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A phenomenographic approach to students' conceptions of learning artificial intelligence (AI) in secondary schools

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Abstract
AI education for K-12 students is an emerging necessity, and considering students' perspectives when developing effective AI education curricula in K-12 settings is essential. Few studies investigated secondary students' conceptions of learning AI. Phenomenography is an empirical research method widely used to understand students' conceptions of learning new phenomena. Therefore, we investigated students' conceptions of learning AI using a phenomenographic approach. 88 secondary school students in Hong Kong were invited to participate in an interview after implementing an AI curriculum in two batches. Six categories of students' conceptions were identified: (1) gaining awareness, (2) acquiring knowledge, (3) satisfying interest, (4) considering social impacts, (5) improving self-competency, and (6) seeing in a new way. The hierarchical relationships of the concepts were organized as an outcome space. The space shows a range of reproductive to constructivist conceptions and offers an understanding of how students perceive AI education through their learning experience. Theoretical, empirical, and practical implications are suggested for future AI education, providing insights for educators and policymakers to enhance curriculum alignment with students' goals and promote general AI education for K-12 students.

Keywords AI education for K-12 · Conceptions of learning · Students' conceptions of learning AI · Phenomenography

1 Introduction

AI has emerged as a transformative force across various sectors including education (Chai et al., 2024). Moreover the emergence of generative artificial intelligence (GenAI) such as ChatGPT has significantly transformed how people live learn and

Extended author information available on the last page of the article work (Belghith et al., 2024). To maintain competitiveness in an increasingly AI-infused society it is imperative for learners to acquire the necessary knowledge and skills related to AI (Baidoo-Anu & Ansah, 2023; Chai et al., 2024; Touretzky et al., 2019; Yang, 2022). Hence, equipping students with AI literacy has emerged as an important global strategic move to educate the next generation (UNESCO, 2022). It is also necessary for students to develop a productive perspective to learn about AI and learn with AI.

While there is a growing body of research on AI education much of it centers on the perspectives of educators and technologists (Chai et al., 2024; Yau et al., 2023). These studies provided essential information to academia policymakers and stakeholders to identify gaps in current AI education practices. However, the successful implementation of AI education requires a deep understanding of how students perceive and engage with this knowledge, i.e. students' conceptions of learning AI. Incorporating student perspectives on AI education ensures the effective development of K-12 AI education (Chai et al., 2020). For instance, a study examining primary school students' conceptions of learning AI revealed that students generally exhibited positive attitudes toward learning AI perceiving it as related to programming and robotics activities (Gao et al., 2024). Nevertheless, few studies have focused on secondary students' conceptions of learning AI. This gap highlights the need for a deeper exploration of students' conceptions of AI learning in secondary education.

Phenomenography is a widely acknowledged qualitative research method to investigate how a community perceives the conception of learning in emerging educational settings without predetermined conceptual frameworks (Åkerlind, 2008; Marton & Pong, 2005; Richardson, 1999). This method suggests that individuals' learning experiences are partial rather than entire and always related to a phenomenon. Researchers can develop a more comprehensive understanding of the phenomenon by gathering individual perspectives. Thus this method has been applied to investigate students' conceptions and identify them with a variety of conceptions (Chou et al., 2021 ; Lee et al., 2008; Tsai, 2004; Tsai et al., 2011).

AI education is an emerging field in secondary education, and the diversity of students' backgrounds influences their learning process of AI. This study aims to identify and categorize secondary students' conceptions of learning AI, providing insights for educators and policymakers to better align AI education with students' goals and needs. To achieve this purpose, the study addresses the following research questions:

1. What are the secondary students' conceptions of AI learning?
2. What are the variations of secondary students' conceptions of AI learning?

2 Literature review

2.1 AI Education for K-12 Education

To prepare younger generations for the future increasingly influenced by AI policymakers and educators are actively seeking pedagogical strategies (Dai et al., 2023). Notable initiatives were conducted in various countries and areas implementing national guidelines for AI education at K-12 levels (State Council of China, 2017; European Commission, 2020; UNESCO, 2022; Australian Government, 2023). Guided by policies scholars actively investigated key components of AI education from both teachers' and students' perspectives. Studies have explored teachers' intention and their continuous intention to teach AI (Ayanwale et al., 2022; Chiu et al., 2024a; Wu et al., 2025), as well as students' conceptions of AI (Demir & Güraksın, 2022), intentions to learn AI (Kim & Kwon, 2024), and their motivation for learning AI (Lin et al., 2021; Wang et al., 2024). These studies provide essential insights into the readiness and challenges that educators and students face, informing them of the development of effective educational strategies and resources.

Several new AI courses are being implemented to enhance K-12 education. Collaboration among primary computer science teachers has led to a curriculum emphasizing contextual learning (Dai et al., 2023), while the AI textbook covering topics like image and voice recognition has been piloted in multiple schools (Gao et al., 2024). For secondary school students, a comprehensive two-year AI curriculum has been developed in the European Union (Bellas et al., 2023), and a curriculum co-designed by educators industry experts and policymakers has advanced Hong Kong secondary AI education with students reporting increased AI knowledge (Chiu et al., 2022). Additionally, an AI literacy program for senior secondary students has been created enhancing their understanding of AI concepts (Kong et al., 2023). Collectively, these initiatives underscore the integration of AI education in K-12 curricula, fostering students to engage with the complexities of an AI-driven world. In light of this, research has examined teachers' conceptions of teaching AI (Lim, 2024; Yau et al., 2023), students' AI literacy (Chiu et al., 2024a), and students' conceptions of learning AI (Gao et al., 2024; Zhao et al., 2024). These studies are vital for understanding the impact of AI education on both student learning outcomes and teaching practices.

