

## Navigating AI's educational future: expert scenarios and implications for teaching and teacher preparation

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### ABSTRACT

This paper presents expert perspectives derived from a visioning activity conducted by an international panel of educational researchers from 13 countries and 18 institutions, working under Thematic Working Group 5 for UNESCO's EDUsummIT 2025. Using a futures thinking approach, the experts co-constructed six scenarios imagining AI-enriched educational environments in 2030 across primary, secondary, technical, and higher education sectors. Reflexive thematic analysis of these expert-generated artefacts identified 12 cross-cutting themes. Three meta-patterns emerged: the more-human paradox, in which AI saturation intensifies rather than displaces human pedagogical work; the agency-scaffolding tension, in which student AI agency must be carefully developed rather than assumed; and contextual variation, in which the meaning of critical AI partnership differs across educational phases. Together, these meta-patterns suggest that pre-service teacher preparation moves beyond AI tool training to embed pedagogical rehearsal of scaffolding strategies that make effective use of GenAI's capabilities. We identify three priority areas that reflect the most pressing areas for action: (a) developing critical, agentic AI partnerships, (b) orchestrating AI-enhanced learning ecosystems, and (c) building trustworthy, equitable AI infrastructure. These insights aim to inform the design of teacher education and professional learning that is responsive to rapidly evolving AI-mediated educational environments.

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## 1. Introduction

Artificial Intelligence is among the most transformative and unpredictable technologies to enter educational settings in recent decades and is reshaping educational environments at every level of schooling, from primary classrooms to higher education, yet the trajectory of this transformation remains deeply uncertain. Its rapid evolution means that today's teachers are being asked to integrate tools whose capabilities, risks, and pedagogical implications are still being understood [1,2]. Significant opportunities exist, for example: for personalised learning, formative feedback, and the development of critical AI literacy, but so do substantial challenges, including overdependence, erosion of critical thinking, academic integrity concerns, algorithmic bias, and deepening digital divides [3–5]. Future educators need not only to understand AI literacy principles but to develop practical pedagogical repertoires for scaffolding students' critical and agentic engagement with AI tools. However, current preparation programmes largely lack both the frameworks and the strategies to do this [6,7]. The pace of AI development means this gap is widening faster than existing research can address it. Understanding what AI-enriched education might look like in practice, and what this means for how we prepare teachers, requires us to look beyond current implementations toward plausible future states.

This paper addresses that teacher preparation gap through a structured futures thinking exercise conducted by an international expert panel of educational researchers. Working in sector-specific small groups, participants co-constructed six scenario artefacts imagining AI-enriched educational environments in 2030 across primary, secondary, technical, and higher education contexts. A sub-group of researchers then conducted reflexive thematic analysis of these artefacts to identify cross-cutting themes and derive implications for teacher preparation. This approach of grounding analysis in co-constructed expert artefacts rather than in existing data is appropriate where the phenomenon of interest is still emerging and where expert knowledge constitutes a legitimate and necessary source of insight [8,9]. Reliance on expert judgement necessitates a method built specifically for reasoning about futures that cannot yet be observed or measured, which is precisely what futures thinking offers.

Futures thinking as a conceptual lens provides a structured methodology for this purpose, enabling critical and creative exploration of multiple possible, probable, and preferable futures of education [9]. This is particularly valuable in the context of AI and education, where dominant narratives in the media tend to be shaped by technology industry rather than by educators and learners [10]. At the same time, research on how expert AI practitioners actually work suggests that the competencies required for meaningful AI engagement extend well beyond tool use, encompassing iterative human-AI collaboration, critical evaluation of outputs, and the ability to socialise and justify AI-generated solutions to others [11,12]. Therefore, these insights from expert practice should inform how we conceptualise AI literacy in educational contexts, and, by extension, how we prepare the teachers who will develop it in students.

This study is guided by two research questions:

RQ1: What might teaching and learning in an AI-enriched educational environment look like in 2030?

RQ2: What does this imply for pre-service teacher education?

To answer this, 20 researchers, representing 13 countries, joined Thematic Working Group 5 (TWG5) focusing on Artificial Intelligence (AI) Literacy for Teaching and Learning, as part of EDUsummIT 2025. TWG5 engaged in discussions on developing and implementing effective strategies for enhancing AI literacy and agency of pre-service and in-service teachers, and how to support them to develop the knowledge and skills necessary to embed AI into their classroom practices. This paper presents insights synthesised from the collective expertise of this internationally diverse group of educational researchers to identify

priority areas for preparing future educators for AI-enriched learning environments.

## 2. Futures thinking as a methodological approach

Futures thinking is a structured approach that allows exploration of multiple possible, probable, and preferable futures [9]. It employs critical and creative consideration of multiple perspectives, focusing on long-term visioning with a view to fostering strategic and adaptive thinking that is proactive rather than reactive, to respond to complex and uncertain environments. AI has the potential to impact future education in significant and unpredictable ways. A futures thinking approach may provide space to value discourse, counter dominant narratives, assess long-term societal impacts, and offer a framework for anticipating likely events and extrapolating emerging changes, with the aim to help ensure that human-centred values and social goals remain aligned with societal and technological progress. The process is endorsed by UNESCO, claiming this approach as necessary for navigating a rapidly evolving technological world [13].

In the context of AI and education, futures thinking can help educators to imagine desirable outcomes and prepare for disruptive transitions [10]. In previous research, futures thinking frameworks have been utilised to identify preferable futures in the area of science education [9], and to encourage students to challenge assumptions, explore uncertainties, and become agents of change in their own learning environments [14]. Futures thinking does not claim predictive power; rather, its validity lies in its capacity as a structured sense-making tool that surfaces assumptions, counters dominant narratives, and generates policy-relevant insights that no single expert perspective could produce alone [15,9]. Its value has been demonstrated across multiple educational research contexts, including scenario-based approaches to reimagining higher education in the face of technological disruption [15] and participatory futures research on AI in education [10], establishing it as a legitimate and productive methodological choice for the present study.

