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ARTICLE

EI Search: How to Search for Knowledge in the Age of Generative AI

Berry Billingsley[1] · Sam Clarke[2] · Ted Selker[3]

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Abstract
Many widely available search engines prioritise quick access to information, without acknowledging that knowledge is situated across different disciplines. EI Search is the first search engine to empower users' curiosity about the nature of knowledge and boost epistemic insight into how disciplines work. Unlike conventional search tools that treat knowledge as a monolith, EI Search prompts users to explore complex questions through up to ten disciplines, each offering distinct perspectives. EI Search builds on previous work with the Epistemic Insight Discipline Wheel (DW), an educational graphic that visualises disciplines as interconnected yet distinct fields. Displaying the Discipline Wheel in schools and universities has been shown to empower staff and students to wonder how different disciplines approach a complex topic. However, the DW's static format limits its capacity to teach epistemic insight and help students to engage with the architecture of knowledge itself. Motivated by the opportunity presented by Generative Artificial Intelligence (GenAI), we reconceptualised the DW into an interactive tool—EI Search—whereby entering a question and selecting disciplines by clicking on them means that users receive pen portraits by GenAI about the approach that each discipline takes. In Phase 1, we developed multifaceted prompts for GenAI to model scholarly knowledge and discipline-specific norms. Phase 2 involved co-creative refinement with educators, technologists, and students, leading to a prototype tailored for educational contexts. In Phase 3, we adapted the tool for secondary schools, gathering data on student interactions. Our findings demonstrate that EI Search effectively ignites epistemic curiosity, fosters agentic learning, and builds disciplinary and interdisciplinary epistemic insight. The research takes place at a pivotal point in the evolution of search engines. We make recommendations about how and why the next generation of search tools should respond to the arrival of GenAI. We also make recommendations for education based on what this research reveals about the power of EI Search to boost knowledge literacy and open users' minds to the value of taking different perspectives.

Extended author information available on the last page of the article

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1 Introduction

1.1 Innovation—a World First

This paper introduces EI Search, the first search tool and application of Generative Artificial Intelligence (GenAI) to develop users' curiosity about the nature of knowledge and build their epistemic insight into how science and other disciplines work.

EI Search uses GenAI in an original way to provide users with functionality that was not possible before the arrival of GenAI. As this study reports, when we tested this new functionality with teenagers, it enabled a pedagogical 'breakthrough': Twenty-three of the 24 participants gained insights about the nature of knowledge and made advances in their understanding of abstract ideas that are widely said to be unachievable.

1.2 Timing and the Development of Search Engines so Far

The research takes place at a pivotal point in the evolution of tools and applications available to educators and students. Previous technological advances, such as the Internet and desktop computers, were widely seen as disruptive and resisted by education (Papert, 1981). The disruption that followed GenAI's arrival has been even more seismic, with heated debate about how staff and students should react to it (Niemi et al., 2023), especially in disciplines that work with language (Wang, 2024). GenAI stands out when compared with other technologies because of its more advanced capabilities to mimic human behaviour and generate humanlike conversation (UNESCO, 2023).

GenAI-assisted tools for 'searching', including EI Search, can go well beyond the traditional role and function of a search engine, which was to find websites that are relevant to a user's request for information and list them in order of relevance. Traditional search engines like 'Google' were created to address the problem that the Internet is vast and opaque with content and websites. Without machines to help, we cannot and could not find what we need. Search engines retrieved existing content based on keyword matching and popularity. They deliver results as a single list of websites—or, in the cases of the AI-assisted search engines, as a single summary answer. This may be sufficient for simple searches like 'train timetable' or 'weather today', but there are many other reasons why someone goes to 'search'.

The problem we highlight here is that students in schools and universities go to search engines when they are searching for knowledge to help them answer a complex question. Furthermore, they are using a digital search engine instead of going into their school or college library. As this study shows, their interests are not being met by traditional online search tools.

Education is fundamental to creating a society where people can think for themselves. In the age of GenAI, people are using search engines to make decisions and learn about the world—and not only to look up train times. Search engines, in turn, are offering users ways to make more tailored and complicated searches, creating an additional pressure and opportunity to look at how digital searching is interacting with students' developing epistemic insight and motivation for learning.

Google, OpenAI, and Microsoft are experimenting with adding GenAI to conventional Search Engines. The direction of travel is towards tools that are even more efficient and convenient than the ones that came before. The result is a new breed of GenAI-assisted search engines that can 'chat' with the user and generate customised responses that directly answer their queries, with links to external sites playing a secondary role.

However, there is a different starting point for designing a GenAI-assisted search engine, and it is the one we champion here. Now that we have GenAI, we can look more holistically at what students can and should be learning when they search. This is the moment for educators to create or press for the digital tools that our students need.

As we explain in the sections below, this research begins with an agenda to build education into the design of a new GenAI-assisted search engine. The research questions that produced EI Search explored a paradigm for designing search engines that understands users as learners as well as workers. The empirical findings reveal the impacts for school-aged students of access to a GenAI-assisted search engine designed for education.

1.3 Why Search Engines with GenAI can be Different

The habit when designing new technologies is to focus on tools that save us time and make us more efficient (Zong & Guan, 2025). In that case, however, the impact for education is that search engines in the age of GenAI will use a conversational tone and a single point of entry to tell us what to think.

The approach we take in the theory section of this paper focuses on how students learn and what we lose when students stop using the library and what GenAI can now restore. We also recognise familiar concerns that educators raise about students going online at all and the risks to their happiness and health of misinformation.

The interface is another key consideration. The conventional interface for search engines is a single point of entry where the user enters their question. In this paper, we will challenge this convention and say it is time to change. GenAI is 'multimodal' and can handle several queries at once (Jiang et al., 2024). So far, this new power has been given to the user to manage, and users can write more complex prompts. However, in education, our paradigm is different, and we laboriously teach students 'how to drive fast cars' and 'how to be responsible, creative, and ethical drivers' before we give them control.

1.4 Motivation: Schools and Universities

The research is motivated by pedagogical and ethical concerns. For decades, schools, colleges, and universities routinely included a library, and students were expected to spend time in a space where knowledge is physically organised into disciplines. The expectation that students will spend time in the library was a universal provision. Even those who entered the library simply to find information were immersed in a space that assumed they were capable of learning to think epistemically. Disciplines offer distinctive languages, questions, methods, and contexts that make scholarly knowledge meaningful and contextual. Once these become visible to learners, they can be examined, selected, and combined creatively. The shift to digital search has removed this automatic provision. Conventional search engines do not give users an easy way to investigate the disciplinary roots of knowledge. Using an online search tool is like travelling across a city—using the underground train. Yes, you arrive quickly at your chosen destination, but you have missed seeing the layout of the streets and the possibility of alternative destinations.

The responsibility to teach students how knowledge is structured—and how to think critically about it—now falls to subject teachers (in schools) and academic tutors in higher education. However, that responsibility is not one that many teachers and tutors welcome or feel equipped to take on. Secondary school and university educators tend to be disciplinary specialists and may feel they are not well placed to help students navigate knowledge as a whole. Furthermore, many educators are reluctant to discuss the nature of knowledge in any depth on the basis that the concepts are too advanced and abstract for most students (Erduran, 2022). The move online and away from school libraries has a significant impact on young people's education because there are very few other opportunities for them to build this foundational experience. Along with the loss of a specific type of learning, search engines switch students from an educational mindset with aspirations for their development to the mindset of speed and efficiency, where AI does our thinking for us. The outcome is that students' education and ambitions are diminished because the tools most easily to hand are capping their learning and taking away their incentives to aspire.

1.5 A Pressing Need for Change

In its favour, the Internet is a source of vast amounts of content; however, the quality varies. Even if they are not online yet, students should be developing attitudes and skills that will help them to be vigilant for misinformation in preparation for their adult lives (Allchin, 2022). Webpages become more popular if they can grab readers' attention and monopolise their time. Some content providers use a sensationalist claim like 'Doomsday asteroid that could crash into Earth' (Sky News, 2013). Access to teaching and digital tools that teach epistemic insight can help students to become savvy users of the Internet by helping them to discern and challenge exaggerated claims that are dressed to look like science (Osborne, 2023; Taber, 2019).

1.6 Significance and Impact

For decades, all students aged 13 and above were expected to learn how to find answers to questions using a school library. Even in small or under-resourced schools, the physical organisation of knowledge by discipline provided a universal, educative experience. Students were immersed in an architecture of knowledge that required them to think epistemically, even if they entered the library simply to find information.

1.7 What Makes EI Search Distinctive

The distinctive characteristics of EI Search are, firstly, its interface, which is based on the Epistemic Insight Discipline Wheel—a graphic that has ten disciplines arranged around a shared question (see Fig. 1). Secondly, EI Search is agentic—users can write or select a question and click on the disciplines they want to engage in the search. Thirdly, once the user submits their query, EI Search makes use of GenAI to respond with 'pen portraits' of how the selected disciplines approach the question. These pen portraits are deliberately crafted characterisations of disciplines that each follow the same rubric so that when disciplines are brought together, they can be easily compared (Billingsley et al., 2018). By combining the Discipline Wheel, interactivity, and the application of GenAI to produce pen portraits, EI Search is visually and conceptually different from other search tools.

Conceptually, EI Search does not require users to know in advance that disciplinary perspectives matter. Consider the question, 'What is love?' By adopting an Education agenda, we recognise that a user may not know the best question to ask or how to word a good

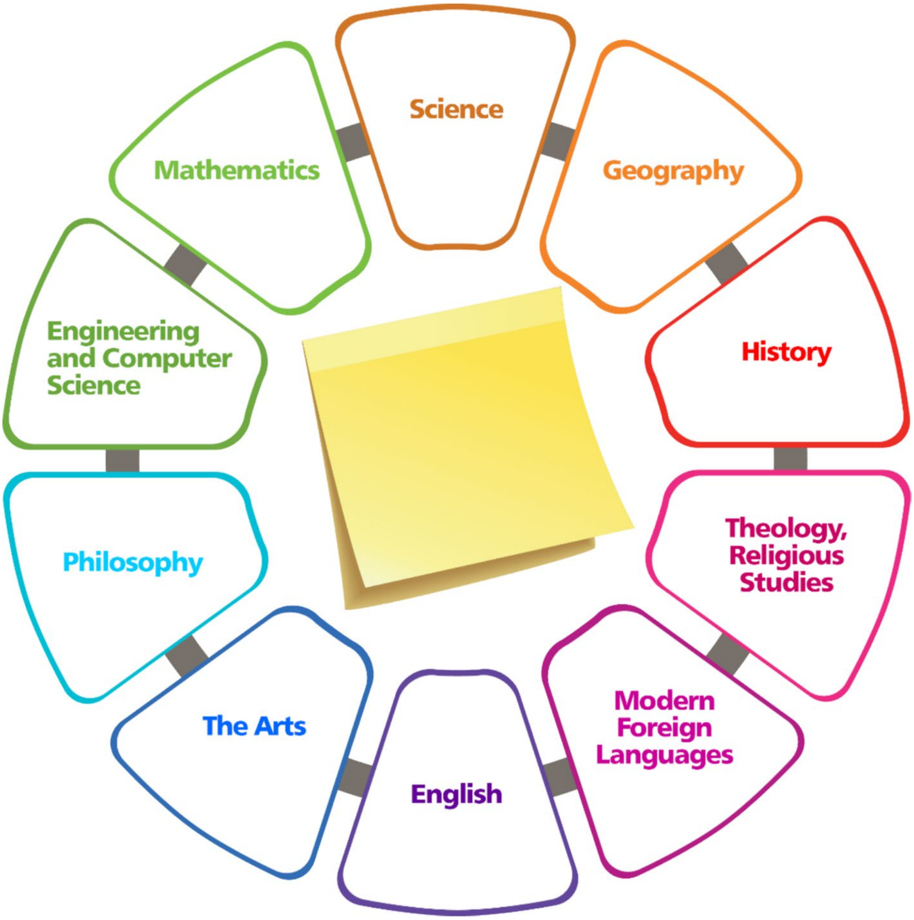

Fig. 1 The EI discipline wheel

prompt. It uses an interactive interface to provoke epistemic curiosity. The outcome is a search engine that 'teaches' the user that this question is discussed and investigated differently in history, theology and biology. In contrast, the widely available search tools provide a 'one-stop shop' for users in any kind of setting, be it a busy parent asking, 'Where is the nearest supermarket?' or a university nursing student asking, 'Can we cure loneliness with a pill?'. There is a big difference between the goals of a parent seeking a supermarket and a student nurse asking how to cure loneliness.

The key question at this point is—does it work in practice?

As this study shows, within minutes of their first encounter and without instruction, secondary school students begin to experiment with disciplinary lenses, revealing that they are not only able—but also demonstrably willing to explore how disciplinary perspectives shape the answers they receive. The findings from Phase 3 demonstrate that EI Search stimulates epistemic curiosity, teaches epistemic insight, and opens students' eyes to the power of multidisciplinary enquiry. EI Search successfully cultivated the critical thinking skills needed to interrogate headlines that grab attention and claim scientific authority. Importantly, this was true for the students we worked with who are in schools in economically disadvantaged areas. This means that education now has an effective tool to overcome a longstanding hurdle in science education: that such meta-level engagement is uninteresting for most school-aged learners. By creating a search tool that recognises the importance of developing and empowering users' understanding of knowledge, this project is distinctively different from projects that prioritise making searching more efficient and faster. EI Search aligns with UNESCO's principles of human-centred design (UNESCO, 2023). This states that AI applications must help humans to make better decisions and not remove humans from decision-making, and must enhance and not undermine education.

EI Search is designed to be inclusive. EI Search does not assume a level of prior knowledge. Instead, the interface for EI Search locks in an expectation that users are not only searching to retrieve information but also to understand how different disciplines construct and justify knowledge. It relies on curiosity, agency, and the reward of getting search results instantly to engage and hold students' attention while they build their familiarity with the tool. This hypothesis is also justified by the research findings. By the end of a 40-min session using EI search, 23 of 24 secondary students aged about 13 demonstrated disciplinary or interdisciplinary epistemic insight—demonstrating that they are inherently capable of independent agentic learning about the nature of knowledge, once given the right tools.

