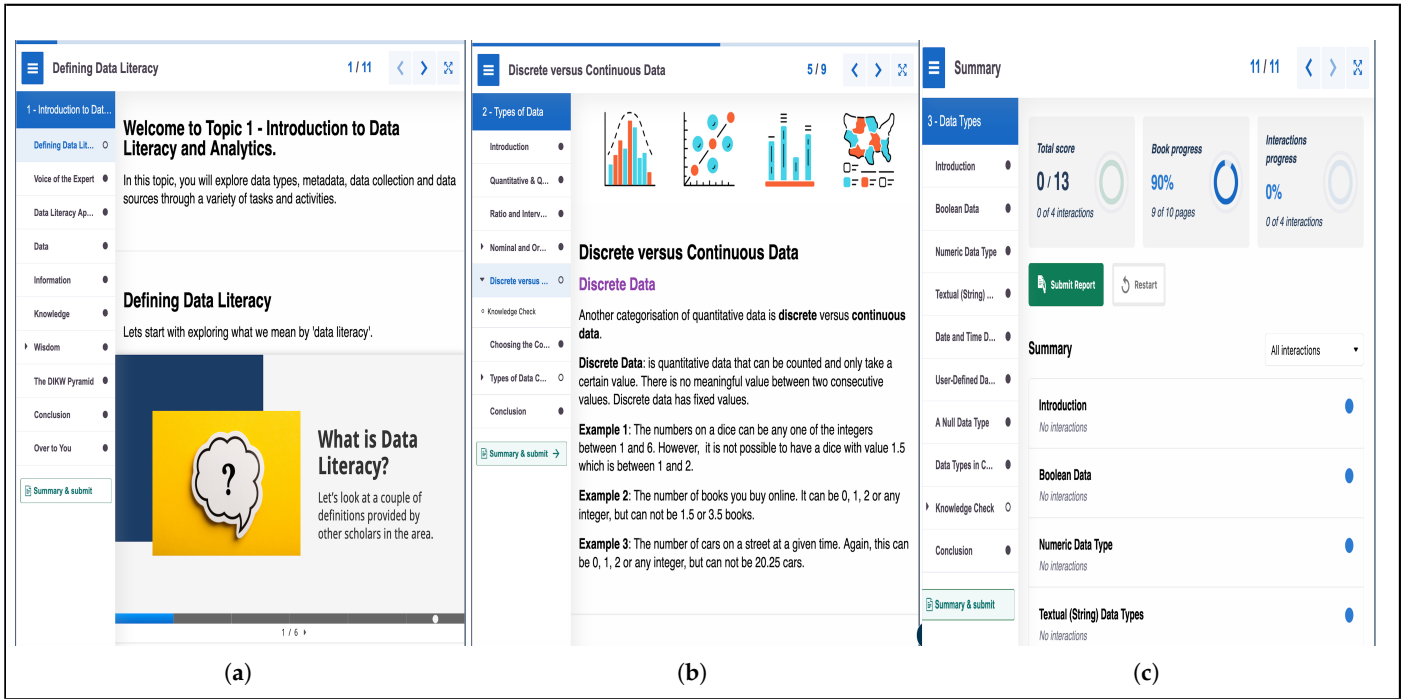


Figure 4. Passive dimension: (a) digital content delivery, (b) multimedia integration, (c) analytics enabling personalised tracking at scale.

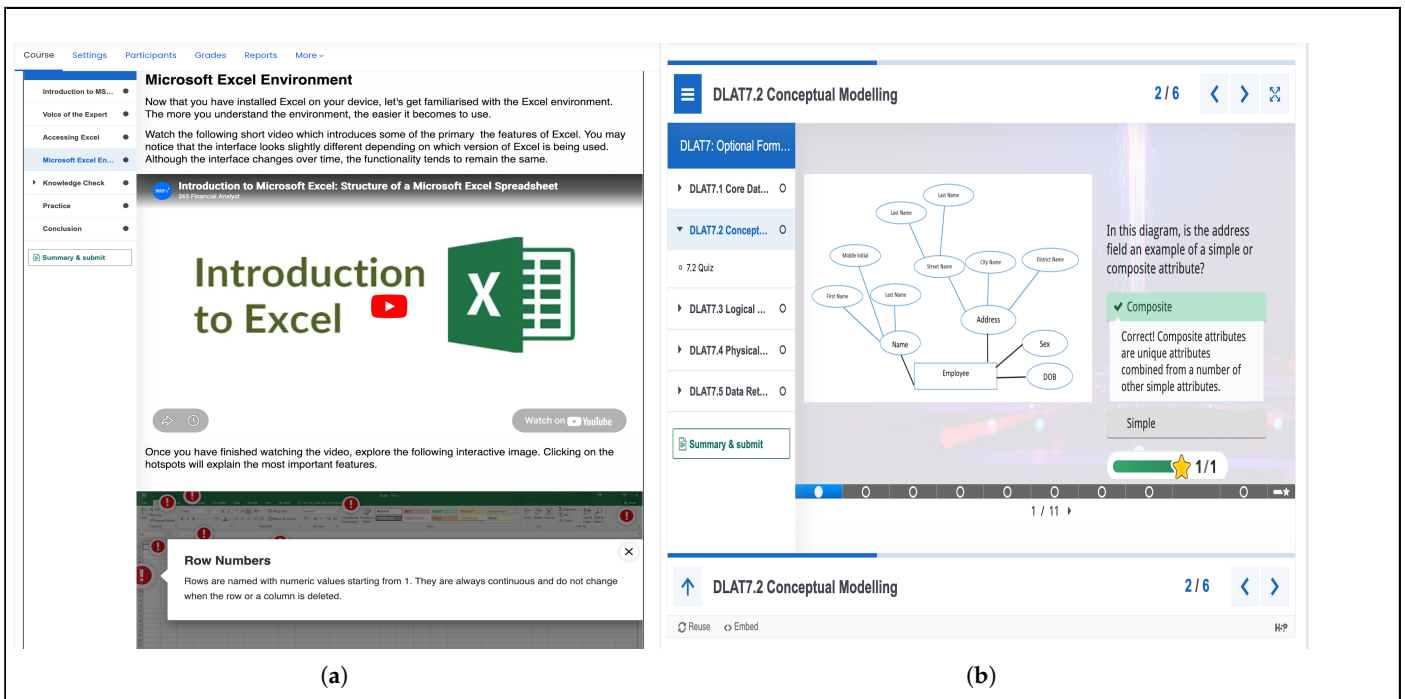
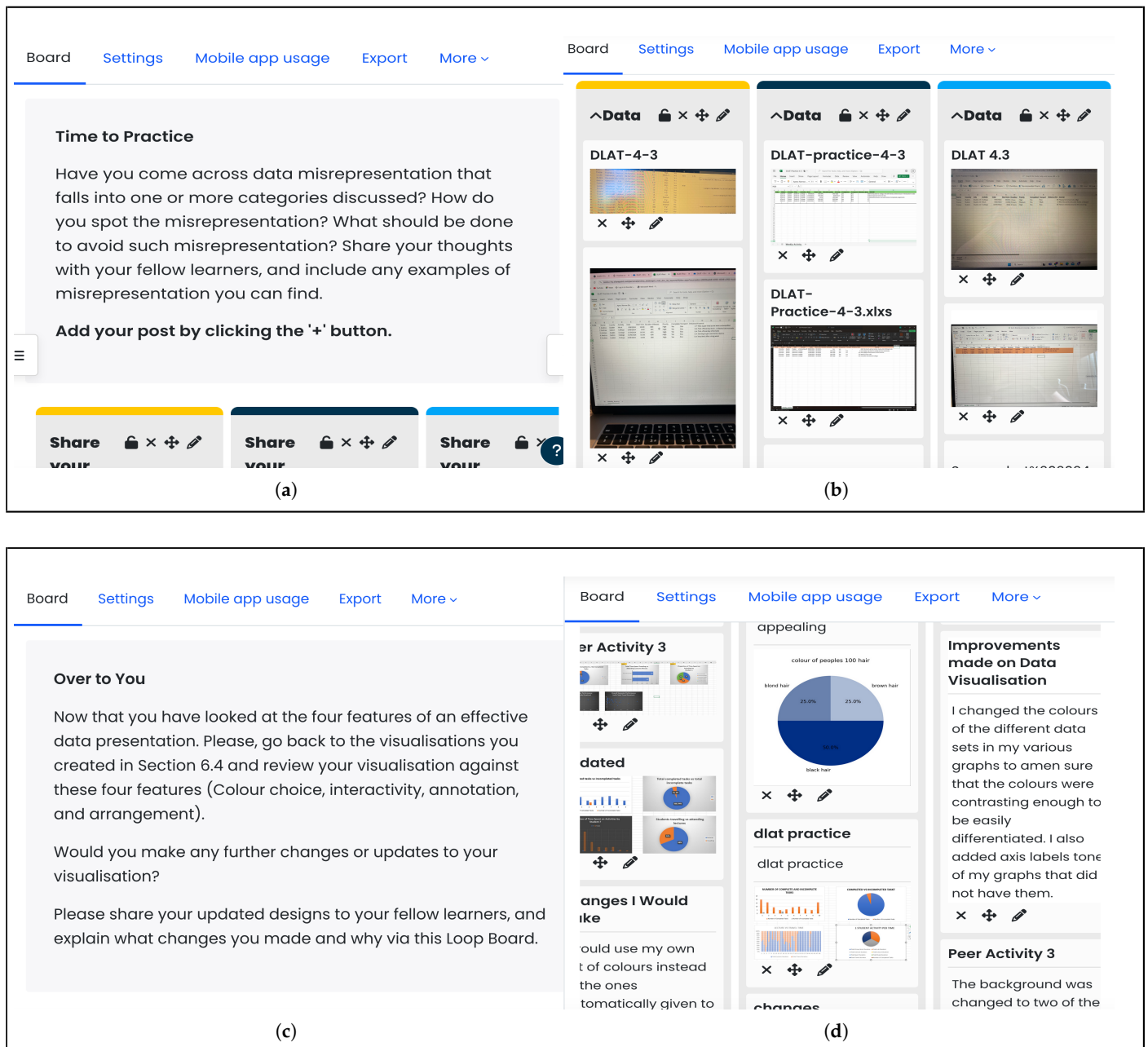


Figure 5. Interactive dimension: (a) interactive content with embedded guidance; (b) diverse formative assessments with detailed feedback.