As an emerging cross-field, AI maintains the interdisciplinary nature that crosses a range of disciplines such as data science, mathematics, and linguistics (Knoth et al., 2024), and the characteristics of rapidly evolving and transforming (Zhan et al., 2024). The knowledge of AI is inherently dynamic and fluid incorporating various dimensions such as "see" (visual recognition) and "hear" (voice recognition and natural language processing) and updating frequently (Chai et al., 2024). Additionally the potential change for their future careers taken by AI may influence students' motivations and intentions regarding their AI education (Wang et al., 2024). Collectively, these factors suggest that students may adopt a more adventurous, diverse, and exploratory conception of learning AI. Exploring students' concepts of learning AI helps maintain a student-centered position in education, emphasizing the active role of learners in constructing knowledge. At the same time, this supports teachers in providing suitable scaffolds and designing appropriate curricula for future AI education.

2.2 Students' conceptions of learning AI

Contextualizing the definition of conceptions of learning by Tsai (2004), the conceptions of learning AI could be defined as "academic AI-specific epistemological beliefs". This term encompasses two key elements: academic epistemological beliefs which are students' beliefs about knowledge and learning in a school context and AI-specific epistemological beliefs reflecting students' views on the nature of AI. Understanding students' beliefs in AI courses is a prerequisite for ensuring student autonomy (Divjak et al., 2023).

The conceptions of learning can be generally categorized into two main categories: constructivist and reproductive or deep- and surface-level conceptions of learning (Chiou et al., 2012). The associated conceptions of learning AI can similarly be divided into these two categories. The constructivist or deep-level conceptions of learning AI with an emphasis on the construction of AI knowledge view learning AI as the active translation of external analyses into understandable and applicable knowledge (Gao et al., 2024). With constructivist conceptions, students are more likely to take the deep learning approach (Chiou et al., 2012, 2013). The deep learning approach is characterized by intrinsic motivations to actively and critically learn new concepts and knowledge, incorporate and apply prior knowledge to new situations, and consequently obtain high learning self-efficacy and better academic performance (Kember et al., 2004; Liang & Chou, 2012). In contrast, the reproductive or surface-level conceptions of learning AI with an emphasis on the repetition and regurgitation of AI knowledge, view learning AI as the passive accumulation of externally fragmented information (Chiou et al., 2013). With reproductive conceptions, students are more likely to adopt surface-learning approaches (Sadi, 2017), which are characterized by extrinsic motivations, passively and mechanically reproducing the learning materials and acquiring knowledge (Kember et al., 2004 ; Liang & Chou, 2012). The surface approach is usually associated with low self-efficacy in learning and poorer academic performance (Wang et al., 2017). These findings indicate students, as the end-users of AI education, their conceptions of learning AI could make a significant contribution to their approaches to learning AI, which consequently exerted an effect on their outcomes (Liang & Chou, 2012) and strengthen the need for probing different conceptions of learning AI held by K-12 students (Tsai, 2004).

While much attention has been given to students' conceptions of AI or AI-related topics (e.g., Antonenko & Abramowitz, 2023; Bewersdorff et al., 2023; Mertala et al., 2022), only a few studies are focusing on students' conceptions of learning AI. Gao et al. (2024) used drawing-based analysis to explore primary students' conceptions of learning AI, finding that primary school students generally held positive attitudes, understood learning AI as programming or robotics, and had some differences in grade and gender. Indeed, AI education should be expanded beyond programming and robotics, incorporating a wider variety of content and practical experiences to foster AI literacy among primary school students. On the other hand, Zhao et al. (2024) also used drawing-based analysis, revealing that junior high school students also viewed learning AI as teacher-centered programming activities in the classroom, and students held positive attitudes. These results suggested that exploring students' conceptions of learning AI could significantly reflect their beliefs and approaches to the subject and highlight their educational needs. However, the application of the phenomenographic method for exploring secondary students' conceptions of learning AI has not been explored yet. It is crucial and necessary to gain a deeper, comprehensive, and arranged understanding of secondary students' conceptions of learning AI.

2.3 Phenomenographic method

Phenomenography is a qualitative research methodology that originated within the domain of educational research. It aims to explore the qualitatively different ways in which individuals experience perceive and conceptualize a particular phenomenon in the world (Chou et al., 2021; Marton, 2014). Rather than focusing on individual differences in itself, phenomenography aims to uncover patterns of variation in how people understand a shared phenomenon, ultimately revealing a collective structure of meaning (Richardson, 1999). Besides, phenomenographic research does not aim to study vague or overly broad phenomena, nor does it seek to explain why people experience a phenomenon differently. Instead, it focuses on describing how people understand and make sense of the phenomenon itself.

At its core, phenomenography is grounded in the idea that human awareness is structured in terms of parts and wholes. Because individuals cannot attend to all aspects of a phenomenon simultaneously, their experiences are inherently partial, and variations in understanding arise from how individuals become aware of these aspects (Marton & Booth, 2013). Therefore, phenomenography underscores that any given phenomenon can be understood through a combination of multiple dimensions or aspects emphasizing the relational nature of experience and the importance of shifting focus from the individual alone to the dynamic interaction between the person and the phenomenon being studied (Åkerlind, 2023).

The findings of phenomenographic studies typically consist of two interrelated components: *meaning* and *structure*. *Meaning* refers to how individuals interpret or make sense of the phenomenon, while *structure* describes how these interpretations relate to one another. These two elements are closely intertwined: meanings emerge from awareness of structural aspects of the phenomenon and structural configurations give rise to meaning (Åkerlind, 2024). This dialectical relationship is reflected analytically in two key constructs: *categories of description* and the *outcome space* (Åkerlind, 2024). *Categories of description* represent how participants experience a phenomenon. For example, Luan et al. (2025) identified five categories in students' conceptions of environmental education, from "receiving information" to "solving problems and taking action". Each category captures a holistic and qualitatively different way of understanding the phenomenon. Meanwhile, the *outcome space* illustrates the hierarchical organization of these categories. It shows how comprehensive understandings encompass less inclusive ones, reflecting the progressive unfolding of experience. Importantly, this hierarchy does not imply superiority or developmental stages but rather increases inclusivity and breadth of perspective (Åkerlind, 2023). In the example above, the category "solving problems and taking action" includes "receiving information", demonstrating how a comprehensive understanding integrates previous levels of awareness.

