



AI and critical thinking: A mixed-method exploration of students' uses of Ask.SMILE for question-generating practices

Trang Phan ^{1*}

 0000-0003-0697-8272

Mariya A. Yukhymenko-Lescroart ¹

 0000-0002-0054-6666

Curtis J. Bonk ²

 0000-0002-6365-9502

¹ Department of Advanced Studies in Education, Kremen School of Education and Human Development, California State University, Fresno, Fresno, CA, USA

² Department of Learning, Design, and Adult Education, Indiana University, Bloomington, IN, USA

* Corresponding author: tphan@mail.fresnostate.edu

Citation: Phan, T., Yukhymenko-Lescroart, M. A., & Bonk, C. J. (2026). AI and critical thinking: A mixed-method exploration of students' uses of Ask.SMILE for question-generating practices. *Contemporary Educational Technology*, 18(3), Article ep672. <https://doi.org/10.30935/cedtech/18936>

ARTICLE INFO

Received: 5 Nov 2025

Accepted: 23 Jun 2026

ABSTRACT

The research study aimed to explore how preservice teachers engaged with an artificial intelligence (AI)-based tool called Ask.SMILE to develop higher-order level of questions based on the criteria of Bloom's taxonomy. Specifically, we evaluated students' questioning techniques, motivation, satisfaction with Ask.SMILE, and assessed their aspirations to use the tool in future classrooms. Using a mixed-methods approach, 178 participants generated over 50 questions each, received feedback from Ask.SMILE, and reflected on their experiences through written responses. The results revealed that Ask.SMILE supported participants in creating questions aligned with Bloom's taxonomy principles, encouraging iterative improvement and fostering metacognitive awareness. Participants reported enhanced understanding of inquiry-based learning and recognized the importance of using structured questioning strategies to promote critical thinking. While the findings highlight the educational potential of AI tools like Ask.SMILE, limitations include reliance on self-reported data, the absence of longitudinal tracking, and varying levels of AI proficiency among participants. It is suggested that future research should focus on the long-term impact of AI-supported questioning strategies and practices in diverse classroom contexts, and professional development to enhance teacher proficiency with AI tools.

Keywords: question-generating, techniques, strategies, inquiry-based learning, engagement

INTRODUCTION

Critical thinking is dynamically defined and described by different academic scholars. At its core, critical thinking refers to the ability to assess information, question assumptions, weigh evidence, and make reasonable judgments (Ennis, 1987; Paul & Elder, 2006). Decades ago, Facione (1990, p. 3) defined critical thinking as "purposeful, self-regulatory judgment," including analysis, evaluation, and inference skills, while Ennis (1985) described it more broadly as "reasonable, reflective thinking focused on deciding what to believe or do" (Ennis, 1985, p. 45). Paul and Elder (2006) characterized critical thinking as the art of analyzing and evaluating thinking with a goal to improving it. These varied but complementary definitions and description indicate critical thinking goes beyond accumulating knowledge to learning to think, analyze, and evaluate in a disciplined and independent manner.

In the age of generative artificial intelligence (GenAI), critical thinking skill becomes more crucial than ever in both academia, social and informal learning environments. The relationship between large language models (LLMs) use and critical thinking is complex and inherently conditional as shown in emerging research. Specifically, systematic reviews indicate that LLMs can support higher-order cognitive processes by facilitating argumentation, idea generation, and the synthesis of multiple perspectives when constructed within structured learning environments (Vendrell & Johnston, 2026; Zawacki-Richter et al., 2019). Specifically, empirical studies demonstrate that artificial intelligence (AI)-supported dialogues and guided tasks can enhance learners' engagement in reflective thinking and collaborative knowledge construction, especially when instructional scaffolds encourage evaluation and justification of AI-generated outputs (Hou et al., 2025). In other words, LLMs function as cognitive partners that can extend learners' reasoning processes and promote active learning.

On the other hand, other sets of evidence highlight potential risks associated with unstructured use or over-reliance on LLMs. Studies have shown that early or continuous reliance on AI tools may lead to cognitive offloading, resulting in reducing learners' reasoning effort and engagement and limiting metacognitive regulation (Vendrell & Johnston, 2026; Zhi et al., 2026). Additionally, while LLMs have demonstrated excellent capabilities in question answering tasks, yet their ability to identify and address ambiguous questions remains underdeveloped (Shi et al., 2025). The fact that learners tend to accept AI-generated content uncritically raises a concern they are in superficial engagement rather than meaningful critical analysis with AI. Experimental findings further suggest that strategic access and the timing of AI use play a crucial role in promoting stronger independent reasoning compared to immediate reliance (Zhi et al., 2026).

Apparently, the current literature does not suggest that LLMs inherently enhance or diminish critical thinking; rather, their impact depends on how they are integrated in educational contexts. Crucially, the use of LLMs appears to shift the nature of critical thinking from knowledge production toward evaluation, verification, and refinement of AI-generated information (Vendrell & Johnston, 2026; Zawacki-Richter et al., 2019). This shift underscores the need for instructional approaches to explicitly cultivate learners' critical engagement with AI outputs. Despite these emerging insights, there remains a need for further empirical research examining how learners, particularly preservice teachers (PSTs), develop and apply critical thinking skills in AI-mediated learning environments.