Comments by this age group and sixth-form students expressed an appreciation of a tool to use in their own studies to explore and think critically about how different disciplines work.

Based on the findings of this study, we make recommendations about how and why the next generation of search tools should respond to the arrival of GenAI. We also make recommendations for education based on what this research reveals about the power of EI Search to boost knowledge literacy and open users' minds to the value of taking different perspectives.

Thirdly, a body of research shows that developing students' epistemic insight boosts their capacities to identify and resist misinformation (Lewandowsky & van der Linden, 2021); Moore & Parker, 2021).

EI Search addresses those concerns and opportunities. By empowering users to question and think critically about how knowledge works rather than only and directly answer their questions, this project recognises UNESCO's principles of human-centred AI (see Billingsley et al., 2025; Clarke et al., 2024; Selker, 2024). These principles state that AI applications can and should help users to think better and understand, and do more (UNESCO, 2023).

The next section of the paper provides a conceptual framework and explanations of key terms. The sections after that explain that we conducted the research in three phases:

Phase one involved the design and testing of prompts for GenAI by the research team to test hypotheses and finalise the design of the prompt that drives the tool's functionality. We also explain that EI Search features a bespoke graphical interface, which directs users to choose which disciplines they want to engage with.

Phase two consisted of co-creation workshops to get input from educators and sixth-form students about a version of EI Search for teachers and other stakeholders in school education.

Phase three recruited 24 secondary school students to test 'EI Search with GenAI Unplugged'. Students from three schools interacted with the tool for about 45 min while responding to a survey.

2 Conceptual Framework: Agentic Learning, Epistemic Curiosity, and Epistemic Insight

2.1 Agentic Learning

Agentic learning empowers learners to be creative and take ownership of their educational journeys (Bransford et al., 2006). Iwuanyanwu (2024, p. 422) explains that in contrast with rote learning, 'agentic learning emphasises the active involvement of students in the learning process rather than being passive recipients of information'. The benefits of agentic learning are associated with students creating their own adventures by adopting an active, questioning frame of mind, purposefully seeking answers, evaluating the answers they find, and developing a deeper understanding (Belland et al., 2020). Yanchar and Spackman (2012, p. 7) go further and say that agentic learning is central to what learning can and should be about—and that when humans learn, it is 'an active, meaningful endeavour that requires purposeful engagement by people as holistic, embodied agents'. Ponton (2021, p. 1) reflects on the challenges of an age that is deluged with information and describes agentic learning as 'intentional' learning where students are engaging with learning as lifelong learners with 'personal and professional pursuits'. Our aims for EI Search are that it meets these goals via a tool that is playful and interactive, akin to 'tinkering' in engineering to discover how something works (see, for example Lyons et al., 2015). Furthermore, we anticipate curiosity and agentic learning taking different forms during students' interactions with EI Search. It can be a stimulus that brings the student to the tool, the motivation to pursue a line of enquiry once they are engaged, and the moment when a new question comes to mind and some additional possibilities come into play (Belland et al., 2020; Lyons et al., 2015; Ponton, 2021).

The idea that students have agency over their learning poses the dilemma—what then is the role of the teacher or tutor? The significance of an educator's agency in a classroom that cultivates agentic learning is explained in the OECD's Teaching Compass (OECD, 2025). The Teaching Compass reimagines teachers as agents of curriculum change and explains that teachers design learner-centred opportunities for students. In other words, the way a teacher or tutor sets up and tailors the activity influences the learner's goals and the extent to which agentic learning can happen (Pontin et al., 2021; Mishra et al., 2023). In keeping with these goals, EI Search gives teachers/tutors a tool they can use to boost their students' curiosity about how knowledge works and build their insight into how to carry out interdisciplinary enquiries. EI Search has other benefits for educators, too. It seems likely that teachers and tutors will develop their own epistemic insight when they experiment with the tool (Cooper, 2023). Educators who specialise can look for bridges between their discipline and others in the curriculum (Felix, 2020). Students using EI Search can be directed by their teachers to explore topics such as sustainability, mental health, climate change, the future of robotics, space travel, and ethical questions for society in the age of GenAI (Beck, 2013; Braidotti, 2013).

2.2 Epistemic Curiosity

Epistemic curiosity is a vital driver in the quest for knowledge, propelling individuals towards a deeper understanding of complex subjects (Kitchener, 1983). Berlyne (1954) defines epistemic curiosity as the 'desire to know'. Litman et al., (2005, p. 559) expand on this by saying, 'epistemic curiosity states are aroused by novel questions, complex ideas, ambiguous statements, and unsolved problems'. These descriptions highlight that discovering gaps in one's existing knowledge and encountering something that does not seem to make sense can ignite curiosity and propel students to want a more complete or coherent understanding. The first mystery that users of EI Search encounter is why this tool exists. We anticipate that students coming to EI Search for the first time will see the visual design of the Discipline Wheel with disciplines you can click on, and this will ignite epistemic curiosity from the moment the session begins. We hypothesise that EI Search can empower students to wonder, 'Which disciplines will I choose?' and to 'think outside the box' when it comes to their selections of which disciplines to employ.

Having defined 'epistemic curiosity', we wonder, is all curiosity 'epistemic', or what other forms exist? In a discussion that resonates with our research aims, Litman and Spielberger (2003) refer to Berlyne (1954) to contrast epistemic curiosity with perceptual curiosity, saying that epistemic curiosity is associated with an intellectual desire to know, whereas perceptual curiosity happens when we perceive a stimulus that we want to explore fully. The authors expand on this to indicate that animals, including humans, react to the world around us with perceptual curiosity 'when we encounter visual, auditory, or tactile stimulation' (Litman & Spielberger, 2003, p. 75).

2.3 Epistemic Agency

Epistemic agency in our conceptual learning journey is where the user interacts with the tool by, for example, clicking on disciplines to select them for a search. Whereas epistemic curiosity and epistemic insight are cognitive and hidden from the outside observer's view, acts of agency are manifest and evident in the world. Heikkilä et al., (2023, p. 459) explain that, 'From a socio-cultural perspective, it has also been emphasised that agency is not achieved in a vacuum, but always manifests itself in relation to a given context'. In the case of EI Search, there are motivations and a wider culture that bring users to the tool (see Fig. 2).

2.4 Epistemic Insight

Epistemic insight (EI) refers to the 'eureka' moment that comes with making a discovery about the nature of knowledge (Billingsley et al., 2018). Researchers have unpacked epistemic insight into disciplinary and interdisciplinary ways of thinking. Disciplinary

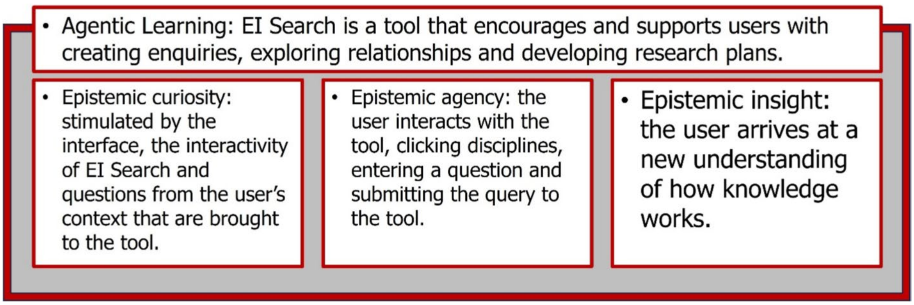

Fig. 2 Conceptual learning journey for users interacting with EI Search

epistemic insight refers to understanding individual disciplines such as science, history, music, and mathematics. The OECD (2025, p. 23) has a related term, epistemic knowledge, and explains that, 'This refers to understanding how knowledge is constructed, validated and used within a discipline—and beyond' and that, 'teachers who engage with epistemic knowledge help students see not just what they are learning, but why it matters and how it connects to their lives, fostering disciplinary thinking and practices in students'.

Interdisciplinary epistemic insight refers to appreciating that disciplines have distinctive perspectives and that combinations of disciplines can fruitfully work together (Billingsley et al., 2024). Chappell et al. (2022) describe a workshop that successfully taught both disciplinary and interdisciplinary epistemic insight by presenting students with the question, 'Why did the Titanic sink?'. Participants developed disciplinary epistemic insight by working with science and history separately and then developed their interdisciplinary epistemic insight by asking students to compare them. Users of EI Search can gain interdisciplinary epistemic insight when they first encounter the Discipline Wheel and see that many disciplines are arranged around a question. Users of EI Search can deepen their disciplinary epistemic insight by clicking on a discipline and reading its pen portrait by GenAI.

3 Phase One: The Design of a new way to Search

3.1 Search Engines

Search engines dominate how people access knowledge and are accepted by most people as an efficient way to resolve the problem of how to find relevant information online (Shrestham and Mahmood, 2019). Most people do not question how they work (Roschelle et al., 2020). Fishkin (2016) reports that in 2016, 44% of queries were short (2–3 words), with 12% at six words and above. A search could be 'train times' or 'define chasm'. Users are presented with a long list of websites ordered with more relevant sites first (Green & Pearson, 2011). If a popular query is associated with a particular discipline, as is the case for more academic and student-focused searches, the results can be a long list of websites that repeat the same answer. For example, the query 'Why is the sky blue? produces many pages that repeat an explanation in physics that blue and yellow wavelengths of light are separated and scattered differently by particles in the atmosphere (Billingsley, 2024). A website with an explanation relating to culture and languages appears much further down the list—and may never be encountered by the user.

Searching 'What is colour?' with Google produces an AI precis above the list of websites, such as 'Color is the visual perception based on the electromagnetic spectrum, specifically the portion we see as light, and is influenced by an object's light absorption, reflection, emission, and interference' (Google, 2025). Analysis of the text indicates that it is almost exclusively scientific, whereas in a school, university, or public library, each of the disciplines occupies its allocated shelf space.

Students using online search tools compose their own queries. If students are mostly using online tools, they will need to conduct word searches in ways that recognise that one discipline can dominate the results. Students will also need to be critical of the knowledge claims they encounter. In contrast, students searching in a library are in a space where the sources of knowledge have been filtered, curated, and organised by librarians—and, although arguably not fully utilised for this purpose, school, public, and academic libraries have physical architectures that recognise disciplines as distinctive ways to create and ratify knowledge (Snow, 2024). Once students are online, the knowledge from different disciplines appears haphazardly in a linear list, and they are at risk of encountering misinformation and misleading, untested knowledge claims (Allchin, 2022).

3.2 Designing the Interface and Interactivity of EI Search

Searching with EI Search is designed to help the user understand how knowledge is created and validated. Scholarly disciplines have distinctive ways to develop, test, and communicate ideas. They have rigour and standards and are the bedrock of thinking and working as a scholar. Scholars, in turn, have created a vast body of knowledge that people trust. However, helping students—especially school-aged students—to engage with these concepts is widely said to be an insurmountable challenge. Sibel Erduran (2022) drew attention to the challenge of building students' understanding of the nature of science even before digitisation. Classroom teaching involves working with a packed curriculum of scientific concepts with little opportunity or time for sharing and discussing the history and philosophy of science. Furthermore, Erduran explains, 'philosophical reflections on the nature of knowledge' are frequently 'too abstract and elusive even for researchers, let alone educators' (Erduran, 2022, p. 563).

EI Search has characteristics that we hypothesised could help students engage with these abstract concepts. Firstly, many teachers already use a static version of the Discipline Wheel on posters and worksheets to teach disciplinary and interdisciplinary epistemic insight. These sessions depend on teachers and additional resources to support and incentivise classroom discussions. Consequently, we were unclear about the extent to which interacting with EI Search as an independent activity would give students an engaging and meaningful experience. A potential factor in its favour is that students using the Discipline Wheel are seeing and interacting with disciplines in a 'knowledge architecture'. The library is an example of a knowledge architecture because it gives each of the disciplines a physical location (Van Den Besselaar, 2001). Researchers have found that challenging students to solve puzzles that require them to visit different areas of a library helps them to create a mental impression of Disciplines. For example, students in small groups competed to find a book in more than one section of their school library to explain, 'Why do we see in colour?' (Billingsley et al., 2024). Our premise was that the physical and embodied experience of moving around the library could be replicated by the visual and tactile experience of interacting with the Discipline Wheel. In the library, disciplines that have some resemblance are near each other. Similarly, disciplines like science and mathematics that 'belong together' are next to each other on the Discipline Wheel, while disciplines in the humanities are on the opposite side of the wheel. The names of disciplines are each written onto a petal, and the user clicks on the ones they want to select. This thickens the border around the discipline, and clicking again deselects the discipline. Working with a mouse and clicking and moving objects around the screen activates the mind's remarkable affinity for working with tools (Velasco & Obrist, 2020). We do not intend EI Search to replace the library, and in a perfect world, students would have access to both. However, in a post-COVID world, the habits of using physical school libraries for schoolwork have given way to going first and sometimes exclusively to online searching (Elliot, 2022; Felix, 2020; Snow, 2024). Given that students are frequently online to do activities that once took place in physical libraries, our aim is to make students' digital experience as educational as possible.

In parallel, we propose that activities to teach epistemic insight in the library can be enriched by combining physical and digital experiences. Suppose that a student can wear special glasses, which mean that they see every instance of a keyword like ‘river’ or ‘planet’ or ‘soul’ shining like a lightbulb amid the darkness of the shelves, What would this add to a student’s understanding of the nature, meaning, and significance of the ways that different disciplines encounter and discuss ideas?

3.3 The Role for GenAI in the Design of EI Search

We turn now to our rationale for exploring the potential for GenAI to enable a new kind of search experience. In our conceptual model, we imagine the process of digitisation as one that extracts content from its physical and scholarly containers. We note, however, that digital content that has a scholarly heritage retains its disciplinary characteristics because these are embedded and woven into the language when the knowledge is created and expressed. For example, scholars working in a specialist compartment are typically using similar words and explaining ideas in similar ways. This led us to reason that Large Language Models can potentially be prompted to generate texts that exemplify and explain how disciplines work (Martzoukou et al., 2021). We turn next to the prompt we designed for this purpose.