Acknowledging that students perceive learning in diverse ways, phenomenographic research helps to identify and understand students' conceptions of learning in various areas by identifying the qualitatively different ways in which they experience and make sense of key concepts (e.g. Chen et al., 2025; Luan et al., 2025). By focusing on students' conceptions of learning, phenomenography promotes learner-centered pedagogy and helps educators align teaching practices with how students understand and engage with learning (Åkerlind, 2023). Furthermore, it encourages reflective teaching by revealing how students perceive educational practices and challenges educators to reconsider whether their methods foster deeper understanding (Chen et al., 2025). Besides, hierarchical outcomes can provide valuable insights that inform curriculum design, improve teaching practices, and ultimately enhance academic development programs (Chou et al., 2021; Marton & Booth, 2013). Adopting this approach to study secondary students' conception of learning AI is likely to contribute to the current efforts in equipping students with AI literacy as it enriches educators' understanding of a range of learners' experiences.

3 Methods

3.1 Settings and participants

The project aims to enhance the AI literacy and competency of secondary school students, thereby cultivating their readiness for an AI-empowered world. The AI curriculum was co-designed by a group of professors from the Faculty of Engineering and the Faculty of Education in a Hong Kong university and frontline teachers from Hong Kong secondary schools. The curriculum framework comprises 12 chapters covering three aspects: (1) knowledge of AI, (2) process in AI, and (3) impacts of AI. Each chapter comprises five modules (Awareness, Knowledge, Ethics, Interaction, and Empowerment) with a progress level (Chiu et al., 2022). The curriculum has been implemented in Information Communication and Technology (ICT) lessons at over 200 secondary schools.

The interviews were conducted in two batches. In the first batch (B1), 55 students (50.9% male, 28 out of 55) from 16 secondary schools participated in focus group interviews (2–4 students per group). The participants included 18 students from grade 7, 11 from grade 8, and 26 students from grade 9. To further understand and explore this phenomenon, we conducted a second batch of interviews. In the second batch (B2), we interviewed 33 students (66.7% male, 22 out of 33). The students were distributed across grades as follows: 17 students from grade 8, 14 students from grade 9, and 1 student each from grades 10 and 11. These participants were selected from 16 secondary schools, using the same focus group format as the first batch. In total, 88 students (56.8% male, 50 out of 88) attended the interview.

All schools are publicly funded by the Government, in accordance with the requirements set by the sponsoring organization. The schools were selected from different districts in Hong Kong, representing a diverse range of students' socio-economic backgrounds. Variations in background are associated with differences in students' learning environments, the availability of digital resources at home, and parental education level. To minimize gender bias, the sample included girls' schools, boys' schools, and coeducational institutions. Additionally, schools with varying overall academic standards were included to ensure comprehensive coverage across the academic spectrum. This diverse sampling strategy aimed to reflect a broad spectrum of student experiences within Hong Kong's diverse educational context. All interviewed students were engaged in learning the curriculum and had studied at least one AI-related topic in their schools (e.g., visual recognition), over a period of three to four weeks.

3.2 Data collection

Convenience sampling was adopted to recruit participants. This study was approved by an Ethics Committee of a Hong Kong University (Approval number: SBRE-21-0830). Prior to data collection, informed consent was obtained from both the parents and the participating students. Parents received comprehensive consent forms outlining the study's purpose, procedures, potential risks, and anticipated benefits. They provided written consent for their child's participation. In addition, students were given age-appropriate explanations with written consent form about the study, and they voluntarily provided their assent in signing the consent form. Participants were informed that their participation was entirely voluntary, that they could withdraw at any time without penalty.

All interviews were videotaped/audiotaped with verbatim transcription. Key interview questions were formulated based on the interview protocols of Chou et al. (2021) and Tsai et al., (2017), which focus on students' conceptual understanding of emerging technologies and provide a framework for exploring learners' conceptions through phenomenographic interviews. The first two questions aimed to explore students' conceptions of learning AI from the perspective of purpose, probing the *meaning* aspect by examining why students engage with AI learning and how they initially conceptualize the phenomenon. These questions reveal different motivations and interpretations, capturing the diverse ways learners purposefully make sense of learning AI, which facilitates the identification of categories of description. The third and fourth questions focused on the process or experience of learning AI—how students perceive the actual learning activities and methods they use—while the last two addressed the outcomes, revealing students' attributions about what they have learned and their aspirations. Together, these questions capture the *structure* aspect by showing how students' conceptions of learning AI processes relate or differ, illustrating how some understandings may be more inclusive or comprehensive than others, thereby mapping onto the hierarchical outcome space. Each question was piloted with a small group of students to ensure clarity and relevance before being used in formal interviews. The interview questions are listed below:

a Why do you want to learn AI?
b How would you describe your experience of AI learning?
c What have you learned from the AI lessons and activities?
d How do you learn AI?
e After having the AI lessons, what is your understanding of AI now?
f What extent of AI knowledge do you want to achieve?

3.3 Data analysis

The phenomenographic approach is considered one of the major approaches to exploring students' conceptions of learning (Chou et al., 2021). It aims to qualitatively investigate the differences in the conceptions of learning among participants and uncover a more structured and hierarchical insight (Richardson, 1999). As the findings of phenomenography, the outcome space describes the logically structured complex relationships of the different ways of learning AI experiences. These findings provide insights for educators to support further refinement (Chen et al., 2021; Yau et al., 2023).