## 3. AI use in education today

AI is recognised as one of the most transformative technologies to emerge in recent years [1]. In particular, Generative AI applications, built on large language models (LLMs) and known for their intuitive interfaces, have accelerated adoption across educational sectors [16, 17].

Both significant opportunities and challenges for GenAI associated with education have been recognised by educational researchers. Opportunities include personalised learning experiences that address unique student needs [18], early identification of learning difficulties [19], and assistive tools to help students overcome barriers [20]. For teachers, GenAI can streamline assessment generation and grading, facilitate collaboration and professional learning, and act as a co-teaching assistant [21,22]. Pedagogical approaches are emerging to integrate AI into learning design by deploying it in different roles, such as simulations, role-plays, coaches, and Socratic tutors, suited to specific learning tasks [23], although the extent to which these approaches impact learning outcomes remains uncertain. To better understand how such innovations might be implemented at scale, this study conducts exploration of future educational scenarios in which AI is deeply embedded in teaching and learning across multiple levels of the education sector.

Despite potentially transformative possibilities, substantial challenges are also widely recognised. For example, overdependence on GenAI may erode students' cognitive skills, reducing creativity, critical thinking, and problem-solving capabilities [3]. Academic integrity concerns are also prominent, as AI-generated content is difficult to detect and may provide unfair advantages while undermining the integrity of academic qualifications [5,21,24]. Data privacy and security

issues persist, with AI systems trained on vast datasets often without users' knowledge or consent, and many operating as 'black boxes' with opaque decision-making processes [4,25]. Hallucinations created by GenAI tools can mislead users due to their responses appearing credible [26]. Finally, concerns remain about equitable access, with potential for a new and perhaps more serious digital divide than ever before [5,19]. Further risks include the reinforcement of algorithmic bias, the potential homogenisation of student thinking through regression to AI-generated norms, and the social and psychological disruption associated with AI-driven transformation of the labour market [27,28].

Given the significant challenges posed by student use of GenAI, particularly its impact on over-reliance and critical thinking, researchers have turned their attention to how to support student agency, self-regulated learning, and accountability in AI-mediated educational contexts [2,29]. Preserving agency is closely linked to supporting self-regulated learning, as students must plan, monitor, and evaluate their AI interactions: metacognitive processes central to self-regulation [30]. Additionally, supporting self-regulated learning requires co-regulation, where teachers provide transitional scaffolding before students internalise regulatory strategies [30]. However, practical guidance for teachers on operationalising these principles in AI-enabled contexts remains scarce. UNESCO's AI Competency Framework for Teachers [2] advocates for human-in-the-loop approaches and the preservation of learner agency when interacting with AI systems, yet it only provides high-level competencies without specifying concrete strategies for fostering agentic AI use. Similarly, research on self-regulated learning with AI has largely focused on AI-mediated learning analytics dashboards and automated feedback systems rather than explicit teacher-scaffolding pedagogical approaches to assist students to critically engage with AI outputs [31].

This gap in pedagogical knowledge regarding the effective use of GenAI is particularly consequential for pre-service teacher education. Future educators must not only develop a robust understanding of AI literacy, but also cultivate practical pedagogical repertoires that enable students to sustain agency and self-regulation in AI-mediated environments. As GenAI tools continue to evolve and reshape educational practices, identifying effective pedagogical strategies that support both student agency and self-regulation in AI-mediated learning environments becomes increasingly important. This is not the first study to use scenario construction to explore AI educational futures; prior work has employed futures thinking and scenario-based methods to reimagine higher education in the context of technological disruption [15], to engage young people in envisioning AI energy futures in schools [10], and to construct near-future scenarios grounded in educators' predictions about managing GenAI challenges [27]. Accordingly, TWG5 undertook a systematic exploration of plausible future scenarios as an analytic strategy to examine how effective pedagogical approaches might be enacted in practice, particularly strategies that support learners to maintain and strengthen their agency while developing their AI literacy across different stages of schooling.

## 4. Methodology

### 4.1. Scenario generation process: future visioning exercise

Scenario construction of this kind is recognised as a legitimate and productive research method for generating insights about complex, uncertain futures, particularly in educational contexts [10]. The activity was structured as an expert panel [8], in which participant-researchers contributed their professional knowledge and disciplinary expertise to co-construct plausible future educational scenarios. This approach is appropriate where, as here, the subject of inquiry involves significant uncertainty and where the knowledge to be elicited resides in the accumulated expertise of specialists rather than in existing empirical datasets.

The expert panel consisted of 20 researchers; their demographic and

institutional composition is summarised in Table 1.

We engaged in a futuring exercise to envision what teaching and learning in an AI-enriched educational environment might look like in the year 2030. Our initial discussion scenario cue stated:

*It's 2030. Five years ago, your educational institution was selected as an AI literacy pioneer and received substantial funding to integrate AI meaningfully across teaching and learning. Teachers are now well versed in pedagogy with AI, students use AI tools naturally in their learning, and AI literacy is embedded throughout your curriculum. You've moved beyond the early adoption challenges and are now operating in a mature AI-integrated educational environment.*

The task was to visualise and discuss a typical day of school teachers and leaders in AI-enriched environments and discuss how AI tools and processes may be seamlessly integrated into their work. Discussions also centred on potential evolutions of teaching approaches, the nature of student engagement and learning, and the assessment and support of student AI literacy development. Participants worked in small groups organised by educational sector expertise, with each group discussing, drafting, and iteratively refining their scenario before submitting a final written version to the group lead. The data corpus for subsequent analysis therefore comprised six co-constructed expert scenario artefacts, one for each educational context (primary, secondary, and post-16 education, with two for higher education), totalling approximately 15 pages. The scenarios were treated analytically as co-constructed expert artefacts, representing the deliberate, knowledge-informed outputs of structured professional deliberation, rather than as transcripts or observational data. The scenarios were developed through structured consideration of three focal areas: a) priority AI literacy needs for teachers within their current context, b) critical capabilities required for educators to operate effectively in AI enriched environment, and c) systemic barriers requiring intervention. Collectively, the resulting Future Scenarios (OSF | Final Scenario Package.docx.pdf) illustrate students demonstrating their competencies in AI-rich environments; teachers enacting AI-integrated pedagogies; and school leaders establishing policies and frameworks needed to guide AI use, mitigate risks, and ensure equity and ethical implementation. Each group presented a 2030-oriented scenario followed by opportunity for cross cultural dialogue and critique. In the months after the in-person meetings in Ireland, a subset group of TWG5 members engaged in sustained collaboration throughout the latter-half of 2025, to refine and edit their scenarios.