Among the many components of critical thinking, the ability to generate meaningful, thought-provoking questions is increasingly recognized as both fundamental and teachable skill for deep learning and intellectual development (Chin & Osborne, 2008). The findings indicate that strong questioning skills play a crucial role in fostering deep learning by prompting learners to explore underlying relationships between concepts. Along these same lines, Paul and Elder (2006) emphasize the importance of asking clear, relevant, and precise questions as part of reasoning and analysis. Unlike accumulating knowledge passively, asking questions activates high-order thinking processes, especially in analysis, evaluation, and creation of new knowledge that are aligned with Bloom's revised taxonomy (Anderson & Krathwohl, 2001). Hence, teaching students to ask good questions to synthesize knowledge, assess evidence, and construct new ideas is essential to cultivating rigorous thinking and deep learning (Becker, 2000; Chin & Osborne, 2008; King, 1994).

In the age of GenAI, the ability to formulate meaningful questions becomes even more critical, as learners are not only consuming information but also evaluating and interrogating AI-generated output. As mentioned above, even though AI tools can rapidly produce responses, explanations, and even arguments; AI tool outputs are not always accurate or contextually appropriate. Consequently, in this increasingly AI dominant age, learners need to have strong questioning skills to critically examine the information provided (Kasneci et al., 2023; Rudolph et al., 2023) by probing the validity, relevance, and underlying assumptions of the responses. In fact, effective engagement with AI involves iterative prompting and questioning practices that shape the quality of outputs and deepen understanding (Holbeck, 2025; Mollick, 2024). In this context, question generation functions as a key metacognitive strategy that allows learners to regulate their thinking, refine inquiries, and co-construct knowledge with AI systems (Vendrell & Johnston, 2026). Therefore, fostering learners' capacity to generate purposeful and critical questions is not only essential for deep learning but also fundamental for navigating and leveraging AI tools in responsible ways.

The present research study aims to explore PSTs' deep engagement with Ask.SMILE, an AI-based feedback provider tool, in their practice of question generation. Specifically, the study reports the participants' deep engagement with the Ask.SMILE AI tool where learner generated questions were evaluated by the system. This study also explored the techniques that learners employed when using Ask.SMILE, the types of questions they asked, how they processed the feedback that they received from Ask.SMILE, and their stated intentions to apply Ask.SMILE in their future teaching endeavors.

In this study, the following research questions (RQ) were asked:

- RQ1:** How do PSTs' questioning techniques (i.e., how questions are asked) and motivation (i.e., why questions are asked) interact and contribute to their question-generation ability?
- RQ2:** To what extent does PSTs' satisfaction with Ask.SMILE vary based on their questioning techniques and questioning motivation?
- RQ3:** What are the perceived impacts of using Ask.SMILE on PSTs' critical thinking development? And what are aspirations of PSTs to implement inquiry-based learning practices in K-12 classrooms?

The study uniquely contributes to the prevailing literature by providing empirical insights into how AI-driven feedback and iterative question refinement can improve students' metacognitive skills development, curiosity, and personal interests in certain topics. It bridges a gap in current studies by exploring the practical classroom applications of AI-supported student-generated questioning (SGQ) practices, highlighting its transformative role in preparing educators to create dynamic, student-centered learning environments.

LITERATURE REVIEW

Student-Generated Questions

SGQ enables PSTs to cultivate critical thinking and active learning through effective peer and instructor or system modeling, timely and pointed instructional scaffolding or facilitation, and opportunities to reflect on the art of inquiry (Buckner & Kim, 2014; Wu et al., 2023). Generating good questions requires diligent practice to think deeply about the material, robust conceptual understanding, and refined metacognitive reasoning (Chin & Brown, 2002; Chin & Osborne, 2008; Davey & McBride, 1986). Such practice not only enhances PSTs' cognitive skills but also enables them to assess their own understanding and learning needs (Yu & Wu, 2020) by effectively crafting increasingly higher-order levels of questions (Kim et al., 2025). As a result, PSTs develop the ability to scaffold similar skills for their future students; thus, creating a more dynamic, inquiry-driven learning environment that fosters sophisticated and powerful classroom discourse (Quintana et al., 2002; Singer et al., 2000).

Incorporating SGQ techniques into TE programs shifts classroom power dynamics towards student agency and collaborative knowledge construction (Wu et al., 2023) through hands-on experiences (Aguilar et al., 2010; King, 1997; Terada, 2020; Yu et al., 2015). As an inquiry-based framework, SGQ requires learners to actively participate in a social learning process (Rogoff, 1991; Vygotsky, 1978; Wertsch, 1991) and construct new knowledge (Khasawneh et al., 2023). Through interactions with peers, experts, or digital tutors, learners receive the scaffolded support necessary to pose higher-level questions and deepen their understanding of concepts and ideas (Aflalo, 2021; Bozkurt, 2023; Palincsar & Brown, 1984; Yu & Wu, 2020).