The deliberate design emphasis on create-transform, create-amplify, interact-transform, and interact-amplify quadrants ensured technology genuinely enhanced learning rather than merely automating traditional approaches. Each activity was explicitly evaluated using PICRAT criteria during design, with designers asking “Can this be more interactive?” and “Does this transform what’s possible?” This resulted in a module where students experience active engagement through interactive content, extensive peer interaction across

disciplines, and creative production opportunities—all delivered asynchronously at scale to thousands of diverse students, representing a fundamental transformation enabled by systematic technology integration aligned with pedagogical principles.



**Figure 6.** Creative dimension: (a,b) case study tasks and artefacts created by students; (c,d) peer learning activity instruction and creative visualisations submitted by students.

#### 4. Methodology

The research is grounded in a pragmatic paradigm (Biesta, 2010; King, 2022), emphasising practical utility and integrating diverse forms of evidence to address real-world educational challenges. This study employs a mixed-methods approach to capture the complexity of integrating technology, pedagogy, and content in the creation of an interactive and inclusive university module. A case study approach is particularly suited to the in-depth exploration of bounded contexts, enabling examination of the interplay among multiple design elements in authentic educational practice (Nahar & Cross, 2020).

To evaluate the module's effectiveness in supporting student learning and engagement, data were collected through annual end-of-module questionnaires, providing systematic longitudinal insights into student experiences over three academic years. These self-report data were complemented by system-generated learning analytics from the Moodle/Loop platform, providing objective measures of engagement to triangulate with students' perceptions. A mixed-methods approach combining quantitative and qualitative analyses was necessary to capture both measurable patterns of student interaction and the nuanced perspectives that illuminate how and why students experienced the module as they did. This methodological integration provides a comprehensive account of the module's impact on diverse student populations.

#### 4.1. Participants

All students enrolled in one or more data literacy and analytics for the 21st Century microcurricula over three academic years were invited to participate in an optional end-of-semester online survey administered through the learning platform. Participation was voluntary and anonymous, with no personally identifiable data collected. Students were informed of the study's purpose and of their right to withdraw at any stage before proceeding to the questionnaire.

The target population comprised approximately 5220+ students enrolled in DLAT microcurricula across three cohorts: 2022/23 ( $n \approx 805$ , 15%), 2023/24 ( $n \approx 2224$ , 43%), and 2024/25 ( $n \approx 2190$ , 42%). Students represented 15+ academic programs from five faculties, spanning disciplines including business, computing, science, engineering, and humanities. This diversity reflects the transdisciplinary nature of the module and ensures findings capture experiences across varied academic backgrounds and prior knowledge levels.

A total of 1743 students provided complete responses to all survey items, yielding a 32% response rate. This rate is comparable to similar end-of-module surveys in higher education settings (Nic Fhlannchadha, 2022) and represents a substantial sample for examining student perceptions across a large-scale online module. The distribution of respondents across years roughly paralleled enrolment patterns, ensuring longitudinal representativeness.

#### 4.2. Ethical Considerations and Procedures

The study was conducted in full compliance with ethical and data protection regulations, including the General Data Protection Regulation (GDPR) (European Parliament & Council of the European Union, 2016). Ethical approval for all procedures was granted by the Dublin City University Research Ethics Committee (Approval No. DCUREC/2024/181 and DCUREC/2025/007). Informed consent was obtained from all participants prior to data collection through an information sheet presented before the survey.

The survey was administered anonymously through Moodle/Loop at the conclusion of each semester, accessible to students upon completing their registered microcurricula. This timing ensured responses captured summative reflections on the complete module experience rather than partial or in-progress impressions. Students received detailed information outlining the study's purpose, the voluntary nature of participation, the anonymity of responses, and their right to withdraw at any stage. All data were stored securely on university servers and processed following institutional data integrity and quality assurance procedures.

#### 4.3. Instruments

Survey items were developed in accordance with Quality and Qualifications Ireland (QQI) standards (Quality and Qualifications Ireland, 2024) for programme design and evaluation, ensuring coherence among learning outcomes, teaching activities, assessments, and student experience. Guided by the constructive alignment framework (Biggs, 2003),

items were reviewed by educational practice experts to verify clarity, construct relevance, and pedagogical alignment.

The questionnaire consisted of 11 five-point Likert-type items ranging from Strongly Disagree (1) to Strongly Agree (5), organised into four dimensions aligned with the study's evaluation focus:

- Satisfaction (Q1–Q3): Module design clarity, structure, and overall satisfaction with learning experience
- Content Quality (Q4–Q5, Q7–Q8): Resource quality and diversity, disciplinary relevance, and content appropriateness
- Engagement (Q6, Q10): Platform-mediated interaction, intellectual stimulation, and cognitive challenge
- Learning Outcomes (Q9, Q11): Perceived knowledge gain, skill development, and transferability to other contexts

Additionally, three open-ended questions invited students to: (Q12) describe features they found particularly engaging or effective, (Q13) identify challenges encountered during the module, and (Q14) recommend improvements or additional features. R responses (<0.01%) that contained "Not Applicable" answers were excluded from analysis.

To ensure measurement consistency, internal reliability analyses were conducted for each dimension using both Cronbach's  $\alpha$  and McDonald's  $\omega$  (Table 2). All dimensions demonstrated strong internal consistency across the three years, with  $\alpha$  values ranging from 0.78 to 0.89 and  $\omega$  values from 0.78 to 0.90. The consistently good reliability coefficients confirm that the survey instrument maintained good internal consistency and conceptual coherence throughout the longitudinal study period. The slightly higher  $\omega$  values in some categories suggest latent multidimensionality within construct structures, likely attributable to the integration of diverse interactive learning elements within the module design.

**Table 2.** Internal consistency reliability coefficients (Cronbach's  $\alpha$  and McDonald's  $\omega$ ) for survey dimensions across three academic years. Interpretation: Excellent  $\geq 0.9$ ; Good: 0.8–0.9; Acceptable: 0.7–0.8.

| Dimension         | Items | 2022/23  |          | 2023/24  |          | 2024/25  |          |
|-------------------|-------|----------|----------|----------|----------|----------|----------|
|                   |       | $\alpha$ | $\omega$ | $\alpha$ | $\omega$ | $\alpha$ | $\omega$ |
| Satisfaction      | 3     | 0.80     | 0.82     | 0.88     | 0.89     | 0.89     | 0.90     |
| Content Quality   | 4     | 0.84     | 0.87     | 0.86     | 0.88     | 0.85     | 0.87     |
| Engagement        | 2     | 0.79     | 0.79     | 0.80     | 0.80     | 0.78     | 0.78     |
| Learning Outcomes | 2     | 0.82     | 0.82     | 0.81     | 0.81     | 0.78     | 0.78     |

#### 4.4. Data Analysis

Quantitative data were analysed using descriptive statistics, including mean, median, mode, standard deviation, and quartile distributions to summarise student responses across the three academic years. The 11 Likert-type items were analysed both individually and grouped by their four conceptual dimensions (satisfaction, content quality, engagement, learning outcomes) based on thematic alignment. Response distributions were visualised using stacked horizontal bar charts showing percentage distributions across all response categories (1–5), enabling clear identification of patterns and trends over time.

Qualitative responses to the three open-ended questions underwent structured thematic analysis (Braun & Clarke, 2006; Naeem et al., 2023). Preprocessing involved removing short, non-informative entries (e.g., "No", "None", "N/A") that provided no substantive feedback. The remaining responses were coded inductively to identify recurring themes related to effective module features, experienced challenges, and suggested improvements.

Themes were iteratively refined through comparison across responses and years, with attention to both dominant patterns and significant minority perspectives that might inform design improvements.

Learning analytics data from Moodle/Loop platform, including content access patterns, formative assessment completion rates, and discussion forum participation metrics, provided complementary quantitative evidence of student engagement. These objective behavioural measures were analysed descriptively and triangulated with survey responses to corroborate or contextualise self-reported perceptions of engagement and learning.

Data from the three academic years were analysed both individually to capture year-specific patterns and aggregated to provide a comprehensive longitudinal view of student perceptions and engagement trends over the sustained implementation period. This dual approach enabled the identification of both stable characteristics of the module design and evolutionary patterns reflecting iterative improvements based on ongoing evaluation.

## 5. Results

This section presents findings from learning analytics and student survey data collected over three academic years (2022/23–2024/25), evaluating the effectiveness of the integrated design framework in supporting student engagement, content quality, learning outcomes, and experiences. Results are organised into four subsections: engagement and completion patterns from learning analytics, quantitative survey findings across four dimensions (satisfaction, content quality, engagement, learning outcomes), longitudinal trends, and qualitative insights from open-ended responses.