### 4.2. Thematic analysis: human-AI collaboration

We conducted reflexive and inductive thematic analysis following Braun and Clarke's [32] six-phase approach, adapted to incorporate systematic human-AI collaboration guided by the IAVES framework for Human-Centered AI Interaction [12] based on current uses of AI in industry [11]. This framework extends traditional iterative prompt engineering by requiring researchers to: *Elevate* AI outputs through critical editing and contextualisation and *Socialize* interpretations through team deliberation and stakeholder engagement. These steps ensure that

**Table 1**  
Participant demographics.

| Category                               | n  |
|----------------------------------------|----|
| <b>Total participants</b>              | 20 |
| Gender — Male                          | 7  |
| Gender — Female                        | 13 |
| Countries represented                  | 13 |
| Region — Europe                        | 10 |
| Region — Middle East/North Africa      | 2  |
| Region — Australia/New Zealand         | 5  |
| Region — USA                           | 3  |
| Affiliation — Educational institutions | 17 |
| Affiliation — Non-profit R&D firm      | 1  |

analytical authority remains with human researchers while leveraging AI's capacity for pattern detection and questioning [33]. Our approach recognises that human-AI collaboration is task-dependent and dynamic. In this paper, AI functioned instrumentally during systematic coding activities, as well as worked as an intellectual partner during interpretive theme development and as an analytical consultant during theme refinement and presentation. This process mirrors the different forms of collaborative behaviour and performance that occurs among human research team members during collaborative projects.

Table 2 illustrates detailed information about our human-AI collaborative process during each stage of thematic analysis. We strategically used multiple GenAI models (ChatGPT-5.1 for coding and initial theme generation and Claude 4.5 Sonnet for theme interrogation and argumentation analysis). Analytical consistency was maintained through human (i.e., our own) oversight rather than GenAI model's uniformity. For example, cross-validation across multiple AI models functioned as triangulation, with discrepancies prompting deeper human insight and interrogation (from ourselves) rather than algorithmic adjudication. A quantifiable account of these decisions is evident in Phases 3–4, where nine AI-proposed candidate themes were refined into twelve final themes through human disaggregation of one theme into three. The use of AI in qualitative thematic analysis remains an evolving and contested methodological practice.

While research indicates that AI can enhance analytical efficiency and pattern detection in qualitative coding, significant concerns persist regarding transparency, potential bias in AI outputs, and the risk of opaque or unexplained model operations undermining interpretive rigour [34,35]. We address these concerns by ensuring that human researchers retained full interpretive authority throughout, with AI contributions subject to the same validation standards expected of human analytical work.

This human-AI collaborative process served to deepen and intensify, rather than accelerate, the analytical procedure. The research team engaged in sustained interrogation of interpretive claims, systematic cross-checking against data, and explicit articulation of analytical reasoning, both collaboratively and in critical dialogue with Claude.ai through an auto-interview technique (see Appendix A). This challenges the prevailing assumption that AI integration primarily reduces researcher effort. Our analysis as well as previous work (e.g., [33]) suggests that human-AI collaboration can enhance analytical rigour only when researchers retain interpretive authority and subject AI contributions to established validation standards.

5. Results

Following Braun and Clarke's [32] reflexive and inductive thematic analysis approach, 329 references were coded and 12 themes were identified from the six co-constructed future scenarios. All codes and the frequency of the codes and themes are listed in Appendix B. Below, we present the themes along with supporting evidence from the scenarios. We emphasise themes that emerged across educational sectors and levels. Appendix C provides a typology showing how the 12 themes were distributed across the six scenarios, illustrating the cross-case patterns that informed the three meta-patterns identified in the discussion.

5.1. Students as critical, agentic partners with AI

Our analysis demonstrated that student agency and critical partnership with AI was featured across five scenarios, spanning primary schools through higher education. At the primary level, this positioning was made explicit: *"the AI is their thinking partner, not their decision-maker"*, with students *"pushing back on the AI's assumptions"* and explaining *"why they accepted some AI input and rejected other suggestions"*; their learning process involved critical questioning, verifying, and maintaining independent thinking, while comparing human and AI observations to identify what each noticed or missed. Secondary

Table 2  
Human-AI collaborative process in thematic analysis.

| Thematic analysis [32] | Definition             | Human-AI collaboration                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|------------------------|------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Phase 1                | Familiarisation        | Phase 1 required exclusively human engagement: researchers independently read all six scenarios multiple times, met to discuss initial impressions, and built a shared understanding of the dataset's scope and complexity. This immersive familiarization was essential groundwork for meaningful human-AI collaboration, including judgement and decision-making regarding AI outputs, due to the researchers' deep familiarity with the data.                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Phase 2                | Initial coding         | In Phase 2, one team member employed ChatGPT-5.1 to generate initial codes across all scenarios, which were then systematically validated by four human researchers who reviewed, challenged, modified, and supplemented AI-generated codes to ensure relevance to research questions and fidelity to data content. AI-generated codes were subjected to the same validation standards as codes produced by human analysts, requiring empirical grounding, conceptual clarity, and team consensus.                                                                                                                                                                                                                                                                                                                                                                                                    |
| Phase 3                | Searching for themes   | In Phase 3, ChatGPT-5.1 proposed nine candidate themes derived from the validated codes. The research team deliberated over these proposed themes, renaming several to better reflect the data's nuances.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Phase 4                | Reviewing themes       | In Phase 4, human researchers determined that one theme encompassed excessive conceptual complexity and made the analytical decision to disaggregate it into three distinct themes, resulting in twelve final themes.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Phase 5                | Defining/naming themes | Phase 5 involved intensive theme refinement through Claude 4.5 Sonnet's "auto-interview" technique ([33]b), where Claude posed critical questions to the research team (n=4) that provoked deliberation about each theme's boundaries, internal coherence, and relationship to the research question. This collaborative interrogation was not efficiency-driven but rigor-driven as Claude's questioning forced researchers to articulate, defend, and sometimes revise their interpretive claims. The team also cross-checked thematic interpretations against the original scenario data, identifying instances where human interpretation required stronger empirical grounding or where rich evidence had been overlooked by Claude. Human researchers maintained interpretive authority at all decision gates, with all AI interactions documented in supplementary materials (see Appendix B). |
| Phase 6                | Writing                | In Phase 6, the research team used the auto-interview technique with Claude to perform argumentation analysis to evaluate the logical coherence of thematic claims and develop clusters for presenting the twelve themes in the discussion section. Human researchers evaluated and selected the most analytically defensible approach and conducted the final analytical writing.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |

students similarly *"critically evaluate suggestions and often seek peer input"* rather than accepting AI recommendations outright, recognising AI as *"capable but fallible assistants requiring critical evaluation"* whose outputs should be verified through multiple sources. At a technical and community college, students were positioned as *"independent and in charge or at least partners in their learning"*, with evaluation criteria requiring they

check *"the accuracy and usefulness of the research studies found by their AI partner"*. In higher education, students were depicted as *"adept at questioning and critiquing AI-generated content"*, with AI used as *"a scaffold, not a crutch"*; assessments were designed to ensure students *"demonstrate personal mastery of content"* while arriving to class *"prepared to challenge both their instructor and their digital tools with curiosity, nuance, and critical thought"*.

## 5.2. Self-, co-, and socially-shared regulation of learning

Self-, co-, and socially-shared regulation of learning emerged across all educational sectors but featured prominently in the secondary school scenarios. At the primary level, co-regulation was evident through teacher prompts fostering metacognitive awareness, for example, *"What did you think of that explanation?"* and *"How could you check?"*; this scaffolding explicitly contributed to the development of student self-regulation through *"the daily practice of AI literacy - question, verify, maintain your own thinking"*. At the secondary level, students engaged in structured reflection sessions *"focused on wellbeing and learning reflection"*, discussing *"their feelings, expectations, and reflecting on yesterday's learning challenges and successes"*, before writing *"3-4 daily objectives on electronic tablets, balancing academic goals with behavioural/social objectives"*. AI robot assistants facilitated discussions about collaboration strategies and supported *"collaborative learning regulation"*; during programming lessons, *"the AI monitors collaboration quality, and socially shared regulation of learning"*, prompting reflection and asking students to explain decisions. Students in technical and community college contexts were characterised as *"goal oriented learners"* who planned and checked their work using industry-relevant frameworks, while actively seeking peer feedback to test and refine their assumptions. In one higher education scenario, self-assessment was positioned as integral to learning, with students encouraged to interrogate their own reasoning and the tools they employed, and the deliberate comparison of human and AI-generated responses was found to foster metacognitive awareness.

## 5.3. Communicative and socio-emotional competencies

Communicative and socio-emotional competencies featured across four scenarios, most prominently at the primary level. Primary school students enjoy *"this AI-saturated classroom [that] buzzes with more human connection than classrooms of the past"*, with teachers *"constantly facilitating interactions, coaching social skills... mediating conflicts...and teaching the collaborative competencies that will matter in their futures"*; students learned to *"listen and disagree respectfully"* while presenting and defending solutions. At the secondary level, teachers facilitated students presenting their work while *"others ask questions and provide feedback"* and *"students reach consensus"*, with AI monitoring *"collaboration quality, not just code correctness, encouraging communication skills"* among students. Technical and community college students devoted effort to *"critically thinking through the line of argument ... and to adjust the language used in their report to develop buy-in"*, meeting *"in small groups to discuss and provide feedback on ethical implications"*. One higher education scenario highlighted that *"the arts are reemphasised in curriculum, as meaningful engagement with the arts helps to support students' critical and creative thinking skills"*, with lectures becoming *"interactive discussions"* and critical assessment tasks conducted through *"oral debate, in order to exercise human minds and bodies"*.

## 5.4. Teachers as designers, orchestrators and data-informed professionals

Teachers as designers, orchestrators and data-informed professionals featured across four scenarios, most explicitly at the primary level. At the primary-school level, the teacher's role *"has evolved but not diminished"*, as she designed *"the learning arc, identified the key concepts, and set the success criteria"*, with AI helping *"deliver differentiated versions...all based on her knowledge of each learner and her pedagogical judgment"*. At

the secondary level, teachers *"pre-briefed"* AI assistants before lessons and used *"robot-generated data visualisation alongside direct observation to assess learning and adjust robot programming in real-time"*. In higher education, teachers designed *"chatbots with the teacher's voice"* and *"seamlessly adapt and repurpose instructional materials using AI tools to meet the diverse needs of learners in real time"*, with routine administrative tasks automated to free educators *"to focus on student engagement"*; however, one scenario acknowledged that *"all these implementations won't change our workload as teachers"*.

## 5.5. AI as embedded pedagogical infrastructure and support

AI as embedded pedagogical infrastructure featured across five scenarios, with scenarios employing metaphors of ubiquity: *"AI is everywhere and nowhere"*, *"seamless and almost invisible"*, and *"AI is not a bolt-on gadget - it is the air-handling system of the learning ecosystem... you only notice it when it malfunctions"*. At the secondary level, embodied forms of AI appeared through robots as *"a cheerful companion that has been learning alongside them for several weeks"*, greeting students by name and physically interacting with students to enhance learning engagement. Higher education scenarios described *"personalised AI-powered agents (tutor/mentor chatbots)...almost like a digital twin or knowledgeable peer"* available *"24/7, acting as a telepresence for remote students and a round-the-clock tutor"*. Operational infrastructure appeared through a Campus Digital Twin enabling *"decisions in under ten seconds"*; one scenario noted the technology *"fades into the background. The relationships, the thinking, the growing - that's all in the foreground"*.