3.4 Designing and Testing Prompts for GenAI

The Epistemic Insight Curriculum Framework provides statements about how disciplines work for educators to use in Intended Learning Outcomes and for researchers to use as measures in research analysis (Billingsley & Hardman, 2017). We said previously that the interface for EI Search is a Discipline Wheel. The prompt that sits behind EI Search uses a form of wording that was developed for the paper resource. It characterises enquiry in each discipline by saying there are three steps: to ask a preferred question, to investigate using the discipline’s preferred methods of enquiry and norms of thought. This rubric or characterisation is applied to many disciplines to create a suite of ‘pen portraits’ with a similar structure to help students compare them (Billingsley & Hazeldine, 2020).

To examine what difference it makes if we apply our carefully worded rubric to the design of a prompt for GenAI, we first chose a big question where many disciplines have something to say. The question is, ‘What does it mean to be alive?’. For this test, we used Gemini (Google, 2024), and we prompted firstly with the question alone and secondly with a rewording that applied the rubric:

Prompt: What does it mean to be alive?

Being alive means to exist and function as a living organism. It involves essential processes like growth, development, reproduction, and responding to stimuli. Additionally, it often includes subjective experiences like thoughts, feelings, and sensations. The exact definition can vary depending on individual perspectives and beliefs.

Turning now to a more complex prompt designed to support EI Search, here is Gemini’s response to ‘What does it mean to be alive?’ selecting four disciplines on the Discipline Wheel:

EI Search prompt sent to Gemini:
'What does it mean to be alive? Give an answer from each of art, science, theology and history. For each discipline, give a preferred question, its methods to answer it, and its norms of thought'

Discipline	Preferred question	Methods	Norms of thought
Art	What is the essence of human existence as depicted in art?	Analysis of artistic works, such as paintings, sculptures, and literature	Subjectivity, creativity, emotional expression, and cultural context
Science	What are the biological processes that define life?	Scientific experimentation, observation, and data analysis	Objectivity, empirical evidence, testability, reproducibility
Theology	What is the purpose of human life according to religious or spiritual beliefs?	Religious texts, philosophical inquiry, and personal reflection	Faith, spirituality, divine purpose, moral values
History	How have human conceptions of life and its meaning evolved over time?	Historical research, analysis of primary and secondary sources	Contextual understanding, critical thinking, evidence-based analysis

Via a series of experiments along the lines of this one, we became confident that GenAI and, particularly, Large Language Models (LLMs) can support a technological leap and a new search experience. We envisaged a search tool that develops users' interdisciplinary epistemic insight by explaining that many disciplines can approach and address the same question; we envisaged developing users' disciplinary epistemic insight into science, mathematics, geography, and so on by providing pen portraits by GenAI of how each of these individual disciplines works.

4 Designing a Version of EI Search for Secondary Schools

4.1 Part One: Curriculum Context

The previous section explained that we can harness GenAI to provide 'pen portraits' of the ways that different disciplines approach the same question. It works because disciplines are fundamental to how scholarly knowledge is constructed, tested, and agreed upon—and because different disciplines create knowledge in different ways. This section builds a theoretical case that using EI Search will help young people to achieve goals that are widely seen as essential for their education. We also recognise that if EI Search is to have positive impacts in school education, it will also need to engage children's interest, protect them from harmful content, and interact positively with teachers' expectations and goals. Our route to meet these criteria included bringing teachers, students, and other stakeholders into the design team.

The rationale for prioritising our empirical work on working with secondary school education at this point in our research stems firstly from urgent calls by curriculum bodies internationally to give students the critical thinking skills they need to tell the difference between knowledge and misinformation when they read content online (Cooper, 2023; Elliot, 2022; Zeidler et al., 2019). A considerable body of research has designed workshops for secondary school students that address those international curriculum aims. This includes research on SocioScientific Issues by Zeidler et al. (2019) and intervention studies by the Epistemic Insight Initiative Big Questions and Real-World Contexts (Billingsley et al., 2024). Workshops by these projects have helped students achieve the levels of scientific and digital literacy that international education systems expect. To plan these sessions, teachers across subjects met regularly, and students frequently had access to specialists in several disciplines. This is a costly option for schools and creates a hurdle that prevents some schools from participating. We anticipate that EI Search will help teachers to overcome this hurdle.

These rationales gave us three educational agendas to draw into a curriculum to teach students about the nature of knowledge in the age of GenAI. Table 1 gives each agenda a title, a set of questions, and assessable outcomes that indicate epistemic insight.

4.2 Bringing a Scholarly Mindset and Architecture of Knowledge into a Digital World

The Curriculum Framework in Table 1 has three columns for outcomes relating to epistemic insight. The activities are designed to help students develop a scholarly approach and mindset despite pressures and conversations that ebb and flow in a moment. It recognises the importance of helping students to appreciate the rigour and reliability of disciplines like science to counter misinformation. At the same time, students may be expected to know that knowledge is never fixed and certain and changes over time (Taber, 2017). The Epistemic Insight Curriculum Framework combines these goals by explaining that scholars do not make changes lightly and some aspects of knowledge are more firmly established than others. Van den Besselaar and Heimeriks (2001, p. 707) take a similar approach of clustering and comparing in a characterisation of disciplines, which is that 'Researchers within a speciality communicate more with one another than with researchers in other communities and they are expected to refer to one another's work significantly more frequently than to the work of outsiders'.

The learning objectives are arranged from starter to advanced. Students begin to develop epistemic insight by learning to 'think like a scientist', 'think like a geographer', and so on. Schools, university campuses, and libraries are described as multidisciplinary arenas, places where many disciplines are present. Students planning an enquiry can select one, two, or many disciplines to explore, seeing the question through their different lenses (Billingsley et al., 2024).

4.3 Asking and Exploring big Questions in an Awesome but Polarised World

This column recognises that students' curiosity about the nature of knowledge can be stimulated by discovering that different people and places engage with a complex question from different perspectives. The objectives are designed to help teachers develop this curiosity by introducing the language and structure of disciplines alongside a recognition that students are likely to hold their own beliefs and culture. On the Discipline Wheel, there is a petal called 'theology and religious studies'. We chose this wording to acknowledge that religion is not of itself a scholarly discipline and that scholars studying religions are typically in departments for theology and religious studies. Furthermore, the disciplines on the paper and interactive versions of the Discipline Wheel can be edited by teachers to make them more relevant for their settings.

Exploring a big question through the lenses of two disciplines from 'opposite' sides of the Discipline Wheel, such as science and history or science and theology/religious studies, can be an eye-opener for students and teachers in education systems that operate with firm boundaries between subjects (Chappell et al., 2022). Primary school students in England have used the Discipline Wheel to explore 'You are what you eat—or are you?' and 'What

Table 1 Developing students' epistemic insight in the age of GenAI

Level	Investigating complex real-world questions through science and other disciplines	Bringing a scholarly mindset and architecture of knowledge into a digital world	Asking and exploring big questions in an awesome but polarised world
Starter	I can explain with an example that science begins by making and talking about observations in the natural world I can explain with an example that historians come up with ideas by finding and talking about testimonies, letters and artefacts from the past	I can explain to a teacher or librarian that our school is a multidisciplinary arena I can use a Discipline Wheel to help me investigate a question like 'Why did the Titanic sink?' by thinking like a scientist and thinking like a historian I can use a Discipline Wheel to help me explore 'What is colour?' though	I can appreciate and explain that different people and places have different ways to ask and explore a big question I can ask and explore big questions like 'what makes me, me?' and 'Why do we have rules?'
Intermediate	I can co-create a role play to explain that real-world questions like 'Can a robot be a scientist?' 'Why do we see the world in colour' and 'How do we design healthier cities?' cannot be resolved through one discipline alone	I can talk with a teacher or librarian about designing a multidisciplinary enquiry I can use a Discipline Wheel to help me analyse a complex question like 'Why do we love chocolate?' and 'What is a sunset?' through the lenses of different disciplines I can explain with examples that different disciplines have different preferred questions, methods and ways to justify a good answer	I can work in a multidisciplinary group to explain that many disciplines and cultures have something to say about big questions, such as, 'What does it mean to be alive?' 'Why does water matter' and 'What is art?'
Advanced	I can explain with examples that some questions are more amenable to science than others I can use an example such as 'What is love?' or 'Why do some people feel lonely' to explain that scientism is not a necessary presupposition of science I can work in a multidisciplinary team to address a real-world question, such as 'Why do we play games?' and 'Can science cure loneliness with a pill?'	I can create a guide to explain that a library is a multidisciplinary arena I can use a Discipline Wheel to help me plan a multidisciplinary enquiry I can conduct interviews that help me to explain that knowledge and ways to organise knowledge are changing over time	I can work in a multidisciplinary team to explain that big questions seldom have simple, agreed-upon answers I can co-create a role play to explain that some questions are more metaphysically sensitive than others

makes me, me?' In lower secondary school, teachers who want to challenge assumptions that science or indeed any discipline alone can give a complete answer to a big question have chosen questions that students are likely to associate only with science, such as 'What is a sunset?' 'What does it mean to be alive?' and 'Why do we see in colour?' (Billingsley & Hardman, 2017). When the question, 'Why do we see in colour?' is entered into EI Search, the output aligns with the learning objective that multiple disciplines can contribute to an answer. In upper secondary school and university level, workshop participants have explored, 'Can a robot have a sense of curiosity?' 'Why do we exist?' and 'What is love?' (see, for example, Billingsley & Hazeldine, 2020; Chen et al., 2023).

4.4 Investigating Complex Real-world Questions Through Science and Other Disciplines

Workshops to teach interdisciplinary and disciplinary epistemic insight have invited students to research and explore real-world opportunities and problems such as: 'Will people ever live on Mars?' (Chappell et al., 2022) and 'Can a robot be a scientist?' (Billingsley et al., 2020).

The term SocioScientific Issues (SSI) has been coined by Zeidler et al., (2019) to explain that real-world problems are complex because they raise ethical issues alongside the need for evidence-based reasoning. SocioScientific Issues are carefully chosen examples of 'controversial problems' for society where students can wrestle with moral dilemmas that are 'personally relevant' to them (Zeidler et al., (2019, p. 2). The author explains that grappling with these issues is an opportunity to develop students' epistemic insight in the classroom and help them become confident, wise, and ethical members of society (Zeidler, 2024).

Real-world contexts have also been used to develop students' capacities to identify and address misinformation (see, for example Billingsley & Durbin, 2024; Billingsley & Nassaji, 2019). Misinformation is science education's greatest obstacle to learning and, some argue, for education in general (see, for example, Allchin, 2022; Osborne et al., 2023). The urgency is underscored by findings from Funk (2020), which indicate a waning public confidence in scientific expertise, potentially exacerbating the impact of misinformation. While misinformation is a complex issue, science-related sensationalism is a form of misinformation that works as a focus in workshops that have successfully taught epistemic insight. Billingsley and Heyes (2023, p. 337) explain that science-related sensationalism is where a scientific advance is hyped up 'to mislead the reader into supposing that it has more significance than it does'. Sensationalist headlines are used by some content providers as 'clickbait', boosting the time that visitors spend on their sites (Moser, 2014). Readers are drawn into the story by a surprising or shocking headline, such as 'Scientists develop a pill that will cure loneliness' (Billingsley & Heyes, 2023, p. 340) and 'Scientists discover a chatty gene' (Billingsley & Nassaji, 2019, p. 91). In the Curriculum Framework, learning objectives relating to this theme state that students should appreciate that 'scientism is not a necessary presupposition of science' at the advanced level and that 'complex real-world questions cannot be resolved through science alone' at the intermediate level.

Scientism, by contrast, is the belief that science is the only valid way to address questions. Mikael Stenmark (2025, p.8) explains that 'Advocates of scientism privilege science in all areas of life and are consequently suspicious of everything else'. Workshops to teach epistemic insight have encouraged students to recognise that scientism is not a necessary mindset if you want to become a scientist (Billingsley & Hardman, 2017). School workshops where students were given the Discipline Wheel to help them to critique sensationalist headlines successfully stimulated students' epistemic curiosity and boosted their readiness to ask critical questions when they encounter science-related sensationalism (see Billingsley & Durbin, 2024; Billingsley & Heyes, 2023; Billingsley & Nassaji, 2019). For example, in a workshop that examined a topical news story that a pill can 'cure' loneliness, students worked with a graphic of the Discipline Wheel to challenge the idea that a pill can affect a 'cure' (Billingsley & Durbin, 2024). Specialist guest experts helped students to call on medicine, geography, language and economics to say that pills may lift a patient's mood temporarily, but a longer-term solution means engaging with the underpinning causes of loneliness. These workshops required experts on hand to address questions about how different disciplines work. This created a format that can only happen occasionally at large-scale events for several schools at a time. We envisage EI Search becoming a tool that teachers can use in their classrooms to supplement and lead up to these large-scale events.

4.5 Preparing EI Search for Testing with Teachers and Students Aged 16 and Over for Phase Two

The prototype we designed for testing in Phase Three was designed for secondary school students. We held workshops for teachers, sixth formers, and other stakeholders in secondary school education to help us with the design. Another aim of these Phase Two workshops was to find out whether and how a version of EI Search that accesses GenAI directly would be useful to participants. The '16 plus' version of EI Search invites users to enter their own question, select disciplines (which they can edit), and submit a query to GenAI. EI Search returns pen portraits of the selected disciplines and two or more links to webpages that correspond to each discipline (Fig. 3).

4.6 Preparing EI Search for Testing with Students aged about 13 for Phase Three: EI Search with GenAI Unplugged

For Phase Three, we created a student-friendly version of EI Search called 'EI Search with GenAI-unplugged' (see Fig. 4).

This version of the application offers students a drop-down list of questions designed by their teachers, rather than giving them live access to GenAI.