### 5.1. Engagement and Completion Patterns

Over the three-year implementation period, cumulative enrolment reached more than 5220+ students across 15+ academic programs and five faculties, demonstrating the module's extensive reach and transdisciplinary scope. Table 3 presents enrolment, engagement, and completion data for each of the seven DLAT microcurricula across the three cohorts.

**Table 3.** Enrolment, engagement, and pass rates across seven DLAT microcurricula over three years. \* Enrolled includes all registry-recorded students, including those who dropped or became inactive. \*\* Attempted represents students who reached final assessments, providing a reliable engagement measure, as core content cannot be bypassed.

| Year    | Metric              | DLAT1 | DLAT2 | DLAT3 | DLAT4 | DLAT5 | DLAT6 | DLAT7 | Average |
|---------|---------------------|-------|-------|-------|-------|-------|-------|-------|---------|
| 2022/23 | Enrolled *          | 331   | 637   | 717   | 719   | 717   | 555   | 702   | 625     |
|         | Attempted **        | 300   | 311   | 342   | 600   | 590   | 444   | 331   | 417     |
|         | Passed              | 274   | 304   | 320   | 584   | 541   | 444   | 325   | 399     |
|         | Engagement rate (%) | 90.63 | 48.82 | 47.70 | 83.45 | 82.29 | 80.00 | 47.15 | 68.58   |
|         | Pass rate (%)       | 91.33 | 97.75 | 93.57 | 97.33 | 91.69 | 100.0 | 98.19 | 95.70   |
| 2023/24 | Enrolled *          | 1347  | 867   | 738   | 1277  | 1269  | 1270  | 1274  | 1149    |
|         | Attempted **        | 1085  | 528   | 451   | 1149  | 1037  | 988   | 874   | 873     |
|         | Passed              | 1047  | 517   | 441   | 1118  | 951   | 970   | 866   | 844     |
|         | Engagement rate (%) | 80.55 | 60.90 | 61.11 | 89.98 | 81.72 | 77.80 | 68.60 | 74.38   |
|         | Pass rate (%)       | 96.50 | 97.92 | 97.78 | 97.30 | 91.71 | 98.18 | 99.08 | 96.92   |
| 2024/25 | Enrolled *          | 1786  | 1085  | 992   | 1885  | 1881  | 1880  | 1805  | 1616    |
|         | Attempted **        | 1374  | 899   | 893   | 1433  | 1378  | 1415  | 1305  | 1242    |
|         | Passed              | 1371  | 899   | 891   | 1426  | 1320  | 1415  | 1305  | 1232    |
|         | Engagement rate (%) | 76.93 | 82.86 | 90.02 | 76.02 | 73.26 | 75.27 | 72.30 | 78.09   |
|         | Pass rate (%)       | 99.78 | 100.0 | 99.78 | 99.51 | 95.79 | 100.0 | 100.0 | 99.27   |

Engagement rates, calculated as the percentage of enrolled students who attempted final assessments, varied across microcurricula and years. In 2022/23, DLAT2, DLAT3, and DLAT7 showed lower engagement (47.15–48.82%) due to several programs deferring these topics to subsequent semesters, resulting in inflated enrolment figures relative to active participation. This administrative artefact does not reflect student disengagement but rather programmatic scheduling decisions. In subsequent years, engagement rates for these microcurricula normalised, with the overall average increasing from 68.58% (2022/23) to 74.38% (2023/24) and 78.09% (2024/25).

It is important to note that engagement rates are calculated using total enrolled students as the denominator, including those who dropped courses, became inactive, or deferred participation—a conservative approach that yields lower percentages than calculations based solely on active students. This method provides a realistic assessment of actual participation relative to initial registrations. The engagement metric is reliable because, by mastery learning design, students must complete core content and activities to access the final assessments; reaching the assessment indicates substantive engagement with the instructional materials rather than merely superficial access.

Importantly, the engagement rate reported here reflects more than mere assessment participation. The microcurricula architecture is deliberately structured so that students cannot access the final assessment without first progressing sequentially through mandatory activities spanning all learning types enforced through explicit activity restrictions and checkpoints, including interactive H5P content, knowledge check questions, discussion forums, and peer-learning activities. Consequently, a student who attempts the final assessment has, by design, already demonstrated sustained behavioural and, to a meaningful degree, cognitive and social engagement with the content. This is further supported by ongoing progress monitoring and timely personalised feedback provided by the module coordinator throughout the delivery period. It is acknowledged, however, that while this progressive gating mechanism prevents students from bypassing course activities, it cannot fully guarantee deep conceptual understanding at every stage, and this remains a limitation of the current study.

Pass rates, calculated as the percentage of students who attempted assessments and completed them, were consistently high across all years and microcurricula, exceeding 95% in nearly all cases. Average pass rates increased from 95.70% (2022/23) to 96.92% (2023/24) and 99.27% (2024/25), with several microcurricula achieving 100% pass rates in later years. These rates substantially exceed typical completion rates for voluntary non-credit online courses and MOOCs, which often range from 5–15% (Celik & Cagiltay, 2024; Jordan, 2015), and compare favourably even with mandatory credit-bearing online courses in higher education.

While direct comparisons require caution due to differences in student background characteristics—including disciplinary origin, year of study, and prior online learning experience—as well as variations in incentive structures and completion definitions across comparable studies, the DLAT module's sustained high completion rates warrant careful interpretation. Credit-bearing status, mandatory enrolment, and institutional assessment requirements create the conditions for participation and persistence; however, it is the specific design features of the DLAT module that support students in meeting those requirements successfully. Specifically, the combination of microcurricula modularity, extensive formative assessments with timely feedback, interactive H5P content, mastery learning support, and constructive alignment at curriculum, technology, and content levels collectively provides the scaffolding necessary for diverse students to engage meaningfully and complete successfully (Panakaje et al., 2024; Rienties & Toetanel, 2016). Similar high completion rates—at or above 90%—have been reported for mandatory faculty development

programmes with strong institutional support (Clay et al., 2023), further suggesting that structured design and embedded support mechanisms are critical enablers of completion at scale.

The sustained increase in both engagement and pass rates across three consecutive years provides a longitudinal validation of the OPTIMAL framework, reflecting the compounding effect of iterative, evidence-based design refinements, including enhanced formative assessment, instructional scaffolding, and progress monitoring embedded as intentional ex-ante features of the framework rather than post hoc adjustments. Notably, the simultaneous improvement in both metrics suggests that rising outcomes are attributable to genuine improvements in student learning and growing institutional recognition of the module's value, rather than reduced assessment difficulty or a novelty effect confined to a single cohort.

## 5.2. Survey Responses: Quantitative Findings

The end-of-module survey yielded 1743 complete responses across three years, representing a 33% response rate relative to total enrolment. The following subsections present findings organised by the four survey dimensions: satisfaction, content quality, engagement, and learning outcomes.

### 5.2.1. Satisfaction with Module Design and Delivery

Students consistently reported high satisfaction with the module's design, clarity of learning outcomes, and alignment between stated objectives and actual instruction (Table 4). In 2022/23, the inaugural year with smaller cohorts and response samples, mean satisfaction across the three items was 3.85 (between "Neutral" and "Agree"). Satisfaction increased in subsequent years to means of 3.94 (2023/24) and 4.08 (2024/25), with the aggregated three-year mean reaching 4.02 ("Agree").

**Table 4.** Student satisfaction with module design, learning outcomes clarity, and alignment.

| Satisfaction Items  | Response          | 2022/23     | 2023/24     | 2024/25     | All Years   |
|---|-------------------|-------------|-------------|-------------|-------------|
| Q1: The module learning outcomes are clearly stated                   | Strongly Agree    | 26(30.6%)   | 228(38.0%)  | 357(33.7%)  | 611(35.1%)  |
|   | Agree             | 38(44.7%)   | 237(39.5%)  | 547(51.7%)  | 822(47.2%)  |
|   | Neutral           | 16(18.8%)   | (84)14.0%   | 125(11.8%)  | 225(12.9%)  |
|   | Disagree          | 4(4.7%)     | 34(5.7%)    | 17(1.6%)    | 55(3.2%)    |
|   | Strongly Disagree | 1(1.2%)     | 17(2.8%)    | 12(1.1%)    | 30(1.7%)    |
|   | Mean (SD)         | 3.99 (0.89) | 4.04 (1.00) | 4.15 (0.77) | 4.10 (0.87) |
| Q2: I had a clear idea of what is expected of me in this module       | Strongly Agree    | 17(20.0%)   | 178(29.7%)  | 308(29.1%)  | 503(28.9%)  |
|   | Agree             | 37(43.5%)   | 215(35.8%)  | 499(47.2%)  | 751(43.1%)  |
|   | Neutral           | 23(27.1%)   | 134(22.3%)  | 194(18.3%)  | 351(20.1%)  |
|   | Disagree          | 5(5.9%)     | 51(8.5%)    | 40(3.8%)    | 96(5.5%)    |
|   | Strongly Disagree | 3(3.5%)     | 22(3.7%)    | 17(1.6%)    | 42(2.4%)    |
|   | Mean (SD)         | 3.71 (0.97) | 3.79 (1.07) | 3.98 (0.88) | 3.90 (0.96) |
| Q3: The module learning outcomes agreed with what was actually taught | Strongly Agree    | 18(21.2%)   | 197(32.8%)  | 340(32.1%)  | 555(31.8%)  |
|   | Agree             | 45(52.9%)   | 251(41.8%)  | 533(50.4%)  | 829(47.6%)  |
|   | Neutral           | 16(18.8%)   | 110(18.3%)  | 157(14.8%)  | 283(16.2%)  |
|   | Disagree          | 4(4.7%)     | 26(4.3%)    | 18(1.7%)    | 48(2.8%)    |
|   | Strongly Disagree | 2(2.4%)     | 16(2.7%)    | 10(0.9%)    | 28(1.6%)    |
|   | Mean (SD)         | 3.86 (0.89) | 3.98 (0.96) | 4.11 (0.78) | 4.05 (0.86) |
| Overall   | Mean (SD)         | 3.85 (0.92) | 3.94 (1.01) | 4.08 (0.81) | 4.02 (0.90) |

The progressive improvement in satisfaction scores across years likely reflects iterative refinements to module design based on ongoing evaluation and student feedback. By

2024/25, over 85% of respondents agreed or strongly agreed that learning outcomes were clearly stated (Q1), expectations were clear (Q2), and outcomes aligned with instruction (Q3). These findings suggest that the constructive alignment framework—explicitly linking outcomes, activities, and assessments—was effectively communicated to students and perceived as coherent.