## 5.6. AI-enabled assessment, feedback and analytics

AI-enabled assessment, feedback and analytics featured across five scenarios, most prominently at the secondary level. At the primary level, *"AI handles the routine cognitive work - the immediate feedback, the re-explaining of concepts in multiple ways, the personalised practice"*, with teachers interpreting analytics through *"deep knowledge of each child"*; human-AI comparative noticing appeared as students asked *"What did we see that it missed? What did it notice that we didn't?"* At the secondary level, robots *"continuously collect learning data, identifying misconceptions and progress"* and provide *"real-time data visualisation showing student mood assessments, emerging issues, and groups needing additional support"*; AI monitored and provided feedback that *"suggests test cases...flags uncommented complex sections, and prompts reflection when students are stuck"*. In higher education, *"assessment is mostly formative and process-oriented"*, with *"routine administrative tasks, like attendance, grading, and scheduling, fully automated"* and a comparative analysis of human and AI responses, supported by a *"risk-tiering framework"* allowing educators to *"opt out for high-stakes tasks"* and letting AI focus on *"low-stakes feedback loops"*.

## 5.7. Student critical AI literacy

The importance of students' critical AI literacy featured across five scenarios spanning primary through higher education. At the primary level, *"the daily practice of AI literacy"* was *"question, verify, maintain your own thinking"*, with young students learning the skills needed to evaluate AI explanations, push back on assumptions, and express their judgement of AI suggestions. Secondary students viewed AI as *"capable but fallible assistants requiring critical evaluation"*, understanding they must verify outputs through multiple sources and recognising that *"human judgement and creativity remain essential"*. At technical and community college levels, ethical dimensions became prominent, with students learning to identify inequities in AI systems, decode software to examine design implications, and demonstrate they had *"found/corrected all errors and hallucinations"* whilst ensuring *"responsible use of AI"*. In higher education, students were *"adept at questioning and critiquing AI-generated content"*, engaging in comparative analysis between human and AI responses; they arrived to class *"prepared to challenge both their instructor and their*

digital tools with curiosity, nuance, and critical thought".

### 5.8. Teacher critical AI literacy

Teacher critical AI literacy was evident across five scenarios from primary through to higher education. At the primary level, teachers scaffolded students' critical questioning by prompting verification rather than providing direct answers, asking "What did you think of that explanation?" and "How could you check?", while also contributing to institutional vetting processes that ensured classroom AI tools were "robust and trustworthy" with data privacy protections in place. Secondary teachers pre-briefed AI assistants before lessons, adjusted robot programming in real-time based on their observations, and advised students "whether they could improve it using their own knowledge or should seek AI help". Technical and community college educators evaluated student work to ensure they had identified errors and hallucinations and that designs demonstrated "responsible use of AI" with attention to inclusivity. In higher education, teachers used AI professionally to design personalised chatbots and adapt instructional materials, while institutional committees evaluated AI tools to "assess equity and transparency", recognising this as a collective rather than individual burden; educators remained "vigilant about when not to use AI, pushing back against overreliance", supporting "students' inquiry and the ability to exercise agency... particularly considering when AI is actually necessary and when its usage might become unethical".

### 5.9. AI governance

AI governance emerged most prominently in higher education scenarios, where institutional frameworks included algorithmic impact assessments, "AI ingredients labels" providing plain-language transparency, risk-tiering frameworks allowing educators to opt out of AI use for high-stakes tasks, and policy labs involving student delegates, ethicists, and institutional leaders in co-drafting governance policy. Primary and technical college scenarios also referenced years of policy development and industry-developed frameworks as prerequisites for trustworthy AI integration, framing governance as a collective institutional and political endeavour rather than an individual teacher burden.

### 5.10. Authentic and real-world learning and industry-alignment

Authentic learning experiences featured in three scenarios, ranging from primary students engaging with genuine community problems such as water conservation projects, to technical college students learning in both campus and industry settings through "public-private partnerships", to higher education emphasising work placements and projects designed to be "in touch with industry or the public sector" rather than confined to academic contexts.

### 5.11. Access, inclusion and wellbeing

All six scenarios addressed access, inclusion, or wellbeing, with AI described as having become "everywhere and nowhere - as unremarkable as pencils". Differentiated provision appeared through robotic tutors, hyflex teaching, real-time mood monitoring, and accessibility accommodations, with one scenario reporting retention gaps for first-generation learners narrowing and another featuring 24/7 telepresence tutorial access.

### 5.12. Tensions, limits and unintended consequences

Three higher education scenarios explicitly surfaced tensions despite otherwise optimistic portrayals, including workload implications, the importance of knowing when not to use AI, surveillance concerns around gaze-tracking proposals, and the risk of AI becoming invisible infrastructure that escapes critical scrutiny - captured in one scenario's

metaphor of AI as "the air-handling system of the learning ecosystem".

## 6. Discussion

### 6.1. Key insights

#### 6.1.1. AI as augmenting, not displacing, human pedagogical work

Contrary to widespread concerns about AI-driven dehumanisation of education [3]), TWG5 members envisioned AI saturation as augmenting rather than displacing human pedagogical work. This counter-intuitive finding appeared explicitly in primary school scenarios, where AI infrastructure was positioned as liberating teachers from routine cognitive work to focus on facilitating interactions, coaching social skills, mediating conflicts, and teaching collaborative competencies. The pattern extended across contexts: secondary school teachers orchestrating consensus-building discussions; technical college educators conducting stakeholder interviews; and higher education emphasising interactive dialogue and embodied debate. These approaches challenge deficit narratives about AI automation [36] and instead align with emerging research suggesting AI's pedagogical value lies in extending human teaching capabilities [22]. What distinguishes this study from prior AI futures research is the grounding of these findings in cross-sectoral, internationally diverse expert knowledge spanning primary through higher education, revealing not only shared priorities but the developmentally distinct forms they take across educational phases, which is an insight that single-sector or single-context studies cannot produce [15,27].