GenAI further individualizes instructional scaffolding (Crompton & Burke, 2024; Schroeder, 2024) and provides layers of support for learners towards self-directed learning (Ali et al., 2023; Li et al., 2024; Wang et al., 2024) in constructivist learning environments (Kim & Adlof, 2024). In the age of AI, SGQ bridges traditional pedagogy with AI-based technology, enabling PSTs to navigate and generate questions using AI tools (Anistiyasari et al., 2024; Chiu et al., 2023; Digital Education Council, 2024). AI systems can analyze patterns of inquiry to identify areas of strengths and challenges to tailor support that transits learners from factual recall to higher-order thinking (Ali et al., 2023; Kim et al., 2025). For instance, with its responses and analysis, AI can recommend question prompts aligned with Bloom's taxonomy that help PSTs unpack question components to explore deeper levels of understanding and apply knowledge in novel ways. This practice, in its entirety, helps the learners develop a nuanced understanding of the interactions between their questions and the AI responses.

Table 1. A critical thinking rubric based on Bloom's taxonomy

Rating	Bloom's taxonomy question types
Level 1. Knowledge recall	Questions at this level assess basic recall of facts, concepts, or procedures. Example: What are the levels of Bloom's taxonomy?
Level 2. Understanding	These questions require comprehension and the ability to explain ideas or concepts. Example: How would you summarize the purpose of Bloom's taxonomy?
Level 3. Applying	These questions involve using knowledge in a new situation or applying learned concepts to real-world scenarios. Examples: Can you apply Bloom's taxonomy to design a lesson plan?
Level 4. Analyzing	These questions require breaking down concepts into components and examining relationships. Example: How do the levels of Bloom's taxonomy interact to develop critical thinking?
Level 5. Evaluating	These questions involve making judgments on criteria, supporting opinions, or critiquing ideas. Example: Which level of Bloom's taxonomy is most effective for fostering deep learning and why?

Despite these benefits, implementing SGQ remains challenging due to the prevailing focus on examination preparation, traditional lecture approaches and lack of SGQ practices in K-12 school settings (Hsu & Kim, 2016; Wu et al., 2023). Research suggests that well-designed interventions that integrate frameworks like Bloom's taxonomy can help bridge the gaps by fostering both conceptual understanding and reflective thinking (Wu et al., 2023).

Ask.SMILE: An AI-based Assessment Tool for Critical Thinking

The Stanford mobile inquiry-based learning environment (SMILE) is a robust, cloud-based AI-based mobile learning tool designed to stimulate higher order thinking and creative ideation by facilitating the synthesis, analysis, and exchange of critical inquiries (Buckner & Kim, 2014; Kim, 2024). Ask.SMILE operates as an intervention that integrates the SMILE platform with GenAI (GPT 3.5/4) to transition SGQs from an informal activity into an intentional, assessable learning process (McGivney & Kim, 2016). Ask.SMILE also acts like a coach by allowing learners to input their inquiries and offering customized output that reflects differentiated support with individual's learning trajectories. This process leverages learners' cognitive engagement, while promoting an environment of learner-centeredness and empowering participants to become architects of inquiry rather than passive recipients of information.

At the core of the Ask.SMILE interface is an evaluative engine that categorizes SGQs based on a cognitive complexity scale based on the revised Bloom's taxonomy (Anderson & Krathwohl, 2001), which differs from the traditional forms of teaching and learning by emphasizing an active and more dynamic learning process including opportunities to level 1: remember, level 2: understand, level 3: apply, level 4: analyze, and level 5: evaluate and create. Questions are ranked from fundamental recall of knowledge (i.e., level 1 and level 2) to advanced analytical and creative synthesis (i.e., level 3-level 5), using these levels as both learning stimuli and assessment vectors (Kim et al., 2025). To help learners refine the depth of questions, Ask.SMILE provides real-time, formative feedback on the clarity, depth, and cognitive rigor of the inquiries. Critically, the AI tool does not provide direct answers; instead, it offers criterion-based suggestions for improvement, encouraging learners to regulate metacognitive practice and intellectual curiosity (Kim et al., 2025). This iterative feedback loop enables learners to reflect on the nuances of their questioning techniques and facilitates their progression toward high-cognitive inquiry with an emphasis on analytical reasoning (Kim et al., 2025). **Table 1** shows a critical thinking rubric based on Bloom's taxonomy adopted from Hsu and Kim's (2016) study.

Figure 1, Figure 2, Figure 3, Figure 4, and Figure 5 demonstrate the question generation process on Ask.SMILE by each level.