This has several advantages. Firstly, it means that younger students are safeguarded from the risks and distractions of going directly to GenAI. Secondly, the student version can run locally on a computer or school network and does not require an Internet connection. Thirdly, teachers can customise the disciplines on the wheel and design a list of questions that align with their curriculum goals. They can also vet the responses by GenAI before they are presented to students. Fourthly, the same questions and responses can be used multiple times without sending prompts to GenAI, thus massively reducing the impact of GenAI on the environment in terms of energy use and water.

To prepare EI Search with GenAI Unplugged for testing in Phase Three, the research team took the role of teachers and created a drop-down list of questions. Most questions came from the workshops explained in the previous sections, and we checked they were fit for purpose by submitting them to the'16 plus' version of EI Search that sends prompts to GenAI. The tool was directed to get answers at the 'intermediate level', which corresponds to age 11–14. We designed a new question to stimulate curiosity about science-related sensationalism: 'Why do we love chocolate?' Searching the Internet using a conventional

Fig. 3 EI Search for 16 plus—a version that connects to GenAI

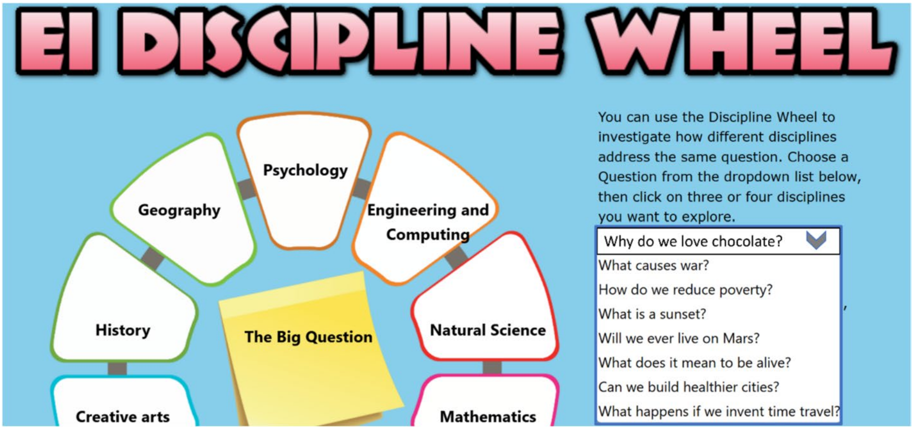

Fig. 4 EI Search with GenAI Unplugged for students

search engine returns some sites that answer by focusing exclusively on the scientific finding that eating chocolate releases brain chemicals associated with being in love (see, for example, BBC, 2017). However, as the responses produced by EI Search exemplify, science is not the only discipline with something to say. Seeing the question through a geographic lens reveals influences of international trade routes, and a historical view reveals our changing societal taste preferences over time. The questions we included for Phase Three are as follows:

- Why do we love chocolate?
- What causes war?
- How do we reduce poverty?
- What is a sunset?
- Will we ever live on Mars?
- What does it mean to be alive?
- Can we build healthier cities?
- What happens if we invent time travel?

We recommend that EI Search with GenAI Unplugged be used within a scheme of work created by a teacher so that students can share and develop what they find out by working on the questions further. On this occasion, we wanted to test the tool ‘on its own’ to discover the extent to which it is an intuitive, curiosity-driven, and agentic way to build epistemic insight, particularly disciplinary and interdisciplinary epistemic insight. We adapted the curriculum learning outcomes in Table 1 for this purpose:

1. I can use a Discipline Wheel to help me analyse a complex question through the lenses of different disciplines.
2. I can explain that real-world questions cannot be resolved through one discipline alone.
3. I can explain that many disciplines and cultures have something to say about big questions.
4. I can explain that different disciplines have different preferred questions, methods, and ways to justify a good answer.

5 Phase 2 and 3: Research Question

To what extent can EI Search take abstract ideas about the nature of knowledge and transform them into an intuitive, curiosity-driven, and agentic way to build epistemic insight, particularly disciplinary and interdisciplinary epistemic insight?

5.1 Methodology

This section outlines the research design and rationale, contextualises the study, details the procedures for data collection and analysis, and addresses ethical considerations.

a. Research Design

The research was conducted in three distinct phases, each contributing to the iterative development of the EI Search tool. This structured, phased approach recognised the complexities of educational contexts and the benefits of combining several distinct research activities where we are gathering data for different purposes and via different methods (Yanchar & Spackman, 2012). In keeping with design-based research, the phases were sequential, and each phase built on the insights gained from the previous one to draw ideas together and comprehensively address the research questions (Xu, 2022).

1. Phase One (described previously) involved the design and testing of prompts for GenAI by the research team to test hypotheses and finalise the design of the prompt that underpins the tool's functionality. This phase gave us confidence that, via a bespoke user interface powered by GenAI, we could provide an innovative way to develop users' disciplinary and interdisciplinary epistemic insight.
2. Phase Two consisted of co-creation workshops involving educators and sixth-form students. The purpose of this phase was to bring stakeholders together to provide suggestions and feedback in workshops that were led by a facilitator and designed to ensure a friendly and collaborative environment (Sillaots et al., 2024). Participants were given a demonstration of a prototype of the version of EI Search that has access to GenAI—so this is a '16 Plus' version (see Fig. 3). This was followed by discussions about ways to use the tool, its functionality, and the design. Participants also provided suggestions for the design of the version for school students, EI Search with GenAI Unplugged.
3. Phase Three recruited 24 secondary school students aged 13–14 from three schools. Students interacted with EI Search with GenAI unplugged for about 45 min. Surveys were administered at key points in the session to capture students' initial reactions, curiosity levels, and moments of epistemic insight while using the tool. We also asked about their attitudes toward using the tool beyond the session. Observations were also recorded to triangulate with the survey data to capture the energy and dynamics within the classroom. Thirdly, follow-up interviews with two students provided deeper insights into their experiences and the ways in which they engaged with the tool.

b. Ethics

Ethical approval for the research was sought and obtained from Swansea University's ethics committee. Ethical matters were examined in a weekly team meeting and as they arose. Permission forms and information sheets were distributed to participating adults and the parents and teachers of students and students. Information sheets explained that taking part is voluntary, how to withdraw from the study, and that participants can skip interview and survey questions they do not want to answer. We also explained that real names would be removed or replaced with synonyms during analysis of the data, aligning with BERA and other ethical research standards (Mertens, 2015). We explained that a video camera would record some parts of the day, and that participants could take part in the activities without being filmed and that taking part in filming was optional.

Ethical considerations included ensuring teachers were present with students, there was time for breaks, and participants were encouraged to ask questions. Key materials, including an edited video and interview transcripts (with no real names), were shared for approval with teachers shortly after the events. Once approved, edited videos and research highlights were disseminated via project websites and conferences to encourage interest and engagement with the research. The edited video and other resources and materials created during the project were uploaded to the open research platform, Zenodo. This dissemination and ethical framework is designed to maintain the integrity of the research process while adhering to the principles of social constructionism, which emphasise the collaborative nature of knowledge construction (British Educational Research Association (BERA), 2018; Parmaxi & Zaphiris, 2015).

5.2 Co-creation Workshops (Phase Two)

Participant selection for this phase combined convenience, purposive, and snowball sampling methods (Cohen et al., 2011). We emailed our research network, which includes schools, academics, and educators in a range of professions. Eight professionals, including teachers, were invited to a co-creation workshop that we held in the morning. This was followed by an afternoon of optional project-related activities for a wider group of invited stakeholders, including teachers. Additionally, three secondary school teachers were invited to bring a colleague and a small group of sixth-form students who have carried out independent research using the Internet, books and other resources. This gave us eight participants for a parallel co-creation workshop for sixth-form students.

These stimulus questions guided participants:

- EI Search is a new search tool that has a Discipline Wheel for its interface. It is designed to explain what makes disciplines distinctive and how disciplines can work together to answer questions. Would that be useful? Why or why not?
- What additional or replacement functionality would you like?

In workshop 1, a researcher took notes while the facilitator ran the session. In workshop 2, school students responded to the stimulus questions using a feedback form. Asking for anonymous written responses encourages comments from students who feel reluctant to voice their ideas (see, for example Rea & Parker, 2014).

5.3 Findings and Analysis for Phase Two

The data analysis methods aligned with the different kinds of data and the different purposes of each phase (Cowles & Nelson, 2019). Phase Two gathered qualitative data via co-creation sessions, and the research team focused on identifying ways to improve the prototype for testing with students in Phase Three.

Eight stakeholders participated in focus group 1 for educators (see Table 2), and eight students participated in focus group 2 (see Table 3). Five of the students were studying the National Curriculum in England, which has a subject-based curriculum, while three students studied the International Baccalaureate, which emphasises epistemic knowledge and the characteristics of different disciplines.

The eight educationalists in focus group one referred mostly to ways that students could use EI Search, with some comments on how the tool can assist with planning and a couple of comments relating to self-development (see Table 1). The feedback included a change to help users coming to the tool for the first time and another to support teachers using the tool for planning. We made both of these changes, for example, adding an animation that 'lights up' the petals in the Discipline Wheel if the user submits a question with no disciplines selected.

Students' responses to these stimulus questions tended to address the first research question—about the potential for EI Search to support and empower agentic learning.

Table 2 Educators' perceptions of uses of EI Search

Profession in relation to the project	Ways to use EI Search
Commissioner of education technologies for a public broadcaster	EI Search is a different kind of search experience which encourages exploration and serendipitous discovery. It reminds me of when I was a child, spending time with an encyclopaedia and dipping into pages that caught my interest
Three secondary School teachers from EI research schools	This will make a vast difference to planning cross-curricular sessions. We can use this in our collaborative curriculum planning in school Older students could investigate a question using EI Search before conducting their own web search. It would help them with where to look for their research Can you add an option to see the search results without the colours and boxes to make it easier to copy and paste into planning documents? Teachers could have a computer running EI Search in 'kiosk mode' at open Ddays so that parents can see what we are doing Can you animate the wheel to capture attention if someone has not selected disciplines when they press submit?
Two primary school teachers from an EI research school	Having a Discipline Wheel you can click on is going to get children very interested We can use this tool when we plan our big question day events. We ran a day on 'What makes me me', and gave the children paper versions of the Discipline Wheel to see how many ways they can answer. With this interactive version, we can ask children to help us design investigations for each discipline and compare our ideas with the ideas we get from the wheel Epistemic insight emphasises questioning and enquiry skills. EI Search matches this because it focuses on explaining enquiry in each discipline
Two university tutors	EI Search can give students a deeper understanding of their own disciplines as well as each other's. It might spark conversations among staff across departments—it would be interesting to see which modules are looking at similar ideas Masters students would also benefit from something like this—they could learn about each other's disciplines as preparation for collaborating on an interdepartmental project on sustainability

Students described how they would use EI Search for their own purposes while emphasising how this tool behaves differently from those they already have (see Table 2). Students suggested adding a way to change the level of the responses, and we added this to the version of the tool that sends prompts to GenAI.

Table 3 Students' proposed uses of EI Search

Agentic learning	Illustrative comments
To see a problem or opportunity associated with one discipline through the lens of another	Yes, as you can draw parallels from different perspectives. For example using philosophy ideas about logic to approach questions about quantum physics, 'convergence of thinking' You can get a variety of perspectives, which helps you to avoid (or minimise) subjectivity
To filter and focus	I would use this to filter search results by certain categories Yes, because depending on the subject scope you decide to filter your information, different websites will appear.' (Yes) for filtering and tuning into areas of greater interest' Yes, sometimes questions are really broad and ambiguous, so this new search engine would help with them 'Really useful, as it gives us more data to consider and a broader view on the topic that we are searching'
It can be used both to narrow the focus of an enquiry and widen the view	Yes, I may look up topics for one discipline and receive topics for others, so this would be incredibly useful for me as a student Yes, it can be useful to search for something within a specific discipline or across multiple disciplines
Generally, when carrying out research	Yes! As a student, I very often have research work to do; therefore, such a tool is a necessity
Suggestions for changes or additional functionality	Can you customise the academic level, e.g. switch between university level and secondary school level?

5.4 Phase Three: Testing EI Search with Students

Phase Three tested a version of EI Search for secondary school students, called 'EI Search with GenAI Unplugged'. Our approach to recruiting schools focused on finding three schools that have not already used our resources—to assess the extent to which EI Search is intuitive, curiosity-driven and agentic. To recruit schools, we advertised an outreach event for students aged 13–14 about digital technologies to partnership schools of a university in South-East England. The advert announced a workshop with VR headsets as an incentive and a workshop to explore a new computer-based tool. We selected the first three schools to apply to and noted that these schools were all state-funded and in communities associated with economic hardship, perhaps because well-resourced schools have more access to VR headsets. Working with schools in communities associated with economic hardship. We saw this as valuable, as these schools are often underrepresented in educational research and less likely to have access to enriched epistemic learning experiences. The selection of students was made by teachers using guidelines provided by the research team designed to balance genders, abilities, and backgrounds (McChesney & Aldridge, 2019).

The workshop took place in a computer lab so that students had a computer each. A facilitator welcomed them and kept the introduction in keeping with our aim to test the extent to which EI Search is intuitive and self-explanatory. The facilitator explained that the students would be testing a new interactive, and the research team would like feedback, which is voluntary and anonymous. Students were told that feedback questions would be presented at intervals in the session, and we would prompt them to switch windows when a new question was ready. Our brief to teachers was to support any students who seemed to be unhappy with the experience, and we also gave a reminder to everyone in the room that teachers and a facilitator are on hand if anyone wants to ask for help. We were prepared that if most students seemed confused after ten minutes, the facilitator would intervene with suggestions, or if a few students were unclear, they could be individually supported.

The workshop design and ethics approval opened the way for observations to be recorded by the research team and for video 'snapshots' to be recorded by a videographer approaching students who agreed to be filmed. These records can be studied for indications of how students interacted with EI Search and whether they understand its purpose without directions.

5.5 Survey Design

In alignment with our research question, the survey was designed to test the extent to which EI Search takes abstract ideas about the nature of knowledge and transforms them into an intuitive, curiosity-driven and agentic way to build epistemic insight, particularly disciplinary and interdisciplinary epistemic insight.