The data was analyzed by a research assistant and a postdoctoral research associate with expertise in STEM and AI education. The interview transcripts were analyzed in an iterative process as described by Marton and Pong (2005). Initially, the research team aimed to identify categories of students' conceptions of learning AI. A research assistant and a postdoctoral research associate read each student's interview transcript thoroughly and highlighted key statements that best reflected each student's conceptions of learning AI. Data saturation was determined through an iterative process. Saturation was reached when no new themes categories or significant insights emerged from additional interviews or data sources. Specifically after coding and analysing each set of interviews we assessed whether subsequent interviews contributed novel information. Once consecutive interviews failed to generate new codes or concepts data collection was concluded indicating saturation had been achieved. Then these extracted excerpts were compared across all participants to identify recurring themes and variations. Based on the iterative refinement of the categories identified, six different conceptions of learning AI were developed to represent different conceptions held by the students. Using the established categories as a reference, the researchers revisited the selected excerpts from each participant and assigned them to the most appropriate category. As is typical in phenomenographic studies, the focus was on uncovering the range of understandings within the group rather than analyzing individual answers to specific questions (Åkerlind, 2023, 2024). The following example is presented to illustrate the coding process. When students said "My reason to learn AI is because I am very interested to learn it" or "I enjoy the AI lessons because I learn a lot of stuff about it and it's kind of interesting", these statements were identified as students describing their preference towards learning AI. Hence, these statements were coded under the category "Satisfying Interest". In addition to identifying different conceptions, the research assistant and the postdoctoral research associate independently analyzed the transcripts several times to identify and develop initial ideas regarding the relationships among different categories of students' conceptions of learning AI. Based on the studies of Chou et al. (2021) and Yau et al. (2023), the "conception domain", "conception schema", "learning strategies", and "motivation orientation" interconnections among categories emerged, further structuring the outcome space.

To ensure consistency and reliability in the coding process, interrater reliability was calculated using Cohen's kappa. The research assistant coded all the interview transcripts and the postdoctoral research associate coded 40% of the interview transcripts independently. An average pairwise interrater agreement of 0.87 was obtained.

Conventionally a kappa value between 0.81 and 1.0 indicates almost perfect agreement between coders (Landis & Koch, 1977).

4 Results

4.1 What are the students' conceptions of learning AI?

Six categories of students' conceptions of learning AI were identified as (1) Gaining Awareness; (2) Acquiring Knowledge; (3) Satisfying Interest; (4) Considering Social Impacts; (5) Improving Self-competency; (6) Seeing in a new way. Table 1 shows a brief description of six categories of students' conceptions of learning AI.

4.1.1 Category 1: Gaining Awareness

In this category, students described learning AI as a process of gaining a basic awareness of the AI technologies surrounding them. This category captures students' most foundational understanding of AI, where they begin to recognize the presence of artificial intelligence in their daily experiences without necessarily comprehending its mechanisms or implications. Most students initially become aware that the technologies they encounter in daily life are forms of AI:

> *"I realized that I frequently use features like Face ID, which are powered by AI. So, after attending the AI lessons, I noticed that AI is something we encounter in our daily lives all the time." (B1S6).*

> *"I found that AI is present in our daily lives. For example, voice assistants like Siri and Alexa." (B1S14).*

> *"I used to think deepfakes didn't really exist. After class, I realized there are real deepfakes, which changed how I view AI." (B1S17).*

Table 1 The six categories of students' conceptions of learning AI

Category 1: Gaining Awareness	Category 2: Acquiring Knowledge	Category 3: Satisfying Interest	Category 4: Considering Social Impacts	Category 5: Improving Self-competency	Category 6: Seeing in a new way
Gaining awareness of AI technologies, focusing on the identification of AI applications and their significance in daily life.	Acquiring knowledge about AI, such as the use of fundamental functions, without higher-level construction.	Satisfying curiosity and enthusiasm for AI, motivating them to explore further and gain additional knowledge and skills.	Understanding ethical implications and potential societal influence, emphasizing social benefits.	Enhancing capabilities and competitiveness for effective engagement with AI, including practical applications across various fields.	Developing AI-enhanced insights on problems and further transforming perspectives beyond the lens of AI.

> *"I often watch videos on YouTube, and I've realized that YouTube uses AI for video recommendations as well." (B2S22).*

This stage focuses on the identification of AI technologies, reflecting a surface-level recognition of AI applications rather than an in-depth conceptual understanding, without delving into the underlying knowledge and skills. The following excerpts from students illustrate this perspective:

> *"Our interactions with AI in daily life might not be very in-depth, and everyone's level of exposure to AI can vary." (B1S34).*

> *"I used to think that machines were just tools to help us, but I didn't understand that they turned out to be part of AI." (B1S45).*

> *"Studying AI has broadened my understanding, making me realize how pervasive it is in our surroundings, and it's become so common that we often overlook its presence in our daily lives." (B2S21).*

4.1.2 Category 2: Acquiring Knowledge

In this category, students' conceptions of learning AI involve acquiring conceptual knowledge and skills about AI, going beyond the awareness in Category 1. It encompasses understanding the use of basic functions of AI applications in daily life. This process includes students familiarizing themselves with the fundamental concepts and mechanisms of AI. For instance, students articulated how machine learning enables AI to recognize patterns, and how to use online machine learning tools to train AI:

> *"We discussed how AI recognizes different objects. For example, a rabbit has very long ears. If AI analyses many different rabbits and sees long ears, it will understand that this is a rabbit." (B1S16).*

> *"I believe the most important aspect of AI is machine learning. It enables AI to learn from data and identify patterns. For instance, it can analyze information and, after learning, generate new ideas." (B2S21).*

> *"We learned some websites that incorporate AI, such as 'Teachable Machine, where you can upload a photo, and it analyses the image to show who you resemble." (B2S22).*

Beyond solely theoretical knowledge, students also explore the underlying mechanisms under practical applications of AI, such as computer vision and image recognition underlying self-driving, and natural language processing underlying AI translation tools, thereby gaining insights into how AI can enhance various aspects of everyday life.

"Google Lens applies computer vision for image recognition." (B1S30).

"I learned speech recognition, a technology in which AI translates what we say into text." (B2S2).

4.1.3 Category 3: Satisfying Interest

This category captures students' conceptions of learning AI as a personally engaging and curiosity-driven experience. This level reflects students developing an interest in AI after they acquire some basic knowledge. Learning AI is a process of fulfilling their curiosity and enthusiasm for AI, motivating them to delve deeper into the subject. Some students demonstrated initial interest in learning and actively participated in the process.

"AI has a big history and it's really interesting." (B1S2).