#### 6.1.2. Developmentally distinct patterns across educational phases

The scenarios revealed that the shared priorities are also manifested through developmentally distinct stages of pedagogical implementations. Specifically, primary contexts foregrounded socio-emotional competencies and collaborative learning; secondary contexts emphasised self-regulation mechanisms and real-time data interpretation; technical college contexts centred authentic industry partnerships; higher education contexts diverged between pedagogically-focused educator visions and governance-focused leader visions. These variations challenge previously suggested AI literacy frameworks that universally support AI literacy for all students [37,38]. Instead, our analysis calls for context-specific, developmentally appropriate pedagogical strategies to support students' AI competency at different stages of learning, recognising that the meaning of critical AI partnership varies across educational phases.

#### 6.1.3. Toward AI-enhanced pedagogical knowledge: a teacher preparation gap

The findings also highlight that future education expects sophisticated teacher capabilities that current teacher preparation programs inadequately address [6,7]. Our scenarios implicitly suggest what Celik et al. [39] term "AI-enhanced pedagogical knowledge", which is a capability distinct from either technical AI literacy or pedagogical knowledge, yet currently absent from most teacher education programs. We position students as critical, agentic learners who seek to maintain independent judgment, and this agency must be carefully scaffolded through critical partnerships with AI. Such partnerships suggest that learners need to prompt for verification, interrogate AI reasoning, judge when to engage with or bypass AI assistance, and adjust system parameters in real time based on their learning needs. Developing such critical AI evaluation capabilities requires teachers who possess both technical understanding of how AI systems operate [40] as well as pedagogical expertise in scaffolding metacognitive awareness [41].

### 6.2. Implications for pre-service teacher preparation

The priority areas identified below were derived from three meta-patterns that emerged across the 12 themes: the more-human paradox,

the agency-scaffolding tension, and contextual variation (Appendix C). Each meta-pattern signals a distinct preparation area that teacher education programs may need to consider as AI becomes increasingly embedded in educational contexts. Fig. 1 provides an overview of the analytic pipeline from raw scenario data to priority areas.

The meta-patterns were arrived at through sustained team discussion and interpretation of the twelve themes. Table 3 illustrates how the 12 themes map onto these meta-patterns and the priority areas they inform. For example, Theme 5 (AI as embedded pedagogical infrastructure) is grouped under the more-human paradox because, across scenarios, AI infrastructure receding into the background corresponded with human relationships, judgement, and connection being foregrounded as the locus of learning.

#### 6.2.1. Orchestrating AI-enhanced learning ecosystems

Our scenarios suggest that pre-service preparation would benefit from experiences where AI is harnessed to support collaborative meaning-making and self-regulated learning rather than supplanting these processes. While AI can theoretically enable personalised learning and immediate feedback [18,42], realising these benefits requires sophisticated instructional design skills by experienced human teachers [43]. Our findings point toward the value of teacher candidates practicing orchestrating group work where AI serves as collaborative partner rather than answer source, designing protocols ensuring equitable participation in AI-mediated discussions, and creating assessment approaches revealing student regulatory processes. Our scenarios' emphasis on teachers interpreting AI-generated analytics through deep knowledge of individual learners reflects what Cotton et al. [21] identify as essential human judgment that algorithms cannot replace.

#### 6.2.2. Developing critical, agentic AI partnership

These scenarios indicate that teachers in AI-enhanced classrooms will need AI literacy and agency to continuously model verification processes, orchestrate comparative noticing between human and AI observations, and make real-time decisions about when students should engage AI versus develop unassisted capability. Teacher education programs may need to expand supervised practicum experiences to include AI-focused pedagogies, i.e., learning to scaffold student's iterative interrogation of AI's responses to prompts, examining AI-generated content for bias and hallucination before classroom introduction, and documenting pedagogical decision-making about AI use timing and appropriateness. There is a case for purposely incorporating these capabilities into teacher preparation contexts.

#### 6.2.3. Building trustworthy, equitable AI infrastructure

Pre-service preparation may benefit from developing teacher candidates' understanding that AI systems embed values and biases requiring ongoing critical examination, addressing what research identifies as insufficient attention to equity implications in current programs [44]. This includes learning to evaluate AI tools before classroom use for representation bias in training data and outputs, understanding accessibility features and limitations, and developing frameworks for identifying when AI-generated feedback may disadvantage particular student groups. While ultimate responsibility for procuring trustworthy, safe, and equitable AI infrastructure lies with institutions, regulators, and policymakers, there is a case for teacher candidates having skills to

**Table 3**

From themes to meta-patterns to priority areas for pre-service teacher preparation.

| Meta-pattern                   | Contributing themes  | What the themes share                                                                                                                   | Priority area                                     |
|--------------------------------|----------------------|-----------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------|
| The more-human paradox         | Themes 3, 4, 5, 10   | AI infrastructure intensifies rather than displaces human pedagogical, social, and authentic learning work.                             | Orchestrating AI-enhanced learning ecosystems     |
| The agency-scaffolding tension | Themes 1, 2, 6, 7, 8 | Student and teacher agency with AI must be actively developed through critical scaffolding rather than assumed.                         | Developing critical, agentic AI partnership       |
| Contextual variation           | Themes 9, 11, 12     | The conditions for trustworthy, equitable AI integration vary across contexts and require governance, inclusion, and critical scrutiny. | Building trustworthy, equitable AI infrastructure |

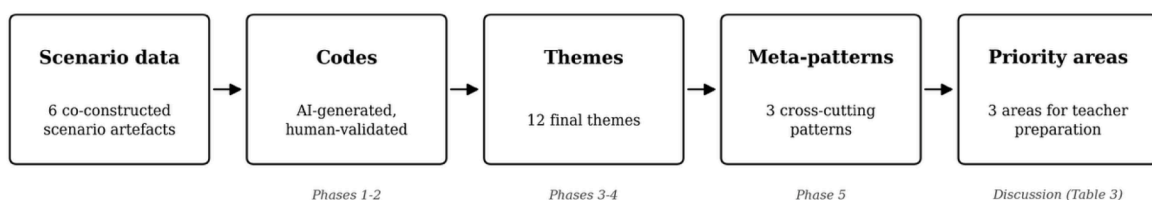
participate meaningfully in governance processes and advocate for equity-centred tool selection [19].