If EI Search is intuitive, we expect most students to explore and discover its purpose without directions from the facilitator and to build their understanding of the tool over time. To test this, survey questions were presented at different points in the session, with question one appearing a couple of minutes into the students' workshop time and asking, 'What are your first reactions when you see EI Search?' We moved around the room to check that students had found the survey, and once they submitted a response, we watched for the screen to flick back to the Discipline Wheel, after which the response cannot be changed.

Questions 2 and 3 were timed to appear together 20 min into the session. Students were told there were five minutes to respond but to tell us if they needed more time.

- Q2. Did EI Search spark your curiosity, and if so, how?
- Q3: What do you think you'll learn or discover while using EI Search?

These questions were designed to look for epistemic curiosity and epistemic insight. Out of curiosity, we expected students to wonder how disciplines and the central question might connect. We anticipate that some students will be drawn to one or more disciplines that particularly engage their interests, which in turn could build their disciplinary epistemic insight. We expected some others could be more 'free-spirited', combining disciplines to see what they get or testing the limits of the tool by clicking on disciplines they expect will have no connection. This, in turn, could build interdisciplinary epistemic insight.

The last question, question 4, was designed to broaden the scope of the survey to include agentic learning not only while using the tool but also relating to why use the tool at all. The question was, 'How could you use the Discipline Wheel in your studies?'. The question was promoted to students 30 min into the session.

To maximise the precision of the instruments and analysis, we mostly focused on direct rather than exploratory questions to test our hypothesis, and we took a deductive approach for our analysis. Closed questions asking for 'yes/no' answers were typically followed by 'please explain' to gather more insight and to address the possibility that students say 'yes' simply to please us.

5.6 Analysis Methodology

The survey was voluntary, and students could skip questions—but on this occasion, all 24 participants returned surveys with a response and comment for every question. This opened the way for a more detailed analysis of students' comments than we expected. We sorted the responses into two sets of 12 by alternation. Referring once again to our research question for the aims of the study, the first author designed an analysis rubric that explained how to code and categorise responses. The author and a researcher worked independently to code and categorise the data using the rubric for the selected 12 students for the first question (see Fig. 5).

The coders met and found complete agreement, continued to analyse the remaining 12, following the rubric. When we met again after coding all 24 students, we found that we were in agreement for all but one student. We chose Cohen's Kappa to convey intercoder reliability for the study because it is well-established in research, accounts for chance agreement and works with two coders (Richards, 2020).

5.7 Formula: Cohen's Kappa (κ)

- $\kappa = (p\_o - p\_e)/(1 - p\_e)$
- **p_o** = Proportion of observed agreements
- **p_e** = Proportion of expected agreements by chance

$\kappa \leq 0$: No agreement,
0.01–0.20: Slight.
0.21–0.40: Fair.
0.41–0.60: Moderate.
0.61–0.80: Substantial.
0.81–1.00: Almost perfect.

Establishing strong intercoder agreement would indicate that the coding is clear, transparent, and transferable, that different researchers can consistently apply the codes. For question 1, the coders agreed 23/24 times with two categories, corresponding to $\kappa = 0.92$, almost perfect.

We next coded the data using the rubric for the 12 students for each of the other survey questions. In our next meeting, we compared our categorisations, and we also discussed our emerging understanding of students' wider perceptions and experiences. This meeting indicated agreement in all but one point, and this was how we each understood agentic learning. One coder was focused only on comments by students about their activity while using the tool. In contrast, the other coder understood illustrations of agentic learning to also include comments students made about how they could use the tool to support projects and enquiries in school. We decided on a broad view where being agentic with EI Search includes reasons to use EI Search at all, as well as agency in practice, using the tool. We updated the rubric accordingly.

EI search analysis rubric

QUESTION 1: "What is your initial impression of this?"

We designed the tool to be self-explanatory. We will track their understanding of its purpose during the session. For first impression we hypothesise they will appreciate it's something to do with 'knowledge', see theory section on epistemic curiosity.

ANALYSIS RUBRIC – 2 categories,

- Do they realise that it's something to do with exploring knowledge eg anything about disciplines, knowledge, knowledge relationships, opinions, etc – record as 'E' for epistemic.
- Do they react to the appearance eg colourful, cool, basic – record as 'A'
- If the comment covers both then record 'E'.
- If it's ambiguous, record X

After coding 12 alternatively selected.

What is your initial impression of this?	Rater 1	Rater 2
very basic not pleasing to the eye	A	A
Looks a bit weird.	A	A
i think it looks cool	A	A
It seems intriguing and I wish to know and understand more about this.	X	X
includes many discipline choices to choose from, but the colours aren't very aesthetically pleasing	E (a)	E
looks cool	A	A
its interesting to see what each discipline will answer the question	E	E
a wheel which shows what you might discipline	E	E
I think it looks complicated however i can see that the big question can cover all categories and aspects of that specific question.	E	E
its a wheel that you are able to explore and talk to/ask questions aswell as choose a certain topic that is may answer with.	E	E
its interesting to see how each discipline will answer the questions	E	E

Fig. 5 Extract from coding notes following the rubric

5.8 Analysis Methodology: Interviews

Interviews were transcribed and coded, and the emerging themes were triangulated with themes we found in the survey. Testing our original hypotheses and being open to unexpected findings kept us actively engaged with examining the data, in line with an interpretivist paradigm, where researchers deepen their understanding of participants' experiences by becoming immersed in the data and looking for insights in the contexts of a theory-driven research design (Johnson & Onwuegbuzie, 2004).

5.9 Findings: Observations

Our analysis of the observations recorded during the session indicated that the energy level in the room stayed positive throughout. We noted that some students initially submitted a question without selecting disciplines—duplicating the issue identified in the co-creation workshop—and the Discipline Wheel 'petals' lit up with a note to choose disciplines, which students then did. A few minutes into the session, a researcher asked a student, 'What do you suppose the tool is doing?' and the student responded, 'Is it just so people can kind of get like understanding of different mindsets and different thought processes?' The observer took about 20 min moving systematically from student. On her second pass, she noted that a teacher had pulled a chair closer to two students and was listening to their conversation, which could correspond to behaviour management or an interest in how students were interacting. She also noted that all the students were engaged in exploring the tool until the session ended. No additional guidance was requested or provided.

5.10 Survey Responses

5.10.1 Survey Question on First Reactions to EI Search

In response to Question One, twelve students gave responses that indicated they understood the epistemic purpose of the tool. The intercoder reliability $\kappa = 0.92$, almost perfect.

Some of these students made comments that indicated they had picked up that the tool is epistemic, but beyond this, said they felt puzzled: 'I think it looks complicated; however, I can see that the big question can cover all categories and aspects of that specific question'. There were also students who were already probing the relationships between the 'petals' and the central question: 'You put a question in and it should answer it in different approaches'; 'it's interesting to see how each discipline will answer the questions'.

We categorised the other twelve students' reactions as non-epistemic. We referred to Litman and Spielberger (2003), who contrast epistemic curiosity with perceptual curiosity, and this helped to distinguish between the categories. Ten students made comments that were focused on the appearance of the tool, such as 'looks cool' or 'looks basic'. We included in this non-epistemic category comments that were ambiguous or vague. One student's comment could have been a perceptual reaction to the sizes of graphics or an epistemic reaction to the sizes of the areas of knowledge (disciplines) on the wheel: 'the first thing that comes to mind is all the things on the wheel are very big.' Another student was puzzled but gave no indication at this stage of understanding its purpose, 'It seems intriguing and I wish to know and understand more about this.'

5.10.2 Survey Question on Curiosity

Twenty minutes into the session, students were presented with the second and third questions. The second question was, 'Did EI Search spark your curiosity and if so, how?' Twenty-one of the 24 students explicitly wrote yes, and all 21 also gave explanations. Our analysis rubric for this question has four categories. The first is for students who did not say they experienced curiosity, coded as 'N'. The second is for students expressing curiosity that is non-epistemic, coded as 'A'. Next is epistemic that is not disciplinary/interdisciplinary (E), and finally, disciplinary/interdisciplinary curiosity (ED).

Alongside those expressing curiosity, three students' comments were explicitly negative, saying 'no' and 'it did not'. Nineteen students who said yes were sub-categorised as having epistemic curiosity (E), and two students were categorised as not having epistemic curiosity (A). An example of a student's comment that was categorised as not epistemic is, 'the bright colours intrigued me'. The responses by 17 students expressing epistemic curiosity were coded as ED—expressing disciplinary and/or interdisciplinary epistemic curiosity, two students' responses were categorised as epistemic but not disciplinary/interdisciplinary epistemic curiosity (see Table 4). The intercoder reliability was 100%, which was aided by students writing 'yes' or 'no' ahead of their comments.

We did not distinguish between disciplinary and interdisciplinary epistemic curiosity in our coding because the comments are individual, and there is the potential for some comments to reference more than one motivation. Instead, we agreed that the tool stimulated examples of both types of epistemic enquiry and chose a selection of illustrative examples.

5.10.3 Examples of Comments that Indicate Interdisciplinary Epistemic Curiosity

Among the students who said that EI Search provoked their curiosity, the anticipation of getting different 'perspectives' on a question was frequently highlighted: 'It did spark my curiosity because the questions were intriguing and it made me want to see lots of perspectives on it.' 'Yes, I was looking at how different mindsets process different questions'. Many of the comments indicated curiosity mixed with surprise at what the tool revealed: 'It sparked my curiosity because I never knew how many different sides of a question you can get'.

5.10.4 Disciplinary Epistemic Curiosity

A smaller proportion of students made comments that related to disciplinary epistemic curiosity. These students explained that they focused on exploring disciplines that they named as particularly interesting to them, 'it sparked my curiosity as it showed psychology's point of view which I am interested in' 'I love learning about random facts to do with the world (science) so when one of the chosen questions was about a sunset i got really interested as to how it happens'.

Two students expressed both forms of epistemic curiosity by identifying disciplines that interest them and how to bring them together: 'It did spark my curiosity because there were perspectives on some subjects I was interested in, such as psychology, English literature and theology. I also like to learn about different viewpoints on several things, so that was nice'. 'Yes, because it told me everything about how things happen historically and physically'.

Several students in this category also expressed surprise, saying that disciplines addressed question where they did not expect a connection: 'It did as I didn't expect certain questions to be thought of from certain subjects' viewpoints' and 'Yes, it made me curious about how even subjects that we think to be irrelevant to the question can still be connected to it, and can still be used to create an answer'.

Table 4 Q2. Did EI Search spark your curiosity, and if so, how?

Yes			No (N)
21 students			3 students
Non-epistemic, e.g. perceptual (A)	Epistemic curiosity (E)		
A: 2 students expressed curiosity but not epistemic: 'the bright colours intrigued me'	E: 2 students expressed epistemic curiosity, but not disciplinary/interdisciplinary, 'yes, helped me learn a lot'	ED: 17 students expressed disciplinary and/or inter-disciplinary epistemic curiosity. Yes, it made me curious about how even subjects that we think are irrelevant to the question can still be connected to it, and can still be used to create an answer	Students' comments were 'No' and 'No, it did not'

5.11 Survey Question 3: What do you Think you will Learn or Discover While Using EI Search?

We followed the analysis rubric for this question, which identified three categories. We coded comments as A for non-epistemic (2 students), E for epistemic but not necessarily disciplinary/interdisciplinary (4 students) and ED for comments that demonstrated disciplinary and/or interdisciplinary epistemic insight (18 students) (Tables 4, and 5). The coders disagreed on one item—moved to the bottom of the list. The intercoder reliability was almost perfect, $\kappa = 0.94$.

Table 5 Results for question 3, what do you think you will learn or discover?

What do you think you will learn or discover while using the Discipline Wheel?	
Something useful	A
I do not know	A
I think I will learn how AI can be advanced even in the early stages	E
Why do people learn certain things?	E
I want to learn more about the way humans think unconsciously, things that even we aren't aware of. However, human thinking is complex, and I am worried that the AI, being artificial, may not comprehend our feelings as an impassive being	E
How AI works together with search engines	E
How people view different subjects in different ways	ED
To help us see how different people view things	ED
I think I'll discover many views and perspectives	ED
The wheel is about investigating the different perspectives of different occupations on the same questions. I think that learning about different points of view is important because it offers insight and ultimately results in a more open mind	ED
The way in which certain subjects or groups of people may see things in similar or contrasting ways	ED
Different subjects have different opinions	ED
I think I will discover how different people from each subject think	ED
I think the Discipline Wheel will show how various topics can link and overlap, and demonstrate the connections between people and how they think in relation to the topics	ED
The different ways you can approach a question with different aspects of subjects	ED
Learn to be more open-minded and learn different views	ED
I can divers people and how the world works	ED
I think that I will learn how all subjects can correspond to one question. Or that you have to find a question that can correspond to all the categories in the wheel	ED
I think that I could learn that 1 question could be answered in so many different ways, according to how different people think	ED
learn to be more open-minded because of different viewpoints	ED
I think I will learn how the world works in the eyes of different people	ED
How different subjects are able to overlap, and how thought processes differ	ED
I think we may begin to understand how many things are able to link into the causes and answers of our questions about the habits and things present within our lives that we may potentially be present in too	ED
How to explore and venture further into a question, and to create an efficient response and theory	ED [E]

Table 6 Extent to which students' engagement with EI Search is epistemic at key points

Q1. A few minutes into the session		Q2. 20 min into the session	
It looks fascinating, and I would like to experiment with it	A	I think the Discipline Wheel will show how various topics can link and overlap, and demonstrate the connections between people and how they think in relation to the topics	ED
Very basic, not pleasing to the eye	A	How people view different subjects in different ways	ED
It looks quite basic	A	I think I will discover many views and perspectives	ED
It seems intriguing, and I wish to know and understand more about this	A	The way in which certain subjects or groups of people may see things in similar or contrasting ways	ED
Not very aesthetically pleasing	A	How to explore and venture further into a question, and to create an efficient response and theory	E
Looks a bit weird	A	How AI works together with search engines	E
When I see this, I do not really understand it due to the question not really linking to the topics	A [E]	I think I will learn how the world works in the eyes of different people	ED
Strange name, simple	A	I do not know	A
I think it looks cool	A	something useful	A

Although our analysis rubric categorised comments as ED for both disciplinary and interdisciplinary epistemic insight, the comments by all 18 students in this category are examples of interdisciplinary epistemic insight.