"I think it's really fascinating. I had little knowledge about AI before, but now I've discovered that I can create a teachable machine at home. I find it very interesting and exciting." (B1S37).

"I find it interesting, especially since I'm curious about AI and what's behind it. That's why I don't find training AI models boring; it's something I enjoy." (B2S23).

These responses indicate that for some students, AI is not only intellectually stimulating but also emotionally rewarding, fostering a sense of personal investment in the learning process. Besides, with interactive learning activities, such as hands-on activities with AI applications, students' interest in exploring AI topics was greatly increased, even involving those with no interest. These findings suggest that well-designed, activity-based pedagogical strategies can effectively transform passive learners into active participants, highlighting the motivational potential of practical AI education.

"I'm really interested in continuing to learn AI… we need to assemble a model AI car by ourselves. This brings a fun element and increases interaction." (B1S21).

"At first, I had no interests. But during the lessons, I found that my interest in learning AI has been increasing more and more." (B2S17).

4.1.4 Category 4: Considering Social Impacts

In this category, students' conceptions of learning AI start to emphasize the importance of understanding its ethical application and potential societal impacts rather than merely individual interest. Central to their perspectives is the imperative to avert harmful applications of AI, while fostering a human-centered approach that prioritizes the human well-being of individuals and communities.

Students expressed a strong awareness of the ethical implications of AI development, which underscores the need for developers to consider the broader implications and pursue socially responsible outcomes of their work.

> *"You have to think about why you're making an AI machine and how it can help certain people, as well as what impact it will have on different individuals." (B1S39).*

> *"We were thinking about inventing AI-powered glasses that would help visually impaired individuals find the items they want at home and also recognize dangerous situations." (B2S5).*

> *"I see a lot of elderly people out alone, and they have trouble walking. The ground is uneven and wet, which makes them fall easily...so I want to explore how AI can provide solutions to help them." (B2S27).*

These responses reflect an emerging sense of social responsibility among students, particularly when considering how AI can be used to support marginalized or vulnerable groups. Furthermore, participants highlighted the potential pitfalls associated with AI misuse and expressed their concerns regarding the dual-edged nature of AI.

> *"There could be some terrorist organizations or bad actors who use AI to impersonate political figures, which could impact the entire functioning of a country. This could lead to both positive and negative outcomes." (B1S29).*

> *"Actually, if you misuse AI, it becomes a problem of abuse. This issue is important and challenging in terms of learning; you need to ensure that everyone is aware of it." (B2S8).*

> *"Users must clearly understand how to use and operate AI. This helps users understand its principles and prevents the loss caused by misuse or operational errors." (B2S11).*

4.1.5 Category 5: Improving Self-competency

In this category, students conceptualize learning AI as a process of improving their capabilities and competitiveness. Their conceptions go beyond basic understanding or interest; instead, they focus on how acquiring AI knowledge can empower them to solve real-world problems and prepare for future challenges, knowing how and what they can do with AI knowledge.

> *"I need to detect different brands of potato chips in Hong Kong, so I must import over two thousand images to accurately recognize which brand is which.*

Throughout this process, I must move around at different angles to prove the machine could obtain the accurate information" (B1S39).

"We experienced the process of machine translation. We observed how the machine generates outputs from the input and discussed its benefits and its applications. We also explore the limitations, such as issues of accountability or the lack of representation for certain languages" (B2S7).

These responses indicate that students are not only learning about AI but are also actively applying it in meaningful ways. This level of engagement supports deeper conceptual development and fosters a sense of agency in using AI as a tool for application and problem-solving. Some students even actively engage in applying AI concepts, create original AI-based solutions, and demonstrate their ability to synthesize knowledge and apply it creatively.

"Previously, we developed an app allowing people to chat with an animated panda by applying speech recognition techniques." (B2S8).

"When people go hiking, they often leave behind camping waste and trash. My previous project was an AI smart cabinet that can provide intelligent recommendations according to users' requirements and historical habits, enabling users to rent camping supplies with no waste and cost. I hope it contributes to environmental protection." (B2S19).

4.1.6 Category 6: Seeing in a new way

In this category, students view learning AI not merely as acquiring domain-specific knowledge but as a broader intellectual experience that enhances their general cognitive abilities. They perceive that learning AI helps them develop general intellectual skills such as critical thinking, problem-solving, and creativity, and transforming their AI competency into other areas, enhancing their epistemic fluency with AI in the future. Several students explicitly linked their AI learning experiences to the development of critical thinking skills, reflecting that thoughtfully designed AI education can go beyond technical training and support deeper epistemological growth:

"It has also trained our critical thinking. In class, the teacher discussed both the advantages and disadvantages of AI with us." (B1S37).

Moreover, students recognized how learning AI encouraged them to think innovatively and apply concepts in novel ways, indicating that students are beginning to develop what can be described as epistemic fluency—the ability to flexibly use knowledge in new situations and integrate interdisciplinary knowledge. This represents a high-level conceptualization of learning AI, where students see its value not only in technological literacy but also in shaping their broader intellectual capacities:

"I feel that I have learned the skills of innovation. After learning AI, we know how to apply AI in different fields or design a product using these AI concepts. This process helps us enhance our creativity and has been very beneficial overall." (B2S8).

4.2 Distribution of the students' conceptions

A condensed summary of the distribution of students' conceptions across categories based on their reported experiences is presented in Table 2 (For the full detailed table, please see the supplementary materials Table 1). The number of times that the students stated a certain idea and were converted into symbols and identified as "general," "main," and "achieved" conceptions (Yau et al., 2023).

Categories 2 ($n=70$) and 3 ($n=66$) were the most frequently reported conceptions of students, but only 16 and 9 students reported their conceptions of Categories 5 and 6, respectively. If a student's conception is identified to a category, then this category will be marked with a "√", namely the general conception; and the most frequently mentioned category will be marked with a "▲", namely the main conceptions; the highest-level category men were marked with a "※", namely the achieved conceptions. For example, B2S19 had general conceptions regarding learning AI that spread across categories 1–5 (Please see the supplementary materials Table 1 for details). The most frequently mentioned conception was Category 4 (5 counts). Thus, his main conception category was Category 4, but his highest achieved conception was Category 5.