Our scenarios' metaphor of AI as invisible infrastructure raises concerns about maintaining critical scrutiny as systems become normalised. Pre-service programs may therefore consider preparing teachers to recognise surveillance risks, support students' right to decline AI monitoring without penalty, and to contribute to institutional governance mechanisms that ensure learning analytics serve learning rather than compliance [25,28,45].

#### 6.3. Limitations of this study

This study presents several methodological limitations that should be acknowledged. First, the participant-researcher design, in which the same experts who co-constructed the scenarios subsequently contributed to their analysis, introduces a positionality risk. While the use of multiple AI models for initial coding, member checking by wider group members, and the separation of scenario authorship from the core analytical sub-group mitigated this to some degree, the potential for shared assumptions and insider bias cannot be fully eliminated [8].

Second, notably, even when explicitly prompted to consider risks, TWG5 participants, by the nature of our profession focusing on technology integration in education, tended to produce many optimistic scenarios with limited discussions on tensions, limits, or unintended consequences. The positive framing of the visioning scenario cue, which positions participants as pioneers in a mature, well-resourced AI-integrated institution, is likely to have shaped the scenarios produced. A more neutral or critical cue may have generated substantively different findings. Our tendencies aligned with research documenting educators' difficulty anticipating negative AI impacts [46], while suggesting that optimistic framing may obscure critical examination of surveillance risks [45], workload implications [47], and equity effects extending beyond access to algorithmic bias and differential impact [4]. Further developing critical thinking capacities for the proleptic critique of AI systems will remain a distinct professional learning need for both



**Fig. 1.** Analytic pipeline from scenario data to priority areas for teacher preparation.

educational practitioners and researchers alike.

Third, while the use of AI to support thematic analysis was conducted under rigorous human oversight and cross-validated across multiple models, it is important to acknowledge that the internal reasoning processes of large language models are not transparent, and the basis on which patterns are identified or weighted cannot be fully audited [34, 35]. Human interpretive authority was maintained throughout, but readers should be aware of this inherent limitation when evaluating the analytical process.

6.4. Conclusion

The AI-enriched educational futures envisioned by TWG5 researchers suggest that preparing educators for 2030 may require moving beyond technical AI literacy to develop and support fundamentally different professional capabilities. Three priority areas emerge from our analysis: (a) developing critical, agentic AI partnership where teachers scaffold student interrogation of AI outputs and make real-time pedagogical decisions about when to engage or bypass AI assistance; (b) orchestrating AI-enhanced learning ecosystems that intensify rather than displace human interaction while interpreting AI-generated analytics through deep knowledge of individual learners; and (c) building trustworthy, equitable AI infrastructure through active teacher participation in governance mechanisms from bias evaluation to algorithmic impact assessments. We propose that these capabilities suggest systemic transformation of pre-service preparation may be needed. The educational futures articulated in this paper remain aspirational until coordinated action across system levels addresses the fundamental

preparation gaps our analysis reveals.

CRediT authorship contribution statement

**Joyce Malyn-Smith:** Writing – review & editing, Writing – original draft, Project administration, Investigation, Formal analysis, Conceptualization. **Jodie Torrington:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation. **Mary Webb:** Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Deirdre Butler:** Writing – review & editing, Writing – original draft, Formal analysis, Data curation. **Jihyun Lee:** Writing – review & editing, Writing – original draft. **Peter Tiernan:** Writing – review & editing, Writing – original draft, Conceptualization. **Yousra Chtouki:** Writing – review & editing, Writing – original draft, Conceptualization. **Matt Bower:** Resources, Conceptualization. **Manal Yazbak Abu Ahmad:** Resources. **Ana Amélia Carvalho:** Resources. **Jonathan D. Cohen:** Resources. **Pierre Gorissen:** Resources. **Tanya Linden:** Resources. **Kathryn MacCallum:** Resources. **Juliana E. Raf-fagheli:** Resources. **Fredrik Mørk Røkenes:** Resources. **Martina Ronci:** Resources. **Chris Shelton:** Resources. **David Smith:** Resources. **Hen-riikka Vartiainen:** Resources.

Declaration of competing interest

Authors declare that they have no conflicts of interest. There is no financial or personal relationship with a third party whose interests could be positively or negatively influenced by the article’s content.

Appendix A

To ensure transparency and enable methodological scrutiny, we provide documentation of our human-AI analytical interactions throughout this study. The supplementary materials include:

- (1) the scenarios developed by the research team;
- (2) representative prompt sequences from Phase 2 initial coding, demonstrating how AI-generated codes were interrogated and validated by human researchers;
- (3) transcripts of Claude’s auto-interview sessions during Phase 5 theme refinement, showing the critical questions posed and the research team’s collaborative responses;
- (4) examples of Claude’s Phase 6 argumentation analysis with annotations indicating which structural suggestions were adopted, modified, or rejected by human researchers.

These materials demonstrate that AI functioned as an analytical contributor subject to rigorous human validation rather than as an oracle whose outputs were uncritically accepted. The scenarios and prompt logs are available at: [https://osf.io/vc9fw/overview?view\\_only=4bff58da292141faa215a5be906e98c1](https://osf.io/vc9fw/overview?view_only=4bff58da292141faa215a5be906e98c1)