The platform also allows collaboration in developing, sharing, and evaluating questions against both peer responses and AI-generated assessments. This process not only allows teachers to monitor classroom-wide inquiry patterns in real-time but also provides immediate insights into the learners' cognitive and metacognitive needs. For teacher education field, Ask.SMILE serves as a vital tool for bridging pedagogical theory and classroom practice. By engaging with the platform, PSTs can model and reflect upon the interaction between their own questioning techniques, the structural "how" of inquiry and their underlying questioning motivation, the "why" that drives cognitive curiosity. The data generated through these interactions allows for a nuanced assessment of how questioning strategies and intrinsic motivation contribute to the development of higher-level critical thinking. Moreover, evaluating PSTs' satisfaction with

Ask.SMILE provides essential data on the tool's efficacy as a scaffolding agent. Ultimately, these experiences inform PSTs' professional identities and their future aspirations to implement sophisticated inquiry-based learning practices in K-12 settings, ensuring they are prepared to navigate the complexities of the modern, AI-augmented classroom.

Finally, to address issues of equity and the digital divide, Ask.SMILE supports offline operation on low-cost hardware such as the Raspberry Pi 5 (Seeds of Empowerment, 2025). This democratization of high-tier educational technology ensures that inquiry-based learning frameworks remain accessible to underprivileged regions with limited infrastructure, making the cultivation of critical thinking both scalable and equitable across diverse global contexts (Kim & Lee, 2020; Kim et al., 2008).

The core technical framework behind this study involved three components:

- (1) a Web application designed to evaluate the levels of questions posed by the user,
- (2) a growing database of user-generated questions and system-generated responses, and
- (3) a mechanism for cleaning and analyzing the data.

Ask a question

With the help of GPT, your question will be evaluated on a rubric from Level 1 to Level 5 aligned to Bloom's Taxonomy

What is critical thinking?

Submit question

I would classify this question as a level 1 question. It is a simple recall question that seeks a definition of a concept without requiring analysis, synthesis, or evaluation. The question does not involve any hypothetical scenarios, uncertain situations, or conditional structures, which would elevate it to a higher level in Bloom's Taxonomy.

To improve your question and elevate it, consider asking something like: "If critical thinking were to be integrated into all educational curriculums, how might that change student outcomes in uncertain future job markets?" This version encourages deeper exploration and speculation about the implications of critical thinking. Keep going; your curiosity can lead to more complex and engaging questions!

Figure 1. Level 1 (<https://ask.smile.seedsofempowerment.org/>)

Ask a question

With the help of GPT, your question will be evaluated on a rubric from Level 1 to Level 5 aligned to Bloom's Taxonomy

How does teacher use technology effectively in the classroom?

Submit question

This question can be classified as level 2. It seeks an explanation of how teachers utilize technology, which involves recalling and understanding methods or strategies. However, it doesn't ask for analysis, evaluation, or creative thinking, which are necessary for higher levels of Bloom's Taxonomy.

To elevate this question, you might consider framing it as: "If various types of technology were available in the classroom, how might teachers effectively integrate these tools to enhance student learning outcomes?" This would introduce a hypothetical scenario and encourage critical thinking about the implications and possibilities in the classroom setting. Keep exploring your thinking and always strive to deepen your questions!

Figure 2. Level 2 (<https://ask.smile.seedsofempowerment.org/>)

Ask a question

With the help of GPT, your question will be evaluated on a rubric from Level 1 to Level 5 aligned to Bloom's Taxonomy

Why is it important to teach students critical thinking?

Submit question

This question would be classified as level 3. It requires the evaluator to analyze and articulate reasons and benefits related to teaching critical thinking, which involves understanding various educational philosophies and their implications on student development. While it does not reach the complexity of a level 4 or level 5 question that encourages deeper analysis or speculation about future scenarios, it does demonstrate a thoughtful consideration of educational methods and their importance.

To enhance this question to a higher level, you might consider phrasing it as: "If educational systems were to prioritize critical thinking, what potential changes might we see in student outcomes and societal problem-solving capabilities?" This revision introduces a hypothetical scenario and explores uncertainty about the future implications.

Keep asking questions and exploring thoughtful ideas; your curiosity about education and its impacts is commendable!

Figure 3. Level 3 (<https://ask.smile.seedsofempowerment.org/>)

Ask a question

With the help of GPT, your question will be evaluated on a rubric from Level 1 to Level 5 aligned to Bloom's Taxonomy

What does it take for my students to become critical thinkers?

Submit question

This question can be classified as a level 4 question. It asks for an exploration of the components, strategies, and conditions necessary to develop critical thinking skills in students. The question invites analysis, as it implies a deeper examination of factors such as curriculum design, teaching methods, and student engagement, rather than simply seeking a direct answer.