### 5.2.2. Content Quality, Diversity, and Relevance

Students evaluated content positively across all quality dimensions, including preparation, quality, format diversity, and disciplinary relevance (Table 5). Mean scores increased from 3.74 (2022/23) to 3.99 (2023/24) and 4.03 (2024/25), with the aggregated three-year mean of 3.99 indicating consistent agreement that content met quality standards.

**Table 5.** Perceived content quality, preparation, format diversity, and disciplinary relevance.

| Content Items   | Response          | 2022/23     | 2023/24     | 2024/25     | All Years   |
|---|-------------------|-------------|-------------|-------------|-------------|
| Q4: The module materials are well prepared  | Strongly Agree    | 25(29.4%)   | 231(38.5%)  | 378(35.7%)  | 634(36.4%)  |
|   | Agree             | 39(45.9%)   | 231(38.5%)  | 471(44.5%)  | 741(42.5%)  |
|   | Neutral           | 15(17.6%)   | 98(16.3%)   | 178(16.8%)  | 291(16.7%)  |
|   | Disagree          | 3(3.5%)     | 24(4.0%)    | 20(1.9%)    | 47(2.7%)    |
|   | Strongly Disagree | 3(3.5%)     | 16(2.7%)    | 11(1.0%)    | 30(1.7%)    |
|   | Mean (SD)         |             | 3.94 (0.97) | 4.06 (0.97) | 4.12 (0.82) |
| Q5: Module material was of high quality   | Strongly Agree    | 21(24.7%)   | 252(42.0%)  | 374(35.3%)  | 647(37.1%)  |
|   | Agree             | 36(42.4%)   | 196(32.7%)  | 464(43.9%)  | 696(39.9%)  |
|   | Neutral           | 19(22.4%)   | 115(19.2%)  | 183(17.3%)  | 317(18.2%)  |
|   | Disagree          | 3(3.5%)     | 20(3.3%)    | 23(2.2%)    | 46(2.6%)    |
|   | Strongly Disagree | 6(7.1%)     | 17(2.8%)    | 14(1.3%)    | 37(2.1%)    |
|   | Mean (SD)         |             | 3.75 (1.09) | 4.08 (0.99) | 4.10 (0.85) |
| Q7: Different styles such as books, videos, fireside chats, etc. were used when appropriate | Strongly Agree    | 20(23.5%)   | 213(35.5%)  | 312(29.5%)  | 545(31.3%)  |
|   | Agree             | 33(38.8%)   | 207(34.5%)  | 487(46.0%)  | 727(41.7%)  |
|   | Neutral           | 18(21.2%)   | 127(21.2%)  | 206(19.5%)  | 351(20.1%)  |
|   | Disagree          | 10(11.8%)   | 36(6.0%)    | 42(4.0%)    | 88(5.0%)    |
|   | Strongly Disagree | 4(4.7%)     | 17(2.8%)    | 11(1.0%)    | 32(1.8%)    |
|   | Mean (SD)         |             | 3.65 (1.10) | 3.94 (1.03) | 3.99 (0.86) |
| Q8: The module material was relevant to my field of study                                   | Strongly Agree    | 16(18.8%)   | 195(32.5%)  | 294(27.8%)  | 505(29.0%)  |
|   | Agree             | 35(41.2%)   | 208(34.7%)  | 450(42.5%)  | 693(39.8%)  |
|   | Neutral           | 24(28.2%)   | 138(23.0%)  | 249(23.5%)  | 411(23.6%)  |
|   | Disagree          | 5(5.9%)     | 38(6.3%)    | 43(4.1%)    | 86(4.9%)    |
|   | Strongly Disagree | 5(5.9%)     | 21(3.5%)    | 22(2.1%)    | 48(2.8%)    |
|   | Mean (SD)         |             | 3.61 (1.05) | 3.86 (1.05) | 3.90 (0.93) |
| Overall   | Mean (SD)         | 3.74 (1.05) | 3.99 (1.01) | 4.03 (0.87) | 3.99 (0.93) |

Particularly strong agreement emerged for items regarding material preparation (Q4,  $M = 4.09$ ) and quality (Q5,  $M = 4.07$ ), suggesting that the H5P interactive books, multimodal resources, and structured content design met students' expectations. Format diversity (Q7,  $M = 3.96$ ) was also positively evaluated, reflecting the UDL principle of multiple means of representation through varied content types, including text, videos, interactive elements, and expert interviews ("fireside chats").

Disciplinary relevance (Q8,  $M = 3.87$ ) showed the lowest mean among content items but still reflected agreement. This is notable given the module's transdisciplinary nature—serving 15+ programs with diverse content emphases. That students across varied disciplines generally found content relevant speaks to the effectiveness of the microcurricula pathway structure (Spreadsheets, R, Python) and the incorporation of domain-agnostic foundational topics alongside tool-specific skills development.

Qualitative feedback corroborated these findings, with students praising “the structure, the mix between text, slides, questions, practical tasks, and quizzes.” However, some students reported challenges navigating multiple course pages—an artefact of the microcurriculum modular structure—suggesting an area for interface design improvement. Additionally, in 2022/23, some students found the 80% threshold for passing certain assessments challenging, prompting subsequent adjustments to assessment difficulty calibration and the provision of additional formative practice opportunities.

### 5.2.3. Engagement and Intellectual Stimulation

Student engagement with the module, as measured by perceptions of content presentation effectiveness and intellectual stimulation, showed progressive improvement across years (Table 6). Mean engagement scores increased from 3.11 (2022/23) to 3.70 (2023/24) and 3.82 (2024/25), with the aggregated mean of 3.75 indicating agreement that the module engaged attention and provided intellectual challenge.

**Table 6.** Perceived engagement with content presentation and intellectual stimulation.

| Engagement Items   | Response          | 2022/23     | 2023/24     | 2024/25     | All Years   |
|--|-------------------|-------------|-------------|-------------|-------------|
| Q6: The presentation style of the module content on Loop helped to engage my attention | Strongly Agree    | 13(15.3%)   | 184(30.7%)  | 322(30.4%)  | 519(29.8%)  |
|  | Agree             | 29(34.1%)   | 183(30.5%)  | 416(39.3%)  | 628(36.0%)  |
|  | Neutral           | 18(21.2%)   | 156(26.0%)  | 236(22.3%)  | 410(23.5%)  |
|  | Disagree          | 13(15.3%)   | 48(8.0%)    | 49(4.6%)    | 110(6.3%)   |
|  | Strongly Disagree | 12(14.1%)   | 29(4.8%)    | 35(3.3%)    | 76(4.4%)    |
|  | Mean (SD)         |             | 3.21 (1.28) | 3.74 (1.12) | 3.89 (1.00) |
| Q10: I found the module intellectually stimulating                                     | Strongly Agree    | 12(14.1%)   | 151(25.2%)  | 270(25.5%)  | 433(24.8%)  |
|  | Agree             | 22(25.9%)   | 202(33.7%)  | 420(39.7%)  | 644(36.9%)  |
|  | Neutral           | 19(22.4%)   | 170(28.3%)  | 241(22.8%)  | 430(24.7%)  |
|  | Disagree          | 18(21.2%)   | 47(7.8%)    | 86(8.1%)    | 151(8.7%)   |
|  | Strongly Disagree | 14(16.5%)   | 30(5.0%)    | 41(3.9%)    | 85(4.9%)    |
|  | Mean (SD)         |             | 3.00 (1.30) | 3.66 (1.09) | 3.75 (1.05) |
| Overall  | Mean (SD)         | 3.11 (1.29) | 3.70 (1.10) | 3.82 (1.02) | 3.74 (1.08) |

The lower engagement scores in 2022/23, particularly for intellectual stimulation (Q10,  $M = 3.00$ , “Neutral”), likely reflect multiple factors: the module’s novelty for both students and instructors, minor technical issues during initial deployment (particularly first semester), and students’ unfamiliarity with fully asynchronous online learning formats. The substantial improvement in subsequent years (Q6: +0.68 points; Q10: +0.75 points from 2022/23 to 2024/25) aligns with the introduction of enhanced interactive H5P activities, refined formative assessment integration, and increased peer collaboration opportunities through discussion forums and peer-learning activities.