We compared students' responses to questions 1 (first reactions) and 3 (what will you learn) (see Table 5). For question 1, a few minutes into the session, the comments by ten students were non-epistemic. After 20 min, eight of these ten students had moved to epistemic, with five students expressing disciplinary/interdisciplinary epistemic insight. As Table 5 sets out, there were no students who moved from epistemic (question 1) to non-epistemic (question 3).

5.12 Survey Question Q4: How Could you use the Discipline Wheel in your Studies?

The final question, question 4, was presented about 30 min into the session. The responses illustrate the individuality and range of students' responses. At this point, the focus for analysis is to look for evidence that the student sees the tool as valuable for exploring disciplines at all, across the questions. In our rubric, we brought questions 3 and 4 together and coded ED for yes and (U) for unclear or other. The code ED covers exploring multiple disciplines together (interdisciplinarity) and probing an individual discipline. When we looked across both questions, the two coders agreed on the outcome, with 23 students meeting the criterion.

Table of results for questions 3 and 4: What do you think you will learn or discover? How could you use the Discipline Wheel in your studies?

Q3 What do you think you will learn or discover while using the Discipline Wheel?		Q4 How could you use the Discipline Wheel in your studies?		In one or both
How people view different subjects in different ways	ED	To find out different questions and answers about that subject	ED	ED
To help us see how different people view things	ED	To help answer any difficult questions	U	ED
How AI works together with search engines	U	When using the Wheel in my studies, I can narrow down my searches by subject. I could use it to inspire an experiment that I could conduct	ED	ED
I think I will discover many views and perspectives	ED	You could give the discipline wheel a focus question and use the information it provides to support answers in your work, and the other questions it gives to make you think more broadly	ED	ED
Something useful	U	Homework	U	U
The wheel is about investigating the different perspectives of different occupations on the same questions. I think that learning about different points of view is important because it offers insight and ultimately results in a more open mind	ED	With a wider variety of questions you could ask, it would be very helpful to understand different perspectives depending on what subject you are doing. It would be useful to differentiate answers as well	ED	ED

Q3 What do you think you will learn or discover while using the Discipline Wheel?		Q4 How could you use the Discipline Wheel in your studies?		In one or both
The way in which certain subjects or groups of people may see things in similar or contrasting ways	ED	It could help in studies by generating answers to certain questions, based on the topics required	ED	ED
Different subjects have different opinions	ED	In your studies, this could be helpful because it gives you a short and simple answer to use within your studies	U [ED]	ED
I think I will discover how different people from each subject think	ED	Be used to compare different subjects	ED	ED
I think the Discipline Wheel will show how various topics can link and overlap, and demonstrate the connections between people and how they think in relation to the topics	ED	I could use the wheel to look at different perspectives of a question, or use it to help make a base structure or base answer to build a final answer from, especially if the question is quite abstract or difficult to answer initially	ED	ED
I think I will learn how AI can be advanced even in the early stages	U	I could select psychology and get the specific answer that I wanted	ED	ED
The different ways you can approach a question with different aspects of subjects	ED	The wheel could help me understand how things happen, why they happen, and how I can apply them to my subjects, for example my art	ED	ED
Learn to be more open-minded and learn different views	ED	If I want to find something out, I can just ask	U	ED
I do not know	U	To make my research subject specific. It links subjects to questions	ED	ED
Why do people learn certain things?	U	It could tell you how to explain things mathematically	ED	ED
I can divers people and how the world works	ED	About geography and how mountains are made	ED	ED
I think that I will learn how all subjects can correspond to one question. Or that you have to find a question that can correspond to all the categories in the wheel	ED	It would be very useful for my studies because I have taken business studies for my GCSE, and I believe that if I were asked a question, I would know the answer to however, they may ask for the business side of that, and the discipline wheel would help me with that	ED	ED
How to explore and venture further into a question and to create an efficient response and theory	U [ED]	Yes, it would be particularly helpful when creating a thesis for an answer or for an essay to gain a greater understanding of other perspectives and viewpoints on a question	ED	ED

Q3 What do you think you will learn or discover while using the Discipline Wheel?		Q4 How could you use the Discipline Wheel in your studies?		In one or both
I think that I could learn that 1 question could be answered in so many different ways, according to how different people think	ED	It could help you evaluate your answers to questions, but also help you with things you're less experienced in	ED	ED
I want to learn more about the way humans think unconsciously, things that even we aren't aware of. However, human thinking is complex, and I am worried that the AI, being artificial, may not comprehend our feelings as an impassive being	U	I could use it to inspire an experiment that I could conduct	ED	ED
Learn to be more open minded because of different viewpoints	ED	If, for example if it is asking for the different impacts of something, you can see all the different ways it would impact things, e.g. psychologically and geographically	ED	ED
I think I will learn how the world works in the eyes of different people	ED	How are countries formed?	E	ED
How different subjects are able to overlap, and how thought processes differ	ED	As it would be able to answer questions in different subject contexts	ED	ED
I think we may begin to understand how many things are able to link into the causes and answers of our questions about the habits and things present within our lives that we may potentially be present in too	ED	Studies can be helped and developed by the answers within the discipline wheel as it may help provide context of how various subjects and learning projects or things within	ED	ED

5.13 Interviews

Two students from different schools participated in post-intervention interviews, selected by their teachers. Both were age 13 (year 9). Their names have been replaced with pseudonyms.

The interviewer asked Della how she worked out the purpose of the tool and whether it was a mystery at first. Della said, 'At the start, I was just kind of, yeah, just kind of experimenting with all the different things and what you can do with it. I didn't really know what to do at the start, but then I gradually found out how it can all be connected'.

Della told the researcher that her first choice of question was, 'Why do we like chocolate?' and that she was struck by the diversity of disciplines and that, 'I think you can't sometimes you can't realise how things like all things from diverse natures are connected […] It helps you connect, connect them up and see how they can be related to each other and see how actually everything can connect to the question. So, like, chocolate helps the industry develop, helps economic growth. But you wouldn't initially think that. You just think chocolate is something. You kind of take it for granted in a way, and you don't think of how many people it can affect and how many things it can affect'.

Della explained that she liked sciences and arts and noted that the tool boosted her awareness of the boundaries around disciplines and their interconnectivity, 'you can kind of find boundaries between them both and where you want to, and how you want to develop throughout within both the artistic side and the academic side'.

The second interviewee, Adam, also explained that his choices were directed by his interests and that he worked through a series of questions to discover how theology responded to each of the questions. Adam's interest in theology was partly motivated by his own theological and cultural questions: 'I like sort of the idea that, although people believe there is a higher power, it's like being able to push and challenge those ideas. And in RE we don't just focus on one religion, there are multiple, so it's nice to take in everything that people, like, believe and want to believe and why people don't believe it and how they go about their practices, how they pray and things like that. It's just really interesting'. Adam also linked his choices to his future career, 'So I want to be a medic in the RAF', and 'if I meet someone with, like, a religious or a certain type of background, I can sort of discuss with them appropriately, like, in the situation of work. I don't offend or do anything or say anything wrong to them'. Thirdly, Adam's choices were directed towards subjects he saw as his strengths, saying of religious education, 'it's just a subject I really enjoy at school and something I do really well'.

6 Discussion Drawing Across the Datasets for Phase 3

Phase 3 was designed to test the extent to which EI Search takes abstract ideas about the nature of knowledge and transforms them into an intuitive, curiosity-driven and agentic way to build epistemic insight, particularly disciplinary and interdisciplinary epistemic insight.

Twenty minutes into the session, the vast majority of students said that the tool had engaged their curiosity in the potential of disciplines to give them new perspectives on a question. Soon after, after 30 min of exploring without instructions, 23 of the 24 students had identified and explored the intended function of the tool to develop their disciplinary and/or interdisciplinary epistemic insight.

The most significant epistemic insight across the group is where students highlight the impact on their own attitudes to knowledge and an excitement at becoming more curious and 'open-minded' about where solutions can come from. Student 10 said the EI Search 'made me curious about how even subjects that we think are irrelevant to the question can still be connected to it, and can still be used to create an answer'. Student 6 highlighted the value of becoming open-minded, 'I think that learning about different points of view is important because it offers insight and ultimately results in a more open mind'. Della, talking about chocolate, said, 'You kind of take it for granted in a way, and you don't think of how many people it can affect and how many things it can affect'.

Throughout the analysis, we kept the code ED for comments where students said they were exploring multiple disciplines together and those where they probed a selected discipline. The findings suggest that students are mostly expressing a curiosity to find out how disciplines connect. However, this activity also develops their understanding of each discipline they select by giving insights into how they differ and are distinctive. Della combined science disciplines and arts and said, 'You can kind of find boundaries between them both and where you want to, and how you want to develop throughout within both the artistic side and the academic side'.

Students mostly refer to the tool providing 'perspectives' on a question. 'Perspectives' is used by several students in the combined responses to questions 3 and 4. Discipline is used less often, with two of these uses referring to the 'Discipline Wheel'. In the classroom and in a longer piece of research, we could explore the impact of the tool on students' use of scholarly terms.

Earlier, we identified learning outcomes in the Epistemic Insight Curriculum for this age group that could be developed in a class workshop. We reviewed students' comments to find illustrations of how EI Search can enhance these workshops (see Table 7).

Student 5 explored the tool without seeing its purpose and consistently made vague comments, such as that it was 'useful' and would help with homework. We observed all the students to ensure they were enjoying the experience. Outside our 'lab conditions',

Table 7 Connecting learning outcomes by students using EI Search with classroom activities

Workshop EI outcomes	Illustrative comments
I can use a Discipline Wheel to help me analyse a complex question through the lenses of different disciplines	I think that I could learn that 1 question could be answered in so many different ways, according to how different people think (student 19)
I can explain that real-world questions cannot be resolved through one discipline alone	Learn to be more open-minded because of different viewpoints; if, for example if it is asking for the different impacts of something, you can see all the different ways it would impact things, e.g. psychologically and geographically (student 21) You could give the discipline wheel a focus question and use the information it provides to support answers in your work, and the other questions it gives to make you think more broadly (student 4)
I can explain that many disciplines and cultures have something to say about big questions	The wheel is about investigating the different perspectives of different occupations for the same questions, I think that learning about different points of view is important because it offers insight and ultimately results in a more open mind (student 6) Interview with Della: 'chocolate helps the industry develop, helps economic growth. But you wouldn't initially think that. You just think chocolate is something… You kind of take it for granted in a way, and you don't think of how many people it can affect and how many things it can affect' 'I like the idea that although people believe there is a higher power, it's like being able to push and challenge those ideas. And in RE we don't just focus on one religion, there's multiple, so it's nice to take in everything that people, like, believe and want to believe and why people don't believe it and how they go about their practices, how they pray and things like that. It's just really interesting'. (Adrian, Interview)
I can explain that different disciplines have different preferred questions, methods and ways to justify a good answer	I could use it to inspire an experiment that I could conduct (student 3)

teachers would have more opportunity to connect the session to work happening in the classroom and provide additional guidance where needed.

7 Discussion of the Three Phases

The research question for this study is, ‘To what extent can EI Search take abstract ideas about the nature of knowledge and transform them into an intuitive, curiosity-driven and agentic way to build epistemic insight, particularly disciplinary and interdisciplinary epistemic insight?’.

Alongside our goal to provide a tool for this purpose, we have also expressed our commitment to the UNESCO principles of human-centred design (UNESCO, 2023). This put a constraint on the design of the tool: that it must supplement and extend teachers’ agency and not undermine or replace them. Similarly, it must engage students’ curiosity and encourage them to explore new ways to enquire and not reduce their sense of wonder and undermine their zest for exploration. In the classroom and particularly at the secondary school level, subject teachers tend to focus on building and sharing their expertise in one or two disciplines at the expense of building and sharing expertise in others. EI Search enhances teachers’ agency by supplementing their skills in this area. We anticipate that working with the tool to plan and deliver lessons can also boost teachers’ interdisciplinary epistemic insight, but that will be tested in future research. Based on the findings here, teachers who add EI Search to their pedagogies have a new way to stir students’ curiosity about how disciplines work and deliver agentic learning whereby students’ interests and goals are actively shaping how their learning goes (Iwuanyanwu, 2024).

In Phase 1, we took a stance that what matters when students search for knowledge goes beyond providing them with answers. We emphasised that when people use search tools online, there is an opportunity and arguably an imperative to develop their appreciation of the ‘architecture of scholarly knowledge’—to replace experiences that are at risk of disappearing, like knowledge-seeking in a library. In Phase One, we showed that searching the Internet with a conventional search engine creates a list of resources that prefer scientific answers. We can explain this and other sources of disciplinary bias towards scientism by contrasting online searching with searching in a library where the resources are limited and curated. EI Search is modelled on the Discipline Wheel, a graphic that displays different fields of knowledge to build users’ epistemic insight and criticality when they create a search. We explained our basis for supposing that GenAI can facilitate our goal by highlighting that ‘knowledge about knowledge’ is embedded in scholarly content through the processes via which it is created and demonstrated how to prompt GenAI to make abstract connections between disciplines and questions into concise and accessible explanations. We combined this with an interface for searching that directs the user to choose which disciplines to engage. Phase 3 provided evidence that students were indeed discovering and challenging ideas they held about which and how many disciplines can inform our understanding of a complex question.

In Della’s interview about the question, ‘Why do we love chocolate?’ she says, ‘I think you can’t sometimes you can’t realise how things like all things from diverse natures are connected … just think chocolate is something. You kind of take it for granted in a way, and you don’t think of how many people it can affect and how many things it can affect’. The survey comments provide many more examples of the way that EI Search can open students' minds to disciplines they have tended to overlook and inspire new ways of thinking (Chen et al., 2023).

7.1 Agentic Learning

To test whether the tool works for users in the ways we intend, Phase 2 sought feedback from people who could potentially use and promote the tool. Phase 3 sought to test a version of the tool for schools, EI Search with GenAI Unplugged.