To encourage growth in this area, consider implementing the following strategies:

1. **Encourage Inquiry:** Foster a classroom environment that encourages questioning and discussion. Promote an atmosphere where students feel safe to express different viewpoints.
2. **Teach Problem-Solving Skills:** Incorporate real-world problems and case studies that require students to analyze, evaluate, and propose solutions.
3. **Emphasize Reflection:** Encourage students to reflect on their learning experiences, thought processes, and the reasoning behind their conclusions.
4. **Use Diverse Learning Strategies:** Incorporate various teaching methods such as debates, group projects, and Socratic seminars that challenge students to think critically and collaboratively.
5. **Model Critical Thinking:** Demonstrate your own critical thinking processes in class discussions and problem-solving exercises. Share your thought processes, successes, and mistakes.
6. **Foster a Growth Mindset:** Remind students that developing critical thinking skills takes time and persistence. Encourage them to embrace challenges and learn from their experiences.

By focusing on cultivating these elements, you're likely to see your students grow into more effective critical thinkers. Your commitment to their development will inspire them to actively engage with their learning!

Figure 4. Level 4 (<https://ask.smile.seedsofempowerment.org/>)

Ask a question

With the help of GPT, your question will be evaluated on a rubric from Level 1 to Level 5 aligned to Bloom's Taxonomy

What if my students do not care to become a critical thinker?

Submit question

This is a level 5 question because it introduces a hypothetical scenario ("What if...") that acknowledges uncertainty about your students' attitudes towards becoming critical thinkers. The question prompts deep reflection and encourages exploration of potential strategies and solutions to address disengagement in critical thinking.

Now regarding your situation, remember that every educator faces challenges and it's important to maintain optimism and a growth mindset. One potential approach is to create an engaging learning environment that piques their curiosity and demonstrates the relevance of critical thinking to their lives. Use real-world examples and foster discussions that encourage students to express their opinions and challenge their thoughts. Building personal connections and showing genuine interest in their perspectives can also inspire them to think critically.

While it may feel disheartening at times, your grit and perseverance can be powerful tools for transformation. Focus on small successes, as even fostering critical thinking in just a few students can create a ripple effect. Keep nurturing your passion for teaching—your dedication can inspire change even in the most reluctant learners!

Figure 5. Level 5 (<https://ask.smile.seedsofempowerment.org/>)

The Web application was designed in Python to facilitate user interactions, allowing users to engage with the system by posing questions and receiving responses generated by the OpenAI model. In addition, a managed NoSQL database instance, Amazon Lambda, was used to store and organize user-generated questions and system-generated responses. Finally, to derive meaningful insights from the user observations, RStudio helped sanitize and find trends and patterns within the data set.

In the Ask.SMILE software tool, enterprise level security measures are in place to protect education data collection. Data encryption ensures the confidentiality of student questions and responses both on the website and within the database at rest. Use of Amazon API Gateway ensures compliance with Amazon's built-in robust security standards for data in transit. Access to research data is limited to authenticated personnel only.

METHODS

Participants

Participants were drawn from eight sections of the CI 100 course, *application of technology in the classroom*, a prerequisite for the teaching credential program offered during Fall 2023, Winter 2024, and Spring 2024 at

Table 2. Students' familiarity level with the concept of AI before using it in course

Prior familiarity level	N	Percentage (%)
1. Never heard of it	11	6.4
2. Heard of it but not familiar at all (never exposed to or used it)	51	29.5
3. Somewhat familiar (seen it but not used it yet)	67	38.7
4. Quite familiar (used it/have some exposure to it)	39	22.5
5. Very familiar (used it quite a bit)	5	2.9
Total	173	100

Note. Five PSTs did not provide a response to this question

a public university on the West coast of the United States. The sample represented a convenience sample of PSTs enrolled in these course sections. Out of the 191 PSTs enrolled in the course, responses were obtained from 178 individuals, of whom 84.8% were female. The majority of enrolled PSTs were from liberal studies department (87.1%). Most PSTs in the sample were either juniors (31.5%) or seniors (62.4%), although the sample also included sophomores (1.7%), post-baccalaureates/graduate students (3.9%), and one participant who did not indicate their academic level (0.6%). The majority of participants self-identified as Hispanic (65.2%), followed by White (17.4%), Asian (5.1%), African American (1.1%), and two or more races (1.1%). In addition, 6.2% were classified as nonresident alien, and 4.0% were classified as unknown/not reported. Their ages ranged from 20 to 41 years, with an average age of 24 years (standard deviation [*SD*] = 3.96). Regarding their prior experience with AI, most PSTs indicated some level of familiarity with the concept prior to using it in the CI 100 course (see [Table 2](#) for distribution of responses).

Instruments

Ask.SMILE and critical thinking course assignment

As part of the course, PSTs individually completed an assignment using the AI tool called Ask.SMILE and reported their user experience with the tool. Specifically, this assignment required PSTs to generate 50 or more questions on the Ask.SMILE platform (<https://Ask.SMILE.stanford.edu/>). Second, they were to reflect on Ask.SMILE as a critical thinking assessment and constructive feedback tool provider (Kim, 2024; Kim & An, 2016; Kim et al., 2025). The reflection concerned:

- (1) whether and how Ask.SMILE fed students' critical thinking with its assessment and feedback,
- (2) how it inspired them to find the answers and learn more in depth about a topic, and
- (3) whether it motivated them to ask better questions to receive better assessment.