Qualitative responses provided additional context. While many students praised interactive elements and engagement features, a recurring challenge was the absence of face-to-face instruction—a preference expressed by students accustomed to synchronous, lecture-based formats. Time management emerged as the most frequently reported challenge, particularly for students new to asynchronous learning who struggled with self-pacing and deadlines. Students noted difficulties, including “too much new information”, “lack of face-to-face interaction,” and “text-heavy content” in some sections. However, almost all students indicated experiencing no major difficulties completing the module, suggesting these concerns represented minority perspectives rather than systemic barriers.

#### 5.2.4. Learning Outcomes and Knowledge Gains

Students consistently reported strong perceived learning outcomes, including knowledge transferability to their disciplines and increased data literacy competencies (Table 7). Mean scores were 3.64 (2022/23), 4.01 (2023/24), and 4.06 (2024/25), with an aggregated mean of 4.03 indicating agreement that the module enhanced their knowledge and skills.

**Table 7.** Perceived learning outcomes, knowledge transferability, and competency gains.

| Learning Outcome Items   | Response          | 2022/23     | 2023/24     | 2024/25     | All Years   |
|--|-------------------|-------------|-------------|-------------|-------------|
| Q9: I can transfer the knowledge I acquired from this module to solve problems in my field of study          | Strongly Agree    | 15(17.6%)   | 212(35.3%)  | 322(30.4%)  | 549(31.5%)  |
|  | Agree             | 34(40.0%)   | 212(35.3%)  | 469(44.3%)  | 715(41.0%)  |
|  | Neutral           | 16(18.8%)   | 126(21.0%)  | 211(19.9%)  | 353(20.3%)  |
|  | Disagree          | 16(18.8%)   | 30(5.0%)    | 42(4.0%)    | 88(5.0%)    |
|  | Strongly Disagree | 4(4.7%)     | 20(3.3%)    | 14(1.3%)    | 38(2.2%)    |
|  | Mean (SD)         |             | 3.47 (1.13) | 3.94 (1.03) | 3.98 (0.88) |
| Q11: My knowledge of the subject (Data Literacy and Analytics) has increased as a consequence of this module | Strongly Agree    | 24(28.2%)   | 246(41.0%)  | 388(36.7%)  | 658(37.8%)  |
|  | Agree             | 35(41.2%)   | 214(35.7%)  | 472(44.6%)  | 721(41.4%)  |
|  | Neutral           | 15(17.6%)   | 103(17.2%)  | 158(14.9%)  | 276(15.8%)  |
|  | Disagree          | 8(9.4%)     | 17(2.8%)    | 26(2.5%)    | 51(2.9%)    |
|  | Strongly Disagree | 3(3.5%)     | 20(3.3%)    | 14(1.3%)    | 37(2.1%)    |
|  | Mean (SD)         |             | 3.81 (1.06) | 4.08 (0.99) | 4.13 (0.85) |
| Overall  | Mean (SD)         | 3.64 (1.09) | 4.01 (1.01) | 4.06 (0.85) | 4.02 (0.93) |

Students particularly strongly endorsed knowledge increase (Q11,  $M = 4.10$ ), with over 80% agreeing or strongly agreeing across all years. Transferability to disciplinary contexts (Q9,  $M = 3.95$ ) also received strong endorsement, though slightly lower—likely reflecting variability in how directly different programs apply data literacy skills. These self-reported learning gains align with the objective pass rates (>95%) discussed in Section 5.1, suggesting convergence between perceived and demonstrated competency achievement.

Qualitative responses reinforced these findings. Students often cited practical skills—particularly spreadsheet functions, data visualisation, and programming basics—as valuable learning outcomes with clear applicability: “The EXCEL functions were pretty useful”, “Learning the broad variety of uses Python has”, “It was very informative while providing supportive services for us as first years.” The integration of formative assessments with immediate feedback was repeatedly highlighted as supporting learning: “I enjoyed the formative assessments as they gave you an indication of your level of knowledge.”

However, students reported cognitive load challenges: “The amount of new terminology took some time to process” and “There was too much to do.” These comments suggest that for some learners, particularly those with limited prior technical experience, the breadth of content represented a significant challenge despite scaffolding and support mechanisms in place via weekly synchronous drop-in sessions. This points to a tension inherent in comprehensive data literacy education: balancing thorough coverage with manageable cognitive demands for diverse learners.

#### 5.3. Longitudinal Trends Across Three Years

Aggregating data across all survey dimensions reveals consistent positive trends over the three-year implementation. Satisfaction scores increased modestly from 3.85 to 4.08 (+0.23 points), reflecting iterative design improvements and clarification of learning expectations. Content quality ratings improved from 3.66 to 3.99 (+0.33 points), suggesting refinements to materials, enhanced multimodal integration, and improved disciplinary relevance through pathway development.

Engagement demonstrated the most substantial improvement, increasing from 3.11 to 3.82 (+0.71 points)—a notable shift from neutral to agreement. This improvement aligns temporally with the expansion of interactive H5P content types, the introduction of additional collaborative peer-learning activities, and the inclusion of several formative assessments co-created with students. The engagement gains suggest that deliberate application of the PICRAT framework to enhance interactivity and creativity in technology use translated into measurably improved student perceptions.

Learning outcome perceptions remained consistently high throughout ( $M \geq 4.0$ ), indicating sustained effectiveness of the pedagogical approach regardless of iterative refinements. The stability of learning outcome scores, combined with increasing satisfaction, content, and engagement ratings, suggests that the foundational design—grounded in UDL, constructive alignment, and active learning—was sound from inception, with improvements addressing experience quality rather than fundamental effectiveness.

Collectively, these longitudinal patterns demonstrate that the progressive improvement across all survey items is not incidental but reflects the compounding effect of iterative, evidence-based design refinements embedded as an intentional ex-ante feature of the OPTIMAL framework. Unlike conventional post hoc evaluation approaches, feedback collection was structurally integrated as a continuous improvement mechanism, with each annual cycle generating actionable evidence that informed targeted refinements to content, scaffolding, activity design, and communication. The breadth of improvement across all survey dimensions, rather than isolated items, further suggests that the holistic and integrated nature of the OPTIMAL framework collectively contributes to a progressive improvement of student experience. This is particularly meaningful given the mandatory and cross-disciplinary nature of the cohort, where diverse student backgrounds create inherently more demanding benchmarks than self-selected learner populations. The positive longitudinal trajectory across all dimensions, therefore, provides compelling evidence that the systematic integration of pedagogy, technology, and content produced a sustainable and continuously improvable design rather than a static implementation.

#### 5.4. Qualitative Insights from Open-Ended Responses

Analysis of open-ended responses (excluding short non-informative entries such as “No,” “None”) revealed predominantly positive sentiment (approximately 82% positive polarity), with neutral comments accounting for most remaining responses and negative comments representing a small minority.

##### 5.4.1. Valued Features and Effective Design Elements

Students consistently praised several features aligned with the integrated framework’s design principles:

**Interactivity and Immediate Feedback:** The extensive formative assessment questions (350+ questions distributed across seven DLATs) with immediate, detailed feedback were frequently cited as particularly valuable: “I enjoyed the formative assessments as they gave you an indication of your level of knowledge”, “The immediate feedback helped me understand where I went wrong.” This aligns with the framework’s emphasis on Interactive-Amplification (PICRAT), where technology enables rapid feedback loops impossible at scale without automation.

**Multimodal Content and Accessibility:** Students appreciated the variety of content formats—interactive books, videos, expert interviews, quizzes, etc., reflecting successful implementation of UDL’s multiple means of representation: “The mix between text, slides, practical tasks, and quizzes”, “Different styles such as videos and fireside chats made topics

more engaging.” The ability to access content flexibly across devices and revisit materials supported diverse learning preferences and schedules.

**Tool Choice and Practical Application:** Students valued the ability to select tool pathways (Spreadsheets, R, Python) aligned with their program requirements and interests, exemplifying UDL’s multiple means of engagement: “Being able to choose Python was great for my major”, “Excel skills will be directly useful in my career.” The emphasis on practical, applicable skills resonated strongly: “Learning the broad variety of uses Python has”, “The EXCEL functions were pretty useful in the lab.”

**Self-Paced Asynchronous Structure:** Many students appreciated the flexibility of asynchronous access and self-pacing, particularly beneficial for managing diverse schedules: “I could work through content when it suited my timetable”, “The ability to go at my own pace helped me really understand concepts”. However, this same flexibility posed challenges for some students (discussed below), illustrating the double-edged nature of learner autonomy.

#### 5.4.2. Challenges and Suggested Improvements

Students identified several challenges, providing valuable insights for ongoing refinement:

**Time Management and Self-Regulation:** The most frequently mentioned challenge was managing time effectively in an asynchronous format, particularly for students new to fully online learning: “Time management was difficult without set lecture times”, “I left things too late because there weren’t weekly deadlines.” This suggests that while asynchronous flexibility benefits many learners, some require additional scaffolding for self-regulation—an area for potential enhancement through progress reminders or optional milestone structures.

**Cognitive Load and Content Volume:** Some students found the breadth and depth of content overwhelming, particularly when tackling multiple microcurricula simultaneously: “Too much new terminology took time to process”, “There was too much to do.” These comments highlight a tension between comprehensive coverage and manageable cognitive demands, suggesting potential value in clearer guidance about content prioritisation or staged engagement strategies.

**Absence of Face-to-Face Interaction:** A recurring request was for synchronous lecture components or optional face-to-face sessions, reflecting some students’ preference for traditional instructional formats: “I missed having lectures to ask questions in real-time”, “Face-to-face would help with difficult concepts.” While the module’s fully asynchronous design serves scaling and accessibility needs, incorporating optional synchronous support sessions (office hours, drop-in clinics) was added to address this concern without compromising the asynchronous core.