4.3 Relationships among categories

Relationships among categories with hierarchical structures were established by comparing their similarities and differences (Chen et al., 2021; Yau et al., 2023). Table 3 shows the outcome space with structural components to illustrate this relationship.

Four key aspects of the relationships emerged from the data analysis: (1) conception's domain, (2) conception's schema, (3) learning strategies, and (4) motivation orientation. The conception domain refers to the nature of the concepts: knowledge attitude or competency. Conception schema refers to how individuals represent and interpret knowledge about concepts events or situations showing a transition from reproductive to constructivist among the categories (Chiou et al., 2012, 2013).

Table 2 The distribution of students' conceptions of learning AI

	Category 1: Gaining Awareness	Category 2: Acquiring Knowledge	Category 3: Satisfying Interest	Category 4: Considering Social Impacts	Category 5: Improving Self-competency	Category 6: Developing Intellect
√ =	62	70	66	51	16	9
▲ =	27	33	31	30	3	2
※ =	2	7	21	39	10	9

√: General Conception - A category identified in a student's conception.

▲: Main Conception - The most frequently mentioned category by a student.

※: Achieved Conception - The highest-level category identified in a student's conception.

Table 3 The outcome space

Category	Category 1: Gaining Awareness	Category 2: Acquiring Knowledge	Category 3: Satisfying Interest	Category 4: Considering Social Impacts	Category 5: Improving Self-competency	Category 6: Seeing in a new way
Conception Domain	Knowledge domain		Attitude domain		Competency domain	
Conception Schema	Reproductive		→		Constructivist	
Learning Strategies	Surface		→		Deep	
Motivation Orientation	Extrinsic		→		Intrinsic	

Learning strategies refer to the learning approaches ranging from surface to deep approaches. Motivation orientation is related to students' learning intentions and objectives.

Categories 1 and 2 classify the students' conceptions as the knowledge domain that involves reproductive knowledge with surface strategies under extrinsic motivation. The students perceive learning AI as developing their awareness and acquiring essential knowledge about AI functions and applications, enabling them to understand the basic AI concepts. Students primarily view learning AI as a passive process of receiving information rather than an active process of constructing knowledge. Thus, they engage in surface learning strategies, such as repeating the material presented by teachers, absorbing information about AI, and completing assignments or immediate tasks. Influenced by the perception that AI knowledge is essential for the future, many students believe that without acquiring this knowledge, they risk being marginalized in an evolving workforce. This extrinsic motivation compels them to engage in learning primarily to fulfill perceived societal expectations.

The conceptions' domain in Categories 3 and 4 shifts to the attitude domain, where intrinsic and extrinsic motivations are involved in learning AI, encouraging a transition from the reproductive to the constructivist schema with the integration of both surface and deeper strategies. Students believe learning AI not only refines their understanding but also satisfies their curiosity. Driven by curiosity, they connect their learning to their personal interests and social influences, exploring AI beyond the curriculum. Students also begin to blend and combine school knowledge with real-world contexts, increasingly connecting learning AI to practical applications and the implications for society with their exploration. They review AI's ethical implications, recognizing its potential societal impacts and how to make more connections between AI applications with social benefits.

In Categories 5 and 6, the conceptions are in the domain of competency, where students focus on constructing knowledge through deep approaches driven by intrinsic motivation. Driven by a genuine interest in AI and a commitment to personal development, learning AI becomes a process of construction rather than absorption, students explore creating socially beneficial AI applications through experiences, interactions, and collaborative learning to address real-world problems and analyze case studies of AI implementations. They actively engage with AI knowledge, applying it in diverse contexts while developing critical thinking skills and solving problems creatively with AI tools.

5 Discussion

5.1 Theoretical and empirical implications: students' conceptions of learning AI

This phenomenographic study proposes a hierarchical framework in students' conceptions of learning AI, which extends the boundary of conceptions of learning studies into AI education, which is an emerging and important phenomenon, and offers an understanding of students' beliefs about the subject. In this study, six categories of students' conceptions were identified. The distribution of the categories presented an understanding of the diversity of the students' individual experiences of learning AI. An outcome space showing the relationships between the categories was presented in a transition with four dimensions: (1) conception domain, (2) conception schema, (3) learning strategies, and (4) motivation orientation. The space showed a range from reproductive to constructivist conceptions and offered an understanding of how students perceive AI education through their academic learning experiences.

The variation in categories with hierarchical relationships indicates different levels of conceptions of learning AI. In our study 62 out of 88 students (70.4%) demonstrated a Category 1 conception while 70 students (79.5%) exhibited a Category 2 conception showing that students view learning AI as gaining essential awareness and knowledge required by society. As end-users of AI applications students must be aware of AI technologies such as identifying real-life applications like facial recognition or Siri and understanding the definitions and fundamental principles behind AI (Chiu et al., 2024b; Long & Magerko, 2020; Touretzky et al., 2019). Additionally, students feel the urgency of the current era to learn how AI works and to acquire relevant skills. These categories align with the requirement of AI literacy (Chiu et al., 2024b) and teachers' aims of technology bridging and knowledge delivery in teaching AI, further emphasizing that developing students' conceptual understanding of basic AI application knowledge is central to effective AI education (Yau et al., 2023).

In Category 3 students perceive learning AI as a process that develops their interest and fulfills their curiosity through hands-on activities. These activities play a crucial role in developing and sustaining student interest. Notably 75% of students (66 out of 88) identify interests as their conceptions of learning AI. Educators also prioritize stimulating student interest highlighting the importance of self-efficacy and positive attitude toward learning AI (Wang et al., 2024). When students are engaged and interested, they tend to have a positive attitude toward learning and exhibit active participation in lessons.