Appendix B

Thematic identification, explanation, and coding frequency

| Theme                                                                  | Theme explanation                                                                                                                                                                                                          | Frequency | Verified scenarios | Scenario details                                                 |
|------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|--------------------|------------------------------------------------------------------|
| Theme 1: Students as critical, agentic partners with AI                | Across phases, students are positioned as decision-makers who use AI as a resource to think with, not a replacement for their own judgement. They are expected to challenge, verify, and selectively adopt AI suggestions. | 44        | 5                  | Primary, Secondary, Technical/CC, HE Educators 1, HE Educators 2 |
| Theme 2: Self, co- and socially shared regulation of learning          | AI-rich routines foreground students’ ability to set goals, monitor their learning and emotions, and regulate learning both individually and with peers.                                                                   | 36        | 4                  | Primary, Secondary, Technical/CC, HE Educators 1                 |
| Theme 3: Collaborative, communicative and socio-emotional competencies | Scenarios emphasise collaboration, communication, and social skills as central competencies, with AI supporting but not replacing human interaction.                                                                       | 34        | 4                  | Primary, Secondary, Technical/CC, HE Educators 1                 |

(continued on next page)

(continued)

| Theme                                                                         | Theme explanation                                                                                                                                                                                                 | Frequency | Verified scenarios | Scenario details                                                                               |
|-------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|--------------------|------------------------------------------------------------------------------------------------|
| Theme 4: Teachers as designers, orchestrators and data-informed professionals | Teachers remain central as designers of learning ecologies, social orchestrators, and interpreters of AI-generated data; their role shifts but does not diminish.                                                 | 24        | 4                  | Primary, Secondary, Technical/CC, HE Educators 1                                               |
| Theme 5: AI as embedded pedagogical infrastructure and support                | AI appears as ubiquitous infrastructure and as embodied/ personalised companions that accompany learners and staff, often fading into the background unless it fails.                                             | 35        | 5                  | Primary, Secondary, Technical/CC, HE Educators 1, HE Leaders                                   |
| Theme 6: AI-enabled assessment, feedback and analytics                        | Assessment becomes more formative and process-oriented, with AI supplying continuous feedback, surfacing misconceptions, and guiding next steps, while humans retain escalation and interpretive authority.       | 32        | 5                  | Primary, Secondary, Technical/CC, HE Educators 1, HE Leaders                                   |
| Theme 7: Student critical AI literacy                                         | Across phases, students are expected to understand what AI can and cannot do, to question and verify AI outputs, and to attend to the ethical and social implications of using AI in their learning and creation. | 33        | 5                  | Primary, Secondary, Technical/CC, HE Educators 1, HE Educators 2                               |
| Theme 8: Teacher critical AI literacy                                         | Teachers are portrayed as needing sophisticated AI literacy themselves: able to interrogate AI tools, scaffold students' critical use of AI, and foreground ethical, equitable practice in everyday pedagogy.     | 25        | 5                  | Primary, Secondary, Technical/CC, HE Educators 1, HE Educators 2                               |
| Theme 9: AI governance                                                        | AI is framed as a governed infrastructure that requires institutional policies, transparency mechanisms, and active resistance to surveillance and bias to protect privacy, equity and trust.                     | 24        | 4                  | Primary (moderate), Technical/CC (moderate), HE Educators 1 (strong), HE Leaders (very strong) |
| Theme 10: Authentic and real-world learning and industry-alignment            | Learning is tightly integrated with real-world problems and industry practices, with AI tools embedded in authentic tasks, placements, and co-taught curricula.                                                   | 13        | 3                  | Primary, Technical/CC, HE Educators 1                                                          |
| Theme 11: Access, inclusion and wellbeing                                     | Scenarios assume significant expansion of access, flexible participation modes, and proactive attention to inclusion and wellbeing within AI-mediated ecosystems.                                                 | 22        | 6                  | All scenarios                                                                                  |
| Theme 12: Tensions, limits and unintended consequences                        | Alongside optimism, the narratives acknowledge trade-offs: persistent teacher workload, risks of surveillance, and the danger that AI becomes invisible and insufficiently scrutinised.                           | 7         | 3                  | HE Educators 1, HE Educators 2, HE Leaders                                                     |

## Appendix C

### Typology of Scenarios: Distribution of 12 Themes Across Six Scenarios

This table shows which of the 12 themes were present in each of the six co-constructed expert scenarios, illustrating how the three meta-patterns: 1) the more-human paradox; 2) the agency-scaffolding tension; and 3) contextual variation, emerge from distinct distributions of themes across educational contexts.

| Theme                                                      | Primary | Secondary | Technical / CC | HE Educators 1 | HE Educators 2 | HE Leaders | Meta-pattern                   |
|------------------------------------------------------------|---------|-----------|----------------|----------------|----------------|------------|--------------------------------|
| 1. Students as critical, agentic partners                  | •       | •         | •              | •              | •              | ○          | The agency-scaffolding tension |
| 2. Self-, co-, socially-shared regulation                  | •       | •         | •              | •              | ○              | ○          | The agency-scaffolding tension |
| 3. Communicative & socio-emotional competencies            | •       | •         | •              | •              | ○              | ○          | The more-human paradox         |
| 4. Teachers as designers & orchestrators                   | •       | •         | •              | •              | ○              | ○          | The more-human paradox         |
| 5. AI as embedded infrastructure                           | •       | •         | •              | •              | ○              | •          | The more-human paradox         |
| 6. AI-enabled assessment & analytics                       | •       | •         | •              | •              | ○              | •          | The agency-scaffolding tension |
| 7. Student critical AI                                     | •       | •         | •              | •              | •              | ○          | The agency-scaffolding tension |
| 8. Teacher critical AI literacy                            | •       | •         | •              | •              | •              | ○          | The agency-scaffolding tension |
| 9. AI governance                                           | ●       | ○         | ●              | •              | ○              | •          | Contextual variation           |
| 10. Authentic & real-world learning                        | ●       | ○         | •              | •              | ○              | ○          | The more-human paradox         |
| 11. Access, inclusion & wellbeing                          | •       | •         | •              | •              | •              | •          | Contextual variation           |
| 12. Tensions, limits & unintended consequences             | ○       | ○         | ○              | •              | •              | •          | Contextual variation           |
| • Strong presence   ● Moderate presence   ○ Absent/minimal |         |           |                |                |                |            |                                |

Note: HE = Higher Education; CC = Community College. HE Educators 1 and HE Educators 2 represent two distinct higher education scenarios focused on pedagogical practice; HE Leaders represents a higher education scenario focused on institutional governance and leadership.

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