In addition, the students reflected on

- (4) the breadth, depth, and usefulness of the feedback,
- (5) how they perceived the authenticity and accuracy of the feedback, and
- (6) how they would apply the tool in their future K-12 classroom.

The predominant learning outcomes of the assignment include the practice of critical and reflective thinking by the PSTs as displayed in their question asking and reflective writing activities, respectively. Specifically, hands-on experience with Ask.SMILE and real-time personalized assessment and feedback on the questions help PSTs improve their question asking skills and question quality. The reflection, which requires deep reasoning and analysis, is metacognitive in nature, and demonstrates growth in reflective analysis and critical thinking over time.

Post-survey

Upon completion of the course, PSTs were invited to participate in a graded survey, part of which focused on their experiences with the Ask.SMILE tool. The survey included items prompting PSTs to describe their questioning techniques (i.e., how questions were asked) and questioning motivation (i.e., why questions were asked). The survey items were developed based on the instructional objectives of the course and the design features of Ask.SMILE and were reviewed by project experts to support content relevance and coverage.

Questioning techniques item read "What were the techniques you used to ask the questions on Ask.SMILE?" with six predefined options related to structure, phrasing, and methods, along with an "other"

option for additional detail. PSTs were able to select multiple response options and offer further details if they chose "other." Hence, they were coded as seven dichotomous items measuring questioning techniques. Because these items represented distinct questioning techniques rather than indicators of a single latent construct, they were treated as independent categorical variables rather than as a scale.

Questioning motivation item involves "What was/were your approach/es to asking questions? (i.e., Why you asked what you asked?) Select all that apply. Please specify if 'other.'" Seven predefined options were provided, along with "Other" category for open-ended responses. Hence, they were coded as eight dichotomous items measuring questioning motivation. Similar to questioning techniques, these items reflected independent categories of motivation and therefore were not conceptualized as a unidimensional scale. In addition, since the questioning techniques and questioning motivation items represented independent categorical indicators rather than reflective scale items, internal consistency reliability estimates were not considered appropriate.

Satisfaction with Ask.SMILE was measured using three Likert-type items assessing students' perceptions of

- (a) how well Ask.SMILE evaluated their critical thinking through their questions,
- (b) the helpfulness of feedback received, and
- (c) their overall experience.

The first two satisfaction items read:

- (1) "How happy/satisfied were you with the Ask.SMILE assessment of your critical thinking skills through the questions?" and
- (2) "How happy/satisfied were you with the feedback given by Ask.SMILE on your questions?"

Responses to these two items were recorded on a 5-point Likert-type scale (from 1 Not satisfied at all to 5 Very satisfied). The third item: (3) How did you rate your overall experience with Ask.SMILE has a different Likert-scale label, ranging from 1 poor to 5 excellent.

Unlike the questioning techniques and questioning motivation items, the three satisfaction items were conceptualized as indicators of a single latent construct (i.e., satisfaction with Ask.SMILE). Therefore, exploratory factor analysis using the principal axis factoring extraction method was conducted to examine dimensionality. The Kaiser-Meyer-Olkin measure of sampling adequacy was .70, and Bartlett's test of sphericity was significant, $\chi^2(3, N = 178) = 250.93, p < .001$, supporting the suitability of the data for factor analysis. Because only one factor emerged, rotation was not applicable. All items loaded onto a single factor, with factor loadings ranging from .75 to .94, collectively explaining 67.7% of the variance. The reliability estimate, assessed by Cronbach's alpha, was .85. Based on these results supporting a unidimensional measure of satisfaction, a composite score was computed by averaging the three items.

Finally, PSTs were invited to provide an open-ended response to discuss how they would utilize Ask.SMILE in their future classrooms if they had access to the data generated by the tool.

Procedure

This study was approved by the Institutional Review Board of California State University, Fresno (Protocol No: 2441-2024). Surveys were administered online using Google Forms at the conclusion of the course.

Security of Data Collection and Use

Collected data for the course include three parts:

- (1) the questions asked by the PSTs together with the ranking and the feedback from Ask.SMILE,
- (2) the PSTs' reflections on Ask.SMILE as an assessment and a constructive feedback provider, and
- (3) the pre- and post-survey data.

All of the data are secured and protected for five years under the university Canvas course shell. For the scope of this project, only the survey data on the question techniques and motivation on Ask.SMILE platform were used. The total surveys collected were 178 (74 for Fall 2023, 14 for Winter 2024, and 90 for Spring 2024).