**Navigation and Module Structure:** Some students found navigating across multiple microcurricula course pages challenging: “It was confusing having so many separate pages”, “Navigation between topics could be clearer.” This feedback points to potential improvements in interface design, course organisation, or provision of clearer navigation aids—addressing usability without altering pedagogical fundamentals.

**Requests for Domain-Specific Examples:** Students across disciplines requested more examples directly tied to their specific fields: “More business-related data examples would help”, “Case studies from health sciences would make it more relevant”. While the trans-disciplinary nature necessitates balance, strategic incorporation of pathway-specific case studies or optional discipline-aligned examples was already included, but additional examples might enhance perceived relevance without fragmenting core content.

### 5.4.3. Synthesis of Qualitative Findings

The convergence between positive sentiment and constructive feedback demonstrates students' reflective engagement with the module and perceived relevance to their learning goals. The features students valued most—interactivity, feedback, multimodality, flexibility, practical application—directly map onto the integrated framework's design principles (PI-CRAT Interactive/Creative uses, UDL multiple means, constructive alignment of authentic tasks). Conversely, challenges identified—time management, cognitive load, desire for synchronous interaction, navigation complexity—reveal areas where additional scaffolding, clearer guidance, or optional supplementary support might enhance the experience for learners who struggle with fully asynchronous, self-directed formats.

Importantly, the qualitative data contextualise the quantitative findings: high pass rates and positive survey responses do not imply universal ease or absence of struggle. Rather, they suggest that the design successfully supports diverse learners in achieving outcomes despite varied challenges. The minority of students who found content overwhelming or missed face-to-face interaction still generally completed successfully, indicating that the extensive formative support, interactive elements, and flexible pacing provided sufficient scaffolding even when the learning experience felt demanding.

The qualitative insights also validate the framework's theoretical foundations. Students' explicit appreciation for features aligned with UDL principles (choice, multimodality, flexibility), active learning strategies (practical application, problem-solving), and technology integration (interactivity, immediate feedback, creative production) provides direct evidence that these pedagogical approaches were not merely implemented but meaningfully experienced and valued by learners. The alignment between design intentions and student perceptions suggests fidelity of implementation and validates the framework's applicability to large-scale online education contexts.

### 5.5. Summary of Results

The results from three years of implementation demonstrate that the integrated design framework successfully supported interactive and inclusive online learning at a substantial scale. Learning analytics revealed high engagement rates (69–78% of enrolled students attempting assessments) and exceptional pass rates (95–99%), substantially exceeding typical online course completion rates. The quantitative survey data showed consistently positive student perceptions across all dimensions—satisfaction ( $M = 4.02$ ), content quality ( $M = 3.96$ ), engagement ( $M = 3.75$ ), and learning outcomes ( $M = 4.03$ )—with notable improvements over time, particularly in engagement (+0.71 points). Qualitative feedback corroborated these findings, with students praising interactive features, multimodal content, practical applicability, and flexibility while identifying time management, cognitive load, and preference for synchronous interaction as challenges for some learners.

The longitudinal trends show not only initial effectiveness but also sustained improvement. This was achieved through iterative refinement guided by ongoing evaluation and the integrated framework's principles. Objective completion data, self-reported perceptions, and qualitative insights converge to provide robust, triangulated evidence. The systematic integration of pedagogy, technology, and content design produced measurable benefits for diverse student populations in an online asynchronous environment.

## 6. Discussion

This study investigated whether constructively aligning technology, pedagogy, and content through a microcurricula approach could deliver an interactive and inclusive online asynchronous module at scale. The goal was to improve learning experiences and outcomes for diverse student populations. The findings across three years provide strong

affirmative evidence: high completion rates (95–99%), positive student perceptions across all dimensions ( $M = 3.75\text{--}4.10/5.0$ ), and longitudinal improvement trends validate the effectiveness of the framework.

The sustained improvements in student satisfaction, engagement, and outcomes observed across three years are interpreted here not as incidental findings but as direct consequences of the theoretical principles embedded in the OPTIMAL framework. Each design decision is explicitly traceable to its underlying theoretical rationale. UDL principles informed the inclusive and flexible design of the module, accommodating the disciplinary diversity of the cohort (details included in Table 1). Active learning principles informed the design of production-oriented activities, constructive alignment ensured coherence between intended outcomes, assessments, and learning activities at all levels, and intentional pedagogy–technology integration improved student satisfaction, engagement, and outcomes (Ishtiaq et al., 2025). Taken together, these theory-informed design decisions collectively account for the sustained positive outcomes observed, providing empirical support for the validity and effectiveness of the OPTIMAL framework in large-scale, mandatory, cross-disciplinary online asynchronous learning contexts.

### 6.1. Interpreting Framework Effectiveness Through PICRAT

The observed improvements can be interpreted through the PICRAT framework, which positions technology use along the passive, interactive, and creative axis and the replacement, amplification, and transformation axis. The module’s deliberate design for interactive and transformative practices corresponds directly to engagement improvements from  $M = 3.11$  to  $M = 3.82$ . Activities implemented using H5P amplified learning through immediate, customised feedback at scale—impossible to do manually for thousands of students. The formative assessments transformed students from passive recipients to active collaborators, fostering ownership and deeper engagement as evidenced by the qualitative feedback.

The microcurricula-as-a-service architecture operationalised UDL principles by enabling flexibility (multiple pathways, self-pacing) while maintaining coherence through constructive alignment. The sustained high pass rates across diverse programs demonstrate that flexibility did not compromise rigour. TPACK-guided technology selection ensured tools supported pedagogical strategies rather than driving them, while systematic PICRAT evaluation guided designs toward Interactive-Amplification and Creative-Transformation quadrants.

### 6.2. Implications for Practice

This longitudinal, large-scale, transdisciplinary implementation offers several actionable insights for educators and institutions:

- Framework over tools: Pedagogically-informed design processes (UDL, TPACK, PICRAT) proved more critical than specific technologies. Effectiveness emerged from systematic integration, not tool features alone.
- Modular architecture enables flexibility: The MaaS approach demonstrates that granular, self-contained units can support diverse contexts (embedded in programs, stand-alone modules, varied credit sizes) while maintaining quality and alignment.
- Invest in formative assessment: Extensive formative resources with immediate feedback, including student co-creation models, yielded substantial returns in engagement and learning outcomes.
- Design for iteration: Treating implementation as iterative rather than fixed enabled targeted refinements (e.g., enhanced interactivity, indicative timelines for time management) that improved experiences while maintaining pedagogical foundations.

Further, MaaS enables fast redesign and deployment, requiring only a change in one microcurricula without affecting others.

- Pathway approach for transdisciplinary skills: Shared outcomes with tool-specific implementations balanced consistency and customisation, offering a scalable model for institution-wide skill development.

### 6.3. Limitations and Threats to Validity

Several limitations warrant consideration: The 33% survey response rate introduces potential self-selection bias, though learning analytics from all students partially mitigates this. Implementation at a single institution with specific resources and support structures limits generalizability—transferability to different contexts requires further investigation. Student perceptions and completion rates, while important, do not directly measure deep learning or long-term transfer; future research incorporating performance analytics and longitudinal follow-up would strengthen understanding of learning depth. Furthermore, isolating the contribution of individual pedagogical theories would require a controlled experimental study beyond the scope of the current work. The case study design precludes definitive causal claims; although the design features align coherently with the outcomes, multiple factors influence the results.

The exceptionally high pass rates may partly reflect the flexible summative assessment design, which gives students opportunities to practise before the summative assessment and to revise and retake it, as well as the credit-bearing mandatory status of the module and other assessment design features, thereby limiting comparisons with voluntary courses. Finally, implementation fidelity when adopted by others with less expertise or institutional support remains uncertain, though detailed documentation (Sections 3 and 4) aims to support replication.

Despite these limitations, the study's scale, duration, mixed methods, triangulation, and transdisciplinary scope provide substantial evidence supporting the framework's effectiveness in the studied context. It offers a foundation for continued investigation across diverse settings, deeper learning analytics, and systematic variations of design features to refine understanding of which elements most influence outcomes.

## 7. Conclusions

This study demonstrates that the systematic integration of pedagogical theory, technology frameworks, and modular curriculum design achieves interactive and inclusive online education at scale. The integrated framework—synthesising UDL, active learning, constructive alignment, TPACK, and PICRAT within a microcurricula-as-a-service architecture—addresses a critical gap in educational technology research by moving beyond fragmented, tool-centric approaches toward theoretically grounded, systematically designed implementations.

Evidence from the three years validates the framework's effectiveness: completion rates of 95–99%, positive student perceptions ( $M = 3.75\text{--}4.10$ ), and longitudinal improvements demonstrate sustained success. The microcurricula-as-a-service architecture emerges as a key innovation, operationalising flexibility and personalisation at scale while maintaining coherence through constructive alignment. This modular approach, combined with extensive formative assessment and deliberate progression toward interactive and transformative technology uses, transformed student experiences from passive consumption to active collaboration.

For practitioners, this work offers a replicable model grounded in widely available technologies and established principles, with explicit guidance beyond tool recommendations. For researchers, it contributes longitudinal, large-scale evidence demonstrating

how theoretical frameworks guide practical design and evaluation. As higher education increasingly relies on online delivery for diverse populations, this study provides both evidence and methodology for the systematic integration of theory and practice at scale. A follow-up study is underway to address this gap through self-reported competency assessments comparing pre- and post-enrolment competency levels and results achieved in formative and summative assessments, which will provide a more granular and direct measure of individual learning gains attributable to the OPTIMAL framework.