Across the studies with students in the two phases, through surveys and interviews, we discovered more about what motivated their choices. Della said she clicked on disciplines on opposite sides of the Discipline Wheel to see perspectives from the sciences and humanities brought together because she is interested in both subjects. Several students, including Adam, moved through the topics, selecting just one or two disciplines each time to get a deeper understanding of a particular discipline, with examples being psychology and theology. He explained that his explorations with EI Search were supporting his personal curiosity about the nature of God and his social curiosity about how to be sensitive to other people's faith positions.

Students in both phases explained that the tool could inform a broader research theme, such as how expertise in different disciplines relates to industry. Students are bringing their holistic selves—they are embodied agents—when they engage with the tool (Belland et al., 2020). EI Search is not thinking for them or giving students a direct embodied experience, but they bring to it their holistic selves, and that means that with the tool, they have a new way to think about questions that matter in society and that interest them (Lyons et al., 2015; Ponton, 2021).

8 Conclusion

Via this study, we launched a new research agenda to explore ways to use GenAI to enable students to grasp the abstract nature of knowledge.

At the start of this paper, we raised the question: Is there a case for organising knowledge into disciplines and explaining how disciplines work if GenAI chatbots can dynamically respond to users' questions by gathering fragments of knowledge, assimilating them alongside the prompt and returning to users with tailored responses? This study has concluded—yes—at least for now. The distinctive languages, questions, methods and contexts of disciplines make scholarly knowledge contextual and meaningful. Once disciplines become visible to us, we can examine them, choose which we apply to new questions and combine them creatively.

The arrival of GenAI is driving the creation of search tools that invite users to present their queries in everyday language. We are concerned that while search tools get 'smarter', our students are missing out on experiences that can help them to be more epistemically insightful. Without sight of disciplines and an education that builds epistemic insight, knowledge-seekers relinquish their capacity to be critical of the answers that chatbots give them. To give an analogy, our students are standing in the foyer of a virtual library with the lights off, while the AI navigates the layout and discovers the architecture of scholarly knowledge. The creation of EI Search is motivated by a learner-centred educational agenda that speaks to the UNESCO (2023) principles of human-centred AI. EI Search combines a novel interface with responses generated by GenAI to help users make better decisions and enhance education rather than replace it.

Looking forward, we envisage developing search tools for school and university students that build their appreciation and capacity to think critically about their own discipline and the value of bringing together their own and other students' disciplines. We will test the impacts of these tools in programmes that aim to bring students with different specialisms together to learn and apply multidisciplinary ways of working.

We also proposed that GenAI can be the innovation that opens new ways to engage with knowledge, unavailable to us before. The research question we asked is, 'To what extent can EI Search take abstract ideas about the nature of knowledge and transform them into an intuitive, curiosity-driven and agentic way to build epistemic insight, particularly disciplinary and interdisciplinary epistemic insight?' The findings from Phase Three demonstrate that EI Search stimulates epistemic curiosity, teaches epistemic insight and opens students' eyes to the power of multidisciplinary enquiry. After playing with the tool for a few minutes, many students commented that EI Search prompted a new sense of curiosity that they had not experienced before: 'It sparked my curiosity because I never knew how many different sides of a question you can get'. 'I didn't expect certain questions to be thought of from certain subjects' viewpoints'. Furthermore, this grasp of intangible invisible concepts to do with how disciplines are characterised and how they relate was not limited to a few students; it was 'across the board' in a sample of 24 school students with only one exception. The foundations for this type of thinking were built prior to this study. The agency of selecting disciplines on the Discipline Wheel and the pen portraits of disciplines returned by GenAI brought students' metaknowledge into view.

Students in Phase Two have previously worked with a paper version of the Discipline Wheel and explained how they could use EI Search to help with projects they do at school. However, across the two phases, students' comments are more often about using EI Search to discover the sides or perspectives that different people take. When we asked whether EI Search is useful, the reason given by a majority is that being open and empathetic to other people's positions is an important competency they will need in their careers and everyday lives. This finding emerged from the research and was not one of our original hypotheses. In the next section, we explain how we plan to take this and other findings forward.

9 Recommendations

9.1 For Schools and Colleges

For students aged 13 and above, we recommend a wholescale rethink and redesign of the search tools that are made available in schools and colleges. This research gives a basis to say that it is unreasonable to confine students to tools that limit their intellectual development and lead them to expect a simple answer to a question. Students demonstrated that once they have the right tools, they can and want to devise their own inquiries and test ideas about how disciplines work. Students using EI Search demonstrated epistemic curiosity, independence, and critical thinking. This paves the way for a future where teachers incorporate EI Search into lessons designed to help students become alert to and critical of sensationalist claims and other forms of misinformation. Given the importance of these 'skills for life', it seems reasonable to say that the provision and embedding of tools to support them should be universal.

In practice, there are ways to introduce EI Search which use a graphic interface (the Discipline Wheel) but vary in the extent to which students are supervised and/or are accessing the Internet. This study demonstrated EI Search with GenAI Unplugged, where the teacher designs the experience around a few questions which are made available to students. EI Search could also be linked to a school library via a bespoke Large Language Model for schools. This would address concerns about quality and enable teachers and librarians to strengthen the links between students' digital and physical experiences.

Children in primary school could learn about searching through a teacher-led activity where the EI Search is displayed on the interactive whiteboard.

9.2 Sixth Form and Teachers

For older students who access the Internet, we recommend that students use EI Search to support independent research and interdisciplinary projects, particularly when preparing for extended essays or university-level study. These opportunities were identified by the research participants, who reported that they benefited from seeing how disciplines differ and overlap.

We also recommend that EI Search be regularly used in teacher education and to support in-school curriculum planning and professional development. Teachers reported that working with EI Search deepened their understanding of their own discipline and fostered cross-curricular collaboration.

9.3 Policy

At the policy level, we recommend that searching online should be recognised as an epistemic activity, where students learn not only how to find information but how to understand its disciplinary origins and evaluate it accordingly. EI Search prioritises education over efficiency in keeping with the UNESCO (2023) principles of human-centred design. It also capitalises on the speed and flexibility that GenAI can offer to deliver on the OECD's vision for creating agentic learners. Policymakers and funders have a model now that can pave the way for more tools that promote and develop students' appetites for collaboration and their appreciation of working with people who have expertise and perspectives that vary from their own.

10 Future Research

10.1 Research in Schools

In further research, we will continue to develop and test ways that EI Search can help teachers to equip students with the knowledge and attitudes they need to address big issues for society. EI Search for teachers is designed to empower teachers with the epistemic insight they need to plan activities that overcome the constraints of their own specialisms. This approach embeds our commitment to create tools that enhance education (including teacher education) and enrich and strengthen human agency, and our alignment with the goals of human-centred AI (UNESCO, 2023). We are also keen to test our hypothesis that EI Search can support classrooms that prioritise learning about individual subjects as well as those that prioritise holistic thinking (Cobb et al., 2003).

These different priorities can be taken to educators, including teachers and informal learning facilitators, to get their input as stakeholders co-developing how it works (Garcias et al., 2024; Lawson et al., 2024).

The workshops we provide for teachers will address how to plan sessions that combine EI Search with activities that take place in their classrooms. This will include class discussions about how EI Search works that examine its strengths and limitations. For users to engage with GenAI ethically and creatively, they will need to understand something about how it works. The use of GenAI to power EI Search helps to make the point because as questions become more precise or unusual, the data available to the AI diminishes, increasing the likelihood of spontaneous and untested connections that scholars might reject (Niemi et al., 2023). To address this weakness, we could add complexity to the prompt and instruct GenAI to order the responses so that disciplines with a lot to say on a question are nearer the top of the list. However, another option is to ask users to reflect on the strengths and weaknesses of the tool and specifically to question whether some of GenAI's connections are 'thin on the ground'. We will continue to use an open-access platform, Zenodo, to make the code and prompts available and transparent so that EI Search can be adapted to different purposes.

10.2 Research to Create Spinoffs from EI Search

EI Search is a search engine that emphasises the nature of knowledge. However, many of the students using EI Search welcomed it as a way to gain insight into the perspectives that different people take. The possibility that GenAI and an interface like the Discipline Wheel can also become a tool to foster greater social harmony may emerge as one of the most exciting discoveries we made by doing this research. The functionality of EI Search is set by the design of the interface, the interactivity and the rubric that words the prompt. The versatility of each of these means that we can use the same setup to create many other scenarios. The petals on the interface could show faces and offer the user a choice of different moods (happy, nervous, thoughtful, and so on). Clicking on 'Jokey' and 'Miserable' with a question like, 'What is the weather today?' could give users insight into the influence of mood on the language people use. The interactivity of the interface means that users can again take an abstract concept and understand it better through their own agency and experimentation. Using our current study as a model, some students might focus on understanding 'angry' better by selecting it and then moving through multiple questions, while other students might want to step into and compare moods on opposite sides of the wheel.

Conventional search tools and GenAI interfaces offer users one portal for their question—a visual that fosters the view that the tool responds with 'one voice'. The interface for EI Search removes the illusion that GenAI is a single mind and instead gives users agency to control the voice or voices. GenAI can also generate fictitious dialogues between personas. So we can imagine the wheel displaying different notable figures from history and/or mythology, and the user selecting two or three to see them debating a question that the user also selects. Once again, a conversation about the strengths and limitations of the tool would be an essential aspect of the student's education. In this case, the output is a fictitious conversation between people who may be separated by centuries. At the same time, the interactive could be useful in history lessons to give students insight into how cultural attitudes change over time.

10.3 Research in Higher Education

Research in Higher Education brings the benefit that many institutions, including our own, give students institutional access to GenAI. Research projects underway include piloting a GenAI interactive called 'the Icebreaker tool', designed to help students from different courses to find shared interests quickly. The Icebreaker tool is based on the Discipline Wheel and has the same underpinning framework of 'interface, interactivity and prompting rubric for GenAI. Students from dance and computer science used the Icebreaker tool to prepare for a one-off workshop to explore ways and reasons why their professions can work fruitfully together (Hazeldine et al., 2024). In other workshops, we have used the Icebreaker tool to generate stimulus materials for students of medicine and economics, featuring GenAI fabrications of debates and conversations between professionals in each field.

Our plans for further research in Higher Education include a project to create 48-h 'hackathons' where small groups of students come together to work in interdisciplinary teams and co-create solutions to challenges that relate to the Sustainable Development Goals (SDGs). Creating future citizens who can meet the SDGs is prioritised internationally but is challenging to make happen in practice in today's schools and universities (Garcia, 2023). EI Search lends itself to encouraging interdisciplinary explorations of issues for society, such as mental health, transport, space exploration and sustainability. By running workshops that make use of tools like EI Search, we hope to bridge silos and open participants' minds to new perspectives and different questions to ask. Furthermore, we will look at whether adding the concept of epistemic insight can provide a new way to measure and track the learning gains that students make.

Our plans for thematic hackathons include inviting students to co-create GenAI applications based on the Discipline Wheel and EI Research. Students will have a limited time to design and review GenAI applications designed to improve people's lives in different communities and age groups. The use of challenge-based learning in hackathons resonates with our ambition to encourage creativity, ethical ways of working, and interdisciplinary collaboration. As such, these events hold out the prospects of students gaining skills and insights that have positive impacts for their own development, alongside innovative outputs that have impacts for society that we cannot imagine today.

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Data Availability There is a video about EI Search, with clips from the student workshop, at https://zenodo.org/records/13966690. Additional resources, research tools, and data relating to this project, and the Epistemic Insight Initiative more widely, are available on the Zenodo website at https://zenodo.org/communities/epistemic-insight/.

Declarations

Ethics approval Ethical approval for this study was obtained from the Humanities and Social Sciences Research Ethics Committee of Swansea University (2 2024 12149 11412).

Conflict of interest The authors declare that they have no conflict of interest.

References

Allchin, D. (2022). Ten competencies for the science misinformation crisis. Science and Education, 1–14. https://douglasallchin.net/papers/Allchin-2022-10-Competencies.pdf

Beck, U. (2013). *Risk society: Towards a new modernity*. SAGE Publications. https://archive.org/details/risksocietytowar0000beck

Belland, B. R., Weiss, D. M., & Kim, N. J. (2020). High school students' agentic responses to modeling during problem-based learning. *The Journal of Educational Research, 113*(5), 374–383. https://doi.org/10.1080/00220671.2020.1838407

Berlyne, D. E. (1954). A theory of human curiosity. *British Journal of Psychology, 45*, 180–191. https://doi.org/10.1111/j.2044-8295.1954.tb01243.x

Billingsley, B. (2024). Epistemic insight search engine. *Zenodo*. https://doi.org/10.5281/zenodo.13966690

Billingsley, B., & Hazeldine, L. (2020). Shattering the subject silos: Learning about big questions and epistemic insights. *Impact: Journal of the Chartered College of Teaching*, (9). https://impact.chartered.college/article/shattering-the-subject-silos-big-questions-epistemic-insight/

Billingsley, B., & Durbin, S. (2024). Cultivating epistemic agents as critical consumers of information. In B. Billingsley, K. Chappell, & S. Simpson (Eds.), *The future of knowledge: The role of epistemic insight in interdisciplinary learning* (pp. 21–38). Bloomsbury.

Billingsley, B., & Hardman, M. (2017). Epistemic insight and the power and limitations of science in multidisciplinary arenas. *School Science Review, 99*(367), 16–18.

Billingsley, B., & Heyes, J. M. (2023). Preparing students to engage with science- and technology-related misinformation: The role of epistemic insight. *The Curriculum Journal, 34*(2), 335–351. https://doi.org/10.1002/curj.190

Billingsley, B., & Nassaji, M. (2019). Exploring secondary school students' stances on the predictive and explanatory power of science. *Science & Education, 28*, 87–107. https://doi.org/10.1007/s11191-019-00031-7

Billingsley, B., Nassaji, M., Fraser, S., & Lawson, F. (2018). A framework for teaching epistemic insight in schools. *Research in Science Education, 48*, 1115–1132. https://doi.org/10.1007/s11165-018-9788-6

Billingsley, B., Simpson, S., & Abedin, M. (2020). Why did the Titanic sink? Bridging two disciplines to teach epistemic insight. *School Science Review, 101*(376), 25–29.