Table 3. Questioning techniques: Frequencies and differences by gender and AI familiarity level

Questioning technique	N	P (%)	Across gender			Across prior familiarity level		
			X-1	<i>p</i>	CV	X-2	<i>p</i>	CV
1. Ask the same question but phrase it differently every time	126	70.8	0.75	.386	.065	1.65	.801	.098
2. Ask more hypothetical questions to get level 5	118	66.3	0.70	.401	.063	2.43	.657	.119
3. Ask questions about topics/answers I care about	108	60.7	2.40	.122	.116	5.11	.277	.172
4. Ask random questions on a variety of topics	106	59.6	0.70	.413	.061	1.12	.892	.080
5. Ask questions that challenge Ask.SMILE's assessment and feedback	94	52.8	0.28	.598	.039	1.68	.795	.098
6. Ask the same question in different languages	26	14.6	0.00	.973	.002	5.81	.214	.183
7. Other	4	2.2	0.73	.392	.064	0.55	.968	.056

Note. P: Percentage; X-1: $\chi^2(1, N = 178)$; X-2: $\chi^2(4, N = 173)$; CV: Cramér's V; & Cramér's V represents the effect size for Chi-square analyses and is interpreted as negligible ($< .10$), small (.10-.29), medium (.30-.49), or large ($\geq .50$)

All of the data were completely de-identified and anonymized to remove the PSTs' identifying information. An IRB approval was obtained for using the archival data on the human subjects. An IRB approval was obtained for using the archival data on the human subjects.

In the Ask.SMILE software, enterprise level security measures were in place to protect the education data collected. Data encryption ensured the confidentiality of user's questions and responses both on the website and within the database at rest. Use of Amazon API Gateway ensured compliance with Amazon's built-in robust security standards for data in transit. Access to research data was limited to authenticated personnel.

Data Analysis

Quantitative analyses were conducted using SPSS, version 29.0.1.0 (IBM Corp., 2023). To address RQ1, frequency and chi-square analyses were used to examine trends and associations between students' questioning techniques and questioning motivation when using Ask.SMILE. To address RQ2, a series of one-way analyses of variance (ANOVA) were performed to examine whether students' satisfaction with Ask.SMILE differed based on their reported questioning techniques and questioning motivation.

The qualitative approach involves a systematic analysis of the open-ended survey responses to gain insight into the PSTs' stated plans to use Ask.SMILE in their future classroom. Content analysis was used to identify recurring patterns, trends, and relationships within the data. The coding process was independently conducted by the researchers, who reviewed and developed the initial set of codes, which were refined through iterative discussions to ensure clarity and consensus. The finalized codes were grouped into broader categories, leading to the identification of key themes. Importantly, these themes provided a nuanced understanding of how the PSTs were inspired to use Ask.SMILE in their future classroom.

RESULTS

Data used in this study include 178 surveys on Ask.SMILE as an assessment and a constructive feedback provider as of April 2024. The data collected was intended to help understand the PSTs' thought process when using the Ask.SMILE application. Specifically, the question technique and motivation items indicated that the PSTs had a natural desire to improve their critical thinking skill level and learning results. The data on the open-ended question revealed the PSTs' experience and satisfaction with Ask.SMILE that led them to consider using it in their future classroom.

Questioning Techniques

As shown in **Table 3**, PSTs used a variety of techniques to ask questions on the Ask.SMILE platform. Many PSTs attempted various techniques, with the most prevalent being asking the same question but phrasing it differently (ask the same question but phrase it differently every time, 70.8%) as a way to explore nuanced perspectives or improve clarity. Additionally, other techniques employed by PSTs included exploring hypothetical questions (i.e., ask more hypothetical questions to get level 5, 66.3%), questions about topics they were familiar with and genuinely interested in or on topics that they often wondered about and had not found answers to (i.e., ask questions on topics/answers I care about, 60.7%), choosing a specific topic and formulating questions around it, and rephrasing questions when unable to think of new ones (i.e., ask random

Table 4. Questioning motivation: Frequencies and differences by gender and AI familiarity level

Questioning motivation	N	P (%)	By gender			By prior familiarity level		
			X-1	<i>p</i>	CV	X-2	<i>p</i>	CV
1. I became competitive and wanted to ask questions to get me to higher levels of critical thinking.	134	75.3%	0.03	.875	.012	4.04	.401	.153
2. I cared about my level of critical thinking but I was more interested in the topic(s).	103	57.9%	1.01	.315	.075	3.24	.519	.137
3. I wanted to test Ask.SMILE with tricky questions.	80	44.9%	0.61	.433	.059	4.03	.402	.153
4. I truly wanted to know the answer and did not really care about the level Ask.SMILE gave me.	53	29.8%	0.19	.661	.033	3.22	.522	.136
5. I had problems coming up with questions.	49	27.5%	1.30	.255	.085	10.57*	.032	.247
6. I neither cared about the answers nor levels of critical thinking, I just randomly put down what came to mind for questions.	13	7.3%	0.61	.435	.059	10.76*	.029	.249
7. I neither cared about the answers nor levels of critical thinking, I just wanted to complete the assignment.	3	1.7%	0.78	.376	.066	4.83	.305	.167
8. Other	10	5.6%	0.19	.661	.033	7.05	.133	.202