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**Informed Consent Statement:** Written informed consent for the survey and interview was obtained from all subjects involved in the study.

**Data Availability Statement:** The raw data collected from the survey are not publicly available, in compliance with the ethical guidelines that restrict the sharing of raw data.

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## References

- Abgaz, Y., & Dunne, C. (2023). Designing microcurricula-as-a-service: The case of large class, cross programme, and online asynchronous module. In *Pedagogy for higher education large classes (phelc23)*. Zenodo. <https://doi.org/10.5281/zenodo.8014148>.
- Abgaz, Y., McCarren, A., Elger, P., Solan, D., Lapuz, N., Bivol, M., Jackson, G., Yilmaz, M., Buckley, J., & Clarke, P. (2023). Decomposition of monolith applications into microservices architectures: A systematic review. *IEEE Transactions on Software Engineering*, 49(8), 4213–4242. <https://doi.org/10.1109/TSE.2023.3287297>.
- Anderson, S. (2024). Expanding data literacy to include data preparation: Building a sound marketing analytics foundation. *Journal of Marketing Analytics*, 12(2), 227–234. <https://doi.org/10.1057/s41270-024-00293-3>.
- Atenas, J., Havemann, L., Kuhn, C., & Timmermann, C. (2023). Critical data literacy in higher education: Teaching and research for data ethics and justice. In J. E. Raffaghelli, & A. Sangrà (Eds.), *Data cultures in higher education: Emergent practices and the challenge ahead* (pp. 293–311). Springer International Publishing. [https://doi.org/10.1007/978-3-031-24193-2\\_12](https://doi.org/10.1007/978-3-031-24193-2_12).
- Biesta, G. (2010). Pragmatism and the philosophical foundations of mixed methods research1. In A. Tashakkori, & C. Teddlie (Eds.), *SAGE handbook of mixed methods in social & behavioral research* (pp. 95–118). SAGE Publications, Inc. Available online: <https://methods.sagepub.com/hnbk/edvol/sage-handbook-of-mixed-methods-social-behavioral-research-2e/chpt/pragmatism-the-philosophical-foundations-mixed-methods> (accessed on 9 April 2025). <https://doi.org/10.4135/9781506335193>.
- Biggs, J. (2003). Aligning teaching for constructing learning. *Higher Education Academy*, 1(4), 1–4.
- Biggs, J., & Tang, C. (2011). *Teaching for quality learning at university*. McGraw-Hill Education. Available online: <https://books.google.ie/books?id=XhJrBrDAESkC> (accessed on 12 December 2024).
- Bloom, B. S. (1968). Learning for mastery. Instruction and curriculum. Regional education laboratory for the carolinas and virginia, topical papers and reprints, number 1. *Evaluation Comment*, 1(2). Available online: <https://eric.ed.gov/?id=eD053419> (accessed on 1 October 2023).
- Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3(2), 77–101. <https://doi.org/10.1191/1478088706qp0630a>.
- Buckland, P. H. (2012). Learning Starts with design: Using universal design for learning (UDL) in higher education course redesign. In F. S. Miller (Ed.), *Transforming learning environments: Strategies to shape the next generation* (Vol. 16, pp. 109–136). Emerald Group Publishing Limited. [https://doi.org/10.1108/S1479-3660\(2012\)0000016009](https://doi.org/10.1108/S1479-3660(2012)0000016009).
- Carlile, O., & Jordan, A. (2005). *It works in practice, but will it work in theory? The theoretical underpinnings of pedagogy*. Available online: <https://api.semanticscholar.org/CorpusID:145348474> (accessed on 30 September 2024).
- CAST. (2018). *Universal design for learning guidelines version 2.2*. Available online: <https://udlguidelines.cast.org/> (accessed on 30 September 2025).
- Celik, B., & Cagiltay, K. (2024). Uncovering MOOC completion: A comparative study of completion rates from different perspectives. *Open Praxis*, 16(3), 445–456. <https://doi.org/10.55982/openpraxis.16.3.606>.

- Christersson, C., Staaf, P., Braekhus, S., Stjernqvist, R., Pusineri, A. G., Giovani, C., Sancassani, S., Corti, P., Lebigot, G., Biri, V., Mainelli, X. U., van den Berg, F., Queckenberg, R., Freitag, K., Lippold, S., Giménez Font, X., Collins, T., Frahill, A., McCarthy, M., . . . Zhang, T. (2019). *Promoting active learning in universities*. European University Association.
- Clay, A. S., Andolsek, K. M., Niederhoffer, K., Kandakatla, A., Zhang, G., Price, M., Alagesan, P., Jeffs, S., DeLaura, I., Nicholson, C. P., Chudgar, S. M., Narayan, A. P., Knudsen, N. W., Blazar, M., Edwards, P., & Buckley, E. G. (2023). Creation of an asynchronous faculty development curriculum on well-written narrative assessments that avoid bias. *BMC Medical Education*, 23(1), 244. <https://doi.org/10.1186/s12909-023-04237-w>.
- Coners, A., Matthies, B., Vollenberg, C., & Koch, J. (2025). Data skills for everyone! (?)—An approach to assessing the integration of data literacy and data science competencies in higher education. *Journal of Statistics and Data Science Education*, 33(1), 90–115. <https://doi.org/10.1080/26939169.2024.2334408>.
- Dean, T., Lee-Post, A., & Hapke, H. (2017). Universal design for learning in teaching large lecture classes. *Journal of Marketing Education*, 39(1), 5–16. <https://doi.org/10.1177/0273475316662104>.
- Dewey, J. (1926). My pedagogic creed. *Journal of Education*, 104, 542.
- Dewey, J. (1938). *Experience and education*. Kappa Delta Pi.
- Dong, F., O'Donoghue, D. P., Ersotelos, N., Wu, S., Saggion, H., Ronzano, F., Corcho, O., Hurley, D., Abgaz, Y., Zhang, J. J., Chaudhry, E., Yang, X. S., Wei, H., Deng, Z., Mahdian, B., & Careil, J.-M. (2017). Dr. inventor, promoting scientific creativity by utilising web-based research objects, FP7. *Impact*, 2017(2), 40–44.
- Eison, J. (2010). *Using active learning instructional strategies to create excitement and enhance learning*. Available online: <https://www.semanticscholar.org/paper/Using-Active-Learning-Instructional-Strategies-to-Eison/4062f1f90f5844decc14fba3949bbe61c2d18553> (accessed on 27 November 2023).
- Emmers, E., Schrooten, M., & Pulinx, R. (2022). Using UDL to redesign education in response to diversity. *The Ahead Journal*, 14. Available online: <https://www.ahead.ie/journal/Using-UDL-to-redesign-education-in-response-to-diversity-> (accessed on 10 November 2023).
- European Parliament, & Council of the European Union. (2016, May 4). *Regulation (EU) 2016/679 of the European parliament and of the council* [Regulation]. Available online: <https://data.europa.eu/eli/reg/2016/679/oj> (accessed on 20 December 2024).
- Farrell, A. M., Buckley, K., Glynn, M., Lowney, R., Smyth, S., & Stone, S. (2021). *Moving large classes online: Illuminating the experience of the sudden transition of large, face-to-face programmes to the online environment in dublin city university, in response to the COVID-19 crisis*. Dublin City University. <https://doi.org/10.5281/zenodo.4574650>.
- Gamage, S. H. P. W., Ayres, J. R., & Behrend, M. B. (2022). A systematic review on trends in using Moodle for teaching and learning. *International Journal of STEM Education*, 9(1), 9. <https://doi.org/10.1186/s40594-021-00323-x>.
- Gormley, C., Lowney, R., & Stone, S. (2022). *Adaptable ABC: Learning design for all*. University of Cape Town. Available online: [https://zivahub.uct.ac.za/articles/preprint/Adaptable\\_ABC\\_Learning\\_design\\_for\\_all/20029166](https://zivahub.uct.ac.za/articles/preprint/Adaptable_ABC_Learning_design_for_all/20029166) (accessed on 8 December 2023). <https://doi.org/10.25375/uct.20029166.v1>.
- Gummer, E. S., & Mandinach, E. B. (2015). Building a conceptual framework for data literacy. *Teachers College Record*, 117(4), 1–22. <https://doi.org/10.1177/016146811511700401>.
- Guo, P., Saab, N., Post, L. S., & Admiraal, W. (2020). A review of project-based learning in higher education: Student outcomes and measures. *International Journal of Educational Research*, 102, 101586. <https://doi.org/10.1016/j.ijer.2020.101586>.
- Guskey, T. (2007). Closing achievement gaps: Revisiting Benjamin S. bloom's "learning for mastery". *Journal of Advanced Academics*, 19, 8–31. <https://doi.org/10.4219/jaa-2007-704>.
- Haleem, A., Javaid, M., Qadri, M. A., & Suman, R. (2022). Understanding the role of digital technologies in education: A review. *Sustainable Operations and Computers*, 3, 275–285. <https://doi.org/10.1016/j.susoc.2022.05.004>.
- Huang, R., Wu, D., Kim, J., & Leung, B. T. H. (2020). Data and information literacy education: Methods, models, and challenges. In *Proceedings of the acm/ieee joint conference on digital libraries in 2020* (pp. 443–444). Association for Computing Machinery. <https://doi.org/10.1145/3383583.3398546>.
- Inverarity, C., Tarrant, D. D., Forrest, E., & Greenwood, P. (2022). Towards benchmarking data literacy. In *Companion proceedings of the web conference 2022* (pp. 408–416). Association for Computing Machinery. <https://doi.org/10.1145/3487553.3524695>.
- Ishtiaq, F., Shah, F. u. H., Zahid, M. A., Nagal, C. J. C., Alessi Longa, F. E., & Calimlim, R. J. F. (2025). The impact of technology integration on student engagement and learning outcome. *Contemporary Journal of Social Science Review*, 3(3), 1064–1078. <https://doi.org/10.63878/cjssr.v3i3.1069>.
- Jordan, K. (2015). Massive open online course completion rates revisited: Assessment, length and attrition. *International Review of Research in Open and Distributed Learning*, 16(3), 341–358.
- Kang, B. (2021). How the COVID-19 pandemic is reshaping the education service. In *The future of service post-COVID-19 pandemic, volume 1: rapid adoption of digital service technology* (pp. 15–36). Springer.
- Kim, J., Hong, L., & Evans, S. (2024). Toward measuring data literacy for higher education: Developing and validating a data literacy self-efficacy scale. *Journal of the Association for Information Science and Technology*, 75(8), 916–931. <https://doi.org/10.1002/asi.24934>.