Category 4 as the highest level that most students achieved 39 students (44.3%) demonstrated a strong awareness of AI's ethical considerations and responsibilities. This reflects a thoughtful engagement with the ethical dimensions of AI. AI curricula throughout the world are emphasizing the importance of AI ethics (e.g. UNESCO, 2024). For the literature of conception of learning, the notion of ethical reasoning for the subject matter has not received much attention (e.g. Chen et al., 2025; Luan et al., 2025) but for the case of AI education, the widespread influences of AI in all aspects of human living (UNESCO, 2022) makes it an important component for AI education (Long & Magerko, 2020). Other investigations of conceptions of learning may need to consider adding this aspect when appropriate, as human learning seldom escapes connections with ethics.

The most sophisticated categories—Category 5 (16 students 18.2%) and Category 6 (9 students 10.2%)—focus on the competency domain aligned with the AI competencies (Chiu et al., 2024b). Teachers assert that "hands-on problem-based approaches contribute to high student engagement and inspire 21st-century skills such as creativity and critical thinking which may enhance their learning and encourage them to pursue AI-related careers" (Yau et al., 2023). Students also recognize that hands-on approaches facilitate their intention and engagement in learning AI as evidenced in Category 3. However, when it comes to higher-level 21st-century skills and aspirations for AI-related careers, teachers' approaches are less effective. Less than 20% of students reached this advanced phase. There are two possible explanations for this result: one is that most students lack a clear rationale or motivation to pursue higher-level AI literacy and competency. As the students are mainly at junior high school levels, they may not have a clear idea about their career choices (Akhsania et al., 2021). This may be further confounded by a Limited understanding of how AI is connected to their future studies or career opportunities. As discussed in Categories 1 and 2, everyday technologies are the main access and aim that most students have towards learning AI. Moreover, many interviewed students explored and interacted with AI for the first time because of the project. Their understanding of AI concepts and applications is often at an introductory level. Additionally, the current curriculum may not have sufficiently emphasized the cross-curricular potential of AI and the limited curriculum time for in-depth learning. All these factors together limit students' opportunities to make such transfers. Hence, students might not yet see the relevance of AI to their personal goals and limit their motivation to pursue advanced competencies. Another factor is the complexity of applying or designing their own AI artifacts which often involves the capabilities that exceed those typically required at the secondary school level (Chang & Tsai, 2024). This may reflect the challenges associated with reaching higher-order conceptual understandings which often require not only prior knowledge and cognitive maturity but also instructional environments that encourage metacognitive reflection and interdisciplinary connections. In comparison to other subject matter such as language learning and mathematics students would have learned the content for six to seven years when they reach junior high school. Conceptions of learning for these subjects seem to be higher level and deeper rather than lower level for secondary students (Yang et al., 2019).

Compared with existing studies on students' conceptions of learning AI (Gao et al., 2024; Zhao et al., 2024) our findings share similarities in that both studies revealed most students hold positive attitudes towards learning AI. However there are also notable differences. In the studies by Gao et al. (2024) and Zhao et al. (2024) students perceived AI learning as occurring primarily in AI classrooms equipped with advanced smart facilities with programming and robotics being the most frequently mentioned elements. This contrasts with our Categories 1 and 2 which highlight daily application and knowledge of learning AI. Additionally ethical elements were not addressed in these two studies. According to Tsai (2004), students' conceptions of learning are influenced by their actual learning experiences. The two previous studies were conducted in mainland China where AI education is largely lecture-based (Zhao et al., 2024). This educational approach likely led to the classroom and programming content taught in class being reflected in students' conceptions. In contrast, in Hong Kong AI education is more practical and integrated into daily life. As a result students in Hong Kong tend to focus on learning AI more on their everyday application as well as the impact of AI on human beings and society. Differences in research methods may also contribute to these discrepancies. Both existing studies employed the drawing method which helps avoid biases related to participants' characteristics such as differences in native languages or age-related writing and speaking competencies (Chang et al., 2020). But at the same time, it may predispose concepts that are more tangible and visual, potentially overlooking some motivational and affective insights that are closely tied to individual characteristics. Additionally, students' drawing capabilities could also influence their expression, potentially contributing to the observed differences. Therefore, future research on students' conceptions of learning, particularly for older students with higher abilities, may adopt a more comprehensive and multifaceted approach to address these limitations. Specifically, integrating multiple research methods, such as combining the drawing method with phenomenographic interviews, could provide a more holistic and in-depth understanding of students' conceptions. The drawing method can serve as an initial and intuitive way for students to express their perceptions of AI learning, while phenomenographic interviews can delve deeper into the underlying motivations, learning strategies, and ethical considerations that students associate with AI learning.

This study documents a range of conceptions of learning AI among Hong Kong secondary school students who have attended AI lessons through the project. The three aspects of the curriculum framework provide the foundation of AI knowledge and skills and foster students' attitudes and values when using or applying AI technologies, and the five modules in each chapter align with the four key principles of the AI Competency Framework for students: human-centered mindset, ethics of AI, AI techniques and applications and AI system design, as proposed by UNESCO (2024). The Awareness and Knowledge modules focus on essential AI concepts and daily life AI applications, allowing students to explore different AI techniques and applications. The Interaction and Empowerment modules emphasize the design and integration of AI technologies, providing hands-on activities to foster students in designing AI systems, deepen their understanding of AI techniques, and develop their practical skills in AI technologies. The Ethics module explores ethical issues and societal implications, cultivates students' ethical awareness, and fosters a human-centered mindset. Together, these elements provide a solid foundation for students to effectively learn AI (Chiu et al., 2022). The emerging conceptions are, in general, positive outcomes of such AI literacy and competency programs. It provides some evidence for the necessity of schools in preparing secondary students for the emerging AI society.

Overall this study adopts the phenomenographic approach to map students' conceptions of learning. While the findings are congruent with most studies of conceptions of learning that reveal lower-order knowledge-acquiring conceptions to higher-order knowledge-constructing conceptions (Chiou et al., 2012; Chou et al., 2021; Tsai et al., 2017) it highlighted rarely reported conceptions that are associated with ethical considerations and social responsibilities. This is obviously due to the social impact of AI as a field of study. The emergence of AI has been identified as the key technology for the fourth industrial revolution (Chaka, 2023; Sanusi et al., 2022). It has emerged as a necessary knowledge for students to function well in the world (UNESCO, 2024). This study has arguably enriched the literature for conceptions of learning. Future research on the conceptions of learning should include investigating the ethical implications of learning, especially for the learning of engineering and technologies.