Billingsley, B., Riga, F., Gordon, A. J., & Windsor, M. (2024). Embedding epistemic insight (EI) in teacher training programmes in English universities: barriers and how to overcome them. *Teacher Development, 28*(2), 195–214. https://doi.org/10.1080/13664530.2023.2236056

Billingsley, B., Grzes, M., & Annetta, L. (2025). The future of knowledge: Conversations about artificial intelligence and epistemic insight. *Science & Education, 1–3*. https://doi.org/10.1007/s11191-025-00636-1

Braidotti, R. (2013). Posthuman humanities. *European Educational Research Journal, 12*(1), 1–19. https://doi.org/10.2304/eerj.2013.12.1.1

Bransford, J., Stevens, R., Schwartz, D., et al. (2006). Learning theories and education: Toward a decade of synergy. In P. Alexander & P. Winne (Eds.), *Handbook of educational psychology* (pp. 209–244). Lawrence Erlbaum Associates.

British Educational Research Association. (BERA) (2018). *Ethical guidelines for educational research*. https://www.bera.ac.uk/publication/ethical-guidelines-for-educational-research-2018

Chappell, C. R., Dhami, M. K., Bitter, M. C., Czech, L., Herrera Paredes, S., Barrie, F. B., Calderón, Y., Eritano, K., Golden, L. A., Hekmat-Scafe, D., Hsu, V., Kieschnick, C., Malladi, S., Rush, N., &

Fukami, T. (2022). Wide-ranging consequences of priority effects governed by an overarching factor. *eLife, 11*, e79647. https://doi.org/10.7554/eLife.79647
Chen, Y., Jensen, S., Albert, L. J., Gupta, S., & Lee, T. (2023). Artificial intelligence (AI) student assistants in the classroom: Designing chatbots to support student success. *Information Systems Frontiers, 25*, 161–182.
Clarke, S., Billingsley, B., & Heath, L. (2024). Big questions and interdisciplinary learning: Issue 1. https://zenodo.org/records/12205280
Cobb, P., Confrey, J., diSessa, A., Lehrer, R., & Schauble, L. (2003). Design experiments in educational research. *Educational Researcher, 32*(1), 9–13.
Cohen, L., Manion, L. and Morrison, K. (2011). *Research Methods in Education*. Oxford: Routledge.
Cooper, G. (2023). Examining science education in ChatGPT: An exploratory study of generative artificial intelligence. *Journal of Science Education and Technology, 32*(3), 444–452.
Cowles, E. and Nelson, E. (2019). *An introduction to survey research, Volume II: Carrying out the survey.* (2nd ed.) New York: Business Expert Press
Elliot, L. (2022). AI ethics and the generational transition from digital natives to AI natives. *Forbes* (12 June). https://www.forbes.com/sites/lanceeliot/2022/06/12/ai-ethics-and-the-generational-transition-from-digital-natives-to-ai-natives-growing-up-amidst-pervasive-ai-including-ubiquitous-self-driving-cars/
Erduran, S. (2022). Too philosophical, therefore useless for science education? *Science & Education, 31*(3), 563–567.
Felix, C. (2020). The role of the teacher and AI in education. In E. Sengupta, P. Blessinger, & M. Makhanya (Eds.), *International Perspectives on The Role of Technology in Humanizing Higher Education* (pp. 33–48). Emerald Publishing Limited.
Fishkin, R. (2016). Keeping Up With SEO in 2017 & Beyond, Accessed 8 September 2024 www.slideshare.net/slideshow/keepng-up-wth-seo-n-2017-beyond/67488664#11
Funk, C. (2020). Key findings about Americans' confidence in science and their views on scientists' role in society. PewResearch Foundation. https://pewrsr.ch/2Hgq31S
Garcia, M. B. (2023). Fostering an innovation culture in the education sector: A scoping review and bibliometric analysis of hackathon research. *Innovative Higher Education, 48*(4), 739–762.
Garcias, A. P., Mesquida, A. D., Rodríguez, J. C., & Ferrer, G. T. (2024). Creation of a protocol for designing didactical processes to promote agentic students. In *EdMedia+ Innovate Learning* (pp. 747–753). Association for the Advancement of Computing in Education (AACE).
Google. (2024). *Gemini*. https://gemini.google.com/app
Google. (2025). *Gemini*. https://gemini.google.com/app
Green, D. & Pearson, J.. (2011). Integrating website usability with the electronic commerce acceptance model. *Behaviour & IT, 30*, 181–199. https://doi.org/10.1080/01449291003793785
Hazeldine, L., Bentley, K., Pickard, A., & Callaghan, A. (2024). Dancing with the Digital: an 'EI' workshop designed to bridge disciplines and spark students' epistemic creativity. *The future of knowledge: The role of epistemic insight in interdisciplinary learning*, 143.
Heikkilä, M., Hermansen, H., Iiskala, T., Mikkilä-Erdmann, M., & Warinowski, A. (2023). Epistemic agency in student teachers' engagement with research skills. *Teaching in Higher Education, 28*(3), 455–472.
Iwuanyanwu, P. N. (2024). Enhancing teacher agentic learning in physics education: The impact of cognitively guided instruction on prospective teachers' science and technologies facilities council cognitive engagement. *Indonesian Journal of Science and Mathematics Education, 7*(3), 421–436.
Jiang, D., Zhang, R., Guo, Z., Wu, Y., Lei, J., Qiu, P., ... & Li, H. (2024). Mmsearch: Benchmarking the potential of large models as multi-modal search engines. arXiv preprint arXiv:2409.12959.
Johnson, R. B., & Onwuegbuzie, A. J. (2004). Mixed methods research: A research paradigm whose time has come. *Educational Researcher, 33*(7), 14–26. https://doi.org/10.3102/0013189X033007014
Kitchener, R. F. (1983). Cognition, metacognition, and epistemic cognition. *Human Development, 26*(4), 222–232. https://doi.org/10.1159/000272885
Lawson, F., Colley, S., & Billingsley, B. (2024). Approaching STEAM via inquiry-based responses to big questions: how "epistemic insight" changes informal science learning. Information Age Publishing
Lewandowsky, S., & van der Linden, S. (2021). Countering misinformation and fake news through inoculation and prebunking. *European Review of Social Psychology, 32*(2), 348–384. https://doi.org/10.1080/10463283.2021.1876983
Litman, J. A., & Spielberger, C. D. (2003). Measuring epistemic curiosity and its diversive and specific components. *Journal of Personality Assessment, 80*(1), 75–86.
Litman, J., Hutchins, T., & Russon, R. (2005). Epistemic curiosity, feeling-of-knowing, and exploratory behaviour. *Cognition and Emotion, 19*(4), 559–582.

Lyons, L., Tissenbaum, M., Berland, M., Eydt, R., Wielgus, L., & Mechtley, A. (2015). Designing visible engineering: supporting tinkering performances in museums. In *Proceedings of the 14th International Conference on Interaction Design and Children (IDC '15)* (pp. 49–58). Association for Computing Machinery. https://doi.org/10.1145/2771839.2771845

Martzoukou, K., Kostagiolas, P., Lavranos, C., Lauterbach, T., & Fulton, C. (2021). A study of university law students' self-perceived digital competences. *Journal of Librarianship and Information Science, 54*(4), 751–769. https://doi.org/10.1177/09610006211048004

McChesney, K., & Aldridge, J. (2019). Weaving an interpretivist stance throughout mixed methods research. *International Journal of Research & Method in Education, 42*(3), 225–238. https://doi.org/10.1080/1743727X.2019.1590811

Mertens, D. (2015). Research and evaluation in education and psychology: Integrating diversity with quantitative, qualitative, and mixed methods (4th ed.). Sage Publications.

Mishra, P., Warr, M., & Islam, R. (2023). TPACK in the age of ChatGPT and generative AI. *Journal of Digital Learning in Teacher Education, 39*(4), 235–251. https://doi.org/10.1080/21532974.2023.2247480

Moore, B., & Parker, R. (2021). *Critical thinking* (13th ed.). McGraw-Hill. https://www.mheducation.com/highered/product/Critical-Thinking-Moore.html

Moser, S. C. (2014). Communicating adaptation to climate change: The art and science of public engagement when climate change comes home. *Wiley Interdisciplinary Reviews: Climate Change, 5*(3), 337–358. https://doi.org/10.1002/wcc.276

Mosley, M. (BBC). (2017). The secret of why we like to eat chocolate. https://www.bbc.co.uk/news/health-39067088

Niemi, H., Pea, D. and Lu Y. (2023). A.I. in learning: Designing the future', New York, NY: Springer

OECD. (2025). OECD teaching compass: Reimagining teachers as agents of curriculum changes", *OECD Education Policy Perspectives*, No. 123, OECD Publishing, Paris, https://doi.org/10.1787/8297a24a-en.

Osborne, J. (2023). Science, scientific literacy, and science education. In N. G. Lederman, D. L. Zeidler, & J. S. Lederman (Eds.), *Handbook of Research on Science Education: Volume III* (1st ed.). Routledge. https://doi.org/10.4324/9780367855758

Osborne, J., Zucker, A. and Pimentel, D. (2023). Tackling scientific misinformation in science education. Graduate School of Education, Stanford University, Stanford, CA. https://sciedandmisinfo.stanford.edu/sites/g/files/sbiybj25316/files/media/file/tackling_misinformation_in_science_education_osborne_zucker_pimentel.pdf

Papert, S. (1981). Computers and computer cultures. *Creative Computing, 7*(3), 82–92.

Parmaxi, A., & Zaphiris, P. (2015). Developing a framework for social technologies in learning via design-based research. *Educational Media International, 52*(1), 33–46.

Pontin, F., Lomax, N., Clarke, G., & Morris, M. A. (2021). Socio-demographic determinants of physical activity and app usage from smartphone data. *Social science & medicine, 284*(1982), 114235. https://doi.org/10.1016/j.socscimed.2021.114235

Ponton, M. K. (2021). A teaching strategy based upon a model of agentic learning. *Journal of Studies in Education, 11*(1), 1–11. https://doi.org/10.5296/jse.v11i1.18125

Rea, L. M., & Parker, R. A. (2014). *Designing and conducting survey research: A comprehensive guide*. John Wiley & Sons.

Richards, L. (2020). Handling qualitative data: A practical guide, London: Sage

Roschelle, J., Lester, J. and Fusco, J. (Eds.) (2020) 'AI and the future of learning: Expert panel report', Digital Promise. https://circls.org/reports/ai-report

Selker, T. (2024) Future libraries' AI focusing on motivations to learn in Billingsley et al (eds) *The future of knowledge: The role of epistemic insight in interdisciplinary learning*, 87–98

Sillaots, P., Tammets, K., Väljataga, T., & Sillaots, M. (2024). Co-creation of learning technologies in school–university–industry partnerships: An activity system perspective. *Technology, Knowledge and Learning, 29*(3), 1525–1549.

Sky News. (2013). *Doomsday asteroid that could crash into Earth*. Sky News. https://news.sky.com/story/doomsday-asteroid-that-could-crash-into-earth-10458352. Accessed 28 July 25.

Snow, K. (2024). *A practical guide to dewey decimal classification*. Rowman & Littlefield.

Stenmark, M. (2025). Worldviews and Science, *Zygon: Journal of Religion and Science*. https://doi.org/10.16995/zygon.16582 Accessed 23 Feb 25

Taber, K. S. (2017). Reflecting the nature of science in science education. In *Science education: An international course companion* (pp. 23-37). Rotterdam: SensePublishers.

Taber, K. S. (2019). *Progressing science education: Constructing the scientific research programme into the contingent nature of learning science*. Springer.

UNESCO. (2023). *Guidance for generative AI in education and research*. https://unesdoc.unesco.org/ark:/48223/pf0000386693
Van Den Besselaar, P. (2001). The cognitive and the social structure of STS. *Scientometrics 51*, 441–460. https://doi.org/10.1023/A:1012714020453
Van den Besselaar, P., & Heimeriks, G. (2001). Disciplinary, multidisciplinary, interdisciplinary: Concepts and indicators. In *ISSI* (pp. 705–716). University of New South Wales.
Velasco, C., & Obrist, M. (2020). *Multisensory experiences: Where the senses meet technology*. Oxford University Press.
Wang, C. (2024). Exploring students' generative AI-assisted writing processes: Perceptions and experiences from native and nonnative English speakers. *Technology, Knowledge and Learning*. https://doi.org/10.1007/s10758-024-09744-3
Xu, B. (2022). Design-based research: A methodological toolkit for educational innovation. *Educational Technology Research and Development, 70*(4), 1021–1040. https://doi.org/10.1007/s11423-022-10103-3
Yanchar, S. C., & Spackman, J. S. (2012). Agency and learning: Some implications for educational technology theory and research. *Educational Technology* 3–13.
Zeidler, D. L. (2024). *A moral inquiry into epistemic insights in science education: Personal and global perspectives of socioscientific issues* (Vol. 61). Springer Nature.
Zeidler, D. L., Herman, B. C., & Sadler, T. D. (2019). New directions in socioscientific issues research. *Disciplinary and Interdisciplinary Science Education Research, 1*(1), 1–9. https://doi.org/10.1186/s43031-019-0008-7
Zong, Z., & Guan, Y. (2025). AI-driven intelligent data analytics and predictive analysis in industry 4.0: Transforming knowledge, innovation, and efficiency. *Journal of the Knowledge Economy, 16*(1), 864–903.

Authors and Affiliations

Berry Billingsley[1] · Sam Clarke[2] · Ted Selker[3]

✉ Berry Billingsley
Berry.Billingsley@swansea.ac.uk

Sam Clarke
s.clarke1@yorksj.ac.uk

Ted Selker
ted.selker@gmail.com

[1] Swansea University, Swansea, UK

[2] York St John University, York, UK

[3] Rochester Institute of Technology, Baltimore, MD, USA