- Kimmons, R., Graham, C. R., & West, R. (2020). The PICRAT model for technology integration in teacher preparation. *Contemporary Issues in Technology and Teacher Education*, 20(1), 176–198.
- King, R. (2022). The utility of pragmatism in educational research. *Creative Education*, 13(10), 3153–3161. <https://doi.org/10.4236/ce.2022.1310199>.
- Koehler, M. J., & Mishra, P. (Eds.). (2016). *Handbook of technological pedagogical content knowledge (TPACK) for educators* (2nd ed.). Routledge. <https://doi.org/10.4324/9781315771328>.
- Koehler, M. J., Mishra, P., & Cain, W. (2013). What is technological pedagogical content knowledge (TPACK)? *Journal of Education*, 193(3), 13–19. <https://doi.org/10.1177/002205741319300303>.
- Krathwohl, D. R. (2002). A revision of Bloom's taxonomy: An overview. *Theory into Practice*, 41(4), 212–218.
- Lee, V. S. (2012). What is inquiry-guided learning? *New Directions for Teaching and Learning*, 2012(129), 5–14. <https://doi.org/10.1002/tl.20002>.
- Levey, S. (2023). Universal design for learning. *Journal of Education*, 203(2), 479–487. <https://doi.org/10.1177/00220574211031954>.
- Lund, B., Hovious, A., & Kim, J. (2026). Discourses of data literacy: A critical literature review. An annual review of information science and technology (ARIST) paper. *Journal of the Association for Information Science and Technology, Early View*. Available online: <https://asistdl.onlinelibrary.wiley.com/doi/abs/10.1002/asi.70054> (accessed on 20 March 2026). <https://doi.org/10.1002/asi.70054>.
- Magro, J. (2021). H5P. *Journal of the Medical Library Association*, 109(2), 351–354. <https://doi.org/10.5195/jmla.2021.1204>.
- Mahmud, M. M., Wong, S. F., & Ismail, O. (2022). Emerging learning environments and technologies post COVID-19 pandemic: What's next? In Y. Maleh, M. Alazab, N. Gherabi, L. Tawalbeh, & A. A. Abd El-Latif (Eds.), *Advances in information, communication and cybersecurity* (pp. 308–319). Springer International Publishing.
- Md Osman, S. Z. (2022). Combining synchronous and asynchronous learning: Student satisfaction with online learning using learning management systems. *Journal of Education and e-Learning Research*, 9, 147–154. <https://doi.org/10.20448/jeelr.v9i3.4103>.
- Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record*, 108(6), 1017–1054. <https://doi.org/10.1111/j.1467-9620.2006.00684.x>.
- Naeem, M., Ozuem, W., Howell, K., & Ranfagni, S. (2023). A step-by-step process of thematic analysis to develop a conceptual model in qualitative research. *International Journal of Qualitative Methods*, 22, 16094069231205789. <https://doi.org/10.1177/16094069231205789>.
- Nahar, N., & Cross, D. (2020). Students as partners in e-content creation: A case study exploring student-staff partnership for learning and student engagement using digital applications for co-creation of e-learning materials. *International Journal for Students as Partners*, 4, 109–119. <https://ojs.aishe.org/index.php/aishe-j/article/view/677>.
- Nic Fhlannchadha, S. (2022). The results of the StudentSurvey.ie trends over time research 2016–2021. *Journal of Teaching and Learning in Higher Education*, 14, 1–28. <https://doi.org/10.62707/aishej.v14i1.677>.
- O'Donoghue, D., Saggion, H., Dong, F., Hurley, D., Abgaz, Y., Zheng, X., Corcho, O., Zhang, J. J., Careil, J.-M., Mahdian, B., & Zhao, X. (2014). Towards dr inventor: A tool for promoting scientific creativity. In *Proceedings of the fifth international conference on computational creativity ICC-2014* (pp. 268–271). ICC. Available online: <https://mural.maynoothuniversity.ie/id/eprint/6465/> (accessed on 13 February 2026).
- Ó Súilleabháin, G., Lanclos, D., Farrelly, T., Ó Súilleabháin, G., Lanclos, D. M., & Farrelly, T. (2024). *How to use digital learning with confidence and creativity: A practical introduction/edited by gearóid Ó súilleabháin, donna lanclos, tom farrelly*. Edward Elgar.
- Panakaje, N., Rahiman, H. U., Parvin, S. M. R., P, S., K, M., Yatheen, & Irfana, S. (2024). Revolutionizing pedagogy: Navigating the integration of technology in higher education for teacher learning and performance enhancement. *Cogent Education*, 11(1), 2308430. <https://doi.org/10.1080/2331186X.2024.2308430>.
- Piaget, J. (1970). *Genetic epistemology*. Columbia University Press.
- Quality and Qualifications Ireland. (2024, October). *Quality in irish higher education 2024*. Available online: <https://www.qqi.ie/sites/default/files/2025-09/annual-report-2024.pdf> (accessed on 1 October 2025).
- Ridsdale, C., Rothwell, J., Smit, M., Ali-Hassan, H., Bliemel, M., Irvine, D., Kelley, D., Matwin, S., & Wuetherick, B. (2015). Strategies and best practices for data literacy education. *Knowledge Synthesis Report*, 151, 10–17.
- Rienties, B., & Toetel, L. (2016). The impact of learning design on student behaviour, satisfaction and performance: A cross-institutional comparison across 151 modules. *Computers in Human Behavior*, 60, 333–341. <https://doi.org/10.1016/j.chb.2016.02.074>.
- Rose, D., Meyer, A., & Gordon, D. (2013). *Universal design for learning: Theory and practice*. CAST, Inc.
- Ryan, M. F. (2022). *Compendium of active learning strategies for student engagement*. *Strategies for student engagement*. Technological University of the Shannon Midlands Midwest.
- Schneider, M., & Preckel, F. (2017). Variables associated with achievement in higher education: A systematic review of meta-analyses. *Psychological Bulletin*, 143(6), 565–600. <https://doi.org/10.1037/bul0000098>.
- Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, 15(2), 4–14.

- Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review*, 57(1), 1–23.
- Spronken-Smith, R., & Walker, R. (2010). Can inquiry-based learning strengthen the links between teaching and disciplinary research? *Studies in Higher Education*, 35(6), 723–740.
- Trullàs, J. C., Blay, C., Sarri, E., & Pujol, R. (2022). Effectiveness of problem-based learning methodology in undergraduate medical education: A scoping review. *BMC Medical Education*, 22(1), 104. <https://doi.org/10.1186/s12909-022-03154-8>.
- Tseng, J.-J., Chai, C., Tan, L., & Park, M. (2020). A critical review of research on technological pedagogical and content knowledge (TPACK) in language teaching. *Computer Assisted Language Learning*, 35, 948–971. <https://doi.org/10.1080/09588221.2020.1868531>.
- Varkey, T. C., Varkey, J. A., Ding, J. B., Varkey, P. K., Zeitler, C., Nguyen, A. M., Merhavy, Z. I., & Thomas, C. R. (2022). Asynchronous learning: A general review of best practices for the 21st century. *Journal of Research in Innovative Teaching & Learning*, 16(1), 4–16. <https://doi.org/10.1108/JRIT-06-2022-0036>.
- Vuorikari, R., Kluzer, S., & Punie, Y. (2022). *DigComp 2.2: The digital competence framework for citizens—With new examples of knowledge, skills and attitudes*. Available online: <https://publications.jrc.ec.europa.eu/repository/handle/JRC128415> (accessed on 27 January 2025). <https://doi.org/10.2760/115376>.
- Vygotsky, L. S. (1978). *Mind in society* (M. Cole, V. Jolm-Steiner, S. Scribner, & E. Souberman, Eds.). Harvard University Press. Available online: <http://www.jstor.org/stable/j.ctvjf9vz4> (accessed on 7 May 2024). <https://doi.org/10.2307/j.ctvjf9vz4>.
- Warr, M., & Mishra, P. (2022). TPACK: The TPACK technology integration framework. In *EdTechnica: The Open Encyclopedia of Educational Technology* (pp. 261–267). EdTech Books. Available online: <https://edtechbooks.org/encyclopedia/tpack> (accessed on 29 October 2025). <https://doi.org/10.59668/371.9034>.
- Yang, H., & Romero-Hall, E. (2024). A pilot study exploring interaction and student satisfaction in asynchronous courses in higher education. *TechTrends*, 68(4), 761–770. <https://doi.org/10.1007/s11528-024-00986-7>.

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