5.2 Practical suggestions: curriculum development for AI education

This study reveals four key insights regarding the current AI curriculum and students' actual needs and aspirations. Firstly, in students' conceptions of learning AI, the characteristics of AI as a tool or application are prominently highlighted. The majority of students express that their primary motivation for learning AI is to prepare for their lives, and future work indicating a practical need for their education. However, the AI curriculum frameworks mainly focus on the conceptions and theories of AI and pay less attention to the skills of using AI technologies in daily life (e.g. Long & Magerko, 2020; Touretzky et al., 2023; UNESCO, 2024). This reflects the need to connect the curriculum with the skills that can address students' daily needs, learning practices, and problems. For example, students may master the mechanisms of machine learning but struggle to use AI to solve problems in their studies, such as using AI to help them understand photosynthesis or to solve a challenging math problem. That is, these curriculum frameworks should place greater emphasis on integrating AI with students' motivation and aspirations, and the educational content should be more closely connected to students' daily lives. It should demonstrate how AI technologies can solve real-world problems and encourage students to reflect on how these technologies might support their personal and career goals.

Secondly, the interdisciplinary potential of AI has not been fully demonstrated. For example, in UNESCO (2024)'s AI competency framework for students, the aspects of AI techniques and applications frequently highlight data algorithms and programming while detailed interdisciplinary application skills are less emphasized. However with the interdisciplinary nature of AI it is essential to integrate AI education across various discipline areas (Knoth et al., 2024; Yau et al., 2023), allowing students to observe and participate in the applications of AI across various fields including science humanities and social studies. Moreover, technology education teachers need to incorporate more interdisciplinary knowledge into their courses while educators from other disciplines should also actively integrate AI-related content. This will ensure that AI education is not limited to computer science or information technology classes. Doing so helps students recognize the broad applications of AI and its potential impact across various fields (Knoth et al., 2024).

Thirdly, many students may encounter challenges associated with reaching higher-order conceptual understandings. In other words, a more carefully planned curriculum that leverages other content knowledge and skills learned for students to learn about AI is needed to build an interconnected understanding and workable curriculum timeframe. AI applications such as speech and voice recognition are based on the basic understanding of sound, while image recognition has much to do with light and shadow. Without some foundational science knowledge, the resulting understanding could be fragmented with misconceptions. To improve students' advanced competencies in learning AI, it is essential to guide students progressively through interdisciplinary projects that move from simple to complex in early stage, for example, following the framework proposed by UNESCO (2024), students begin at the "Understand" stage in primary school, where they investigate basic scientific phenomena such as the reasons behind object coloration, and progress to the "Create" stage in secondary school, where they undertake projects like developing AI tools to support individuals with color vision deficiencies, fostering the development of higher-order thinking skills and deeper conceptual understanding. Concurrently, teachers should create a learning environment that fosters metacognitive reflection and encourages interdisciplinary connections, enabling students to draw on diverse knowledge domains. Moreover, providing ongoing professional development opportunities for teachers is crucial. This enables them to better master AI-related knowledge and skills, allowing them to offer effective scaffolding and support to students as they progress toward higher levels of AI literacy and competency (Yau et al., 2023).

Lastly, students demonstrated a keen awareness of the social impacts of AI, expressing a desire for education that encompasses ethical and societal considerations. UNESCO (2024)'s human-centered mindset and ethics of AI aspects are aligned with students' conceptions of learning AI. The project designed curriculum materials with an explicit focus on impacts and ethics for each area of AI subfields. It seems that this approach not only addresses current concerns about ethical awareness (Chiu et al., 2022, 2024b), but it also enhances students' interest in learning about AI as a potential means for students to care, to critically consider technology advancements, and to designedly consider how to change the world for the better. The study provides support for the importance of the integration of AI ethics, AI for social good, and AI literacy as a pedagogical approach for AI literacy. Future case studies or projects that challenge students to think critically and creatively about the consequences of AI technologies could take the project as an example, fostering a sense of responsibility and ethical awareness.

6 Conclusion and limitations

Students' conceptions are crucial to curriculum development, as they represent the primary users of the educational framework. This study identified six hierarchical categories of students' conceptions regarding AI education and explored the transitional relationships among these categories. The findings underscore significant aspects of AI education from the students' perspectives. These insights are vital for informing educators' design and implementation of AI courses, providing valuable guidance for educators, schools, and curriculum developers aiming to enhance AI education in K-12. The findings extend existing frameworks and methods on conceptions of learning in the domain of AI education and highlight the importance of aligning AI curriculum design with students' evolving conceptions. For instance, early-stage learners benefit most from experiential and contextual activities that foster awareness and interest, while advanced learners require opportunities to apply AI knowledge creation meaningfully and reflect on ethical and societal implications. These insights are valuable for educators, school administrators, and curriculum designers seeking to develop age-appropriate, cognitively responsive, and ethically informed AI education programs at the K-12 level.

However, this study has two limitations. First, from a methodological standpoint, this qualitative study employed interviews to explore students' subjective experiences and reflections on AI learning. While this approach allows for rich, in-depth insights, it is important to acknowledge potential limitations. One key limitation concerns possible social desirability bias, wherein students may have provided answers they believed were expected or favorable rather than their genuine beliefs. To mitigate such biases in future research, it is recommended to triangulate interview data with more objective sources, such as classroom observations, student artifacts, or reflective diaries, which can provide complementary evidence of students' actual learning behaviors and conceptual development. Second, most participants were from Hong Kong public secondary schools, which may not accurately represent other learner populations. It is recommended that future studies replicate this research across a broader cultural context or in other school settings, such as private schools.

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Declarations

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Supplementary file.

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