Note. P: Percentage; X-1: $\chi^2(1, N = 178)$; X-2: $\chi^2(4, N = 173)$; CV: Cramér's V; & Cramér's V represents the effect size for Chi-square analyses and is interpreted as negligible ($< .10$), small (.10-.29), medium (.30-.49), or large ($\geq .50$)

questions on a variety of topics, 59.6%). These findings suggest that PSTs actively adapted their questioning techniques to suit their learning goals, highlighting the versatility of Ask.SMILE in accommodating diverse learning needs and preferences. The prevalence of techniques focused on rephrasing questions, generating hypothetical scenarios, and asking questions related to personally meaningful topics suggests that PSTs were not merely attempting to complete the activity, but were actively experimenting with different approaches to questioning and engaging with the AI-supported feedback process. No significant differences in questioning techniques were observed across gender and prior familiarity levels with AI.

Questioning Motivation

Table 4 presents the prevalence of different questioning motivation to asking questions in Ask.SMILE. The majority of PSTs (75.3%) indicated that they became competitive and wanted to ask questions to get them to higher levels of critical thinking. Additionally, a significant portion of PSTs (57.9%) cared about their level of critical thinking but were more interested in the topic(s). Interestingly, almost half of the PSTs (44.9%) wanted to test Ask.SMILE with tricky questions. Another notable finding was that approximately one-third of PSTs (29.8%) truly wanted to know the answer and did not really care about the level Ask.SMILE gave them. It was troubling to see that more than one in four PSTs (27.5%) reported having problems coming up with questions. Furthermore, ten PSTs selected "other" and explained their questioning motivation but did not specify what they were. They enjoyed asking questions related to familiar topics like banking and housing, aimed to earn high critical thinking ratings, and sought abstract answers from Ask.SMILE. Some PSTs in this study noted their questions were random, sparked further curiosity, or became a competition for higher ratings. Personal interests, such as skincare, and the challenge of testing the AI tool or platform also influenced their questions. Taken together, these findings suggest that PSTs' motivations for interacting with Ask.SMILE extended beyond assignment completion and reflected a combination of curiosity, competitiveness, and experimentation with AI capabilities. At the same time, the presence of PSTs who struggled to generate questions suggests possible differences in PSTs' ease of engaging in AI-supported inquiry and critical questioning practices.

There were no significant differences in questioning motivation by gender. However, differences emerged based on prior AI familiarity level for PSTs who had problems coming up with questions, $\chi^2(4, N = 173) = 10.57$, $p = .032$, Cramér's V = .25, indicating a small association. Adjusted standardized residuals showed that PSTs unfamiliar with AI were more likely to report difficulty formulating questions (adjusted residual = 2.7), whereas those somewhat familiar with AI were less likely to have such difficulties (adjusted residual = -2.9). Additionally, differences emerged based on prior AI familiarity level for PSTs who neither cared about the answers nor their assessed levels of critical thinking, they just randomly put down what came to mind for questions, $\chi^2(4, N = 173) = 10.76$, $p = .029$, Cramér's V = .25, indicating a small association. Adjusted standardized residuals showed that PSTs who had heard of AI but had no prior exposure were more likely to report randomly generating questions without concern for answers or critical thinking levels (adjusted residual = 3.3).

The Relationships Between Questioning Techniques and Questioning Motivation

Table 5 shows the results of chi-square tests examining the relationships between questioning techniques and questioning motivation. Several significant associations emerged between them as indicated by the asterisks.

Table 5. Chi-square test of questioning approaches by questioning motivation, $N = 178$

Questioning technique	Questioning motivation	χ^2	p	CV
1. Ask the same question but phrase it differently every time	1. I became competitive and wanted to ask questions to get me to higher levels of critical thinking.	3.87*	.049	.147
	2. I cared about my level of critical thinking but I was more interested in the topic(s).	4.13*	.042	.152
	3. I wanted to test Ask.SMILE with tricky questions.	1.25	.264	.084
	4. I truly wanted to know the answer and did not really care about the level Ask.SMILE gave me.	0.80	.371	.067
	5. I had problems coming up with questions.	0.24	.628	.036
	6. I neither cared about the answers nor levels of critical thinking, I just randomly put down what came to mind for questions.	1.95	.163	.105
	7. I neither cared about the answers nor levels of critical thinking, I just wanted to complete the assignment.	2.07	.150	.108
	8. Other	2.21	.137	.112
2. Ask more hypothetical questions to get level 5	1. I became competitive and wanted to ask questions to get me to higher levels of critical thinking.	11.36***	< .001	.253
	2. I cared about my level of critical thinking but I was more interested in the topic(s).	7.84**	.005	.210
	3. I wanted to test Ask.SMILE with tricky questions.	8.17**	.004	.214
	4. I truly wanted to know the answer and did not really care about the level Ask.SMILE gave me.	2.06	.152	.107
	5. I had problems coming up with questions.	0.03	.864	.013
	6. I neither cared about the answers nor levels of critical thinking, I just randomly put down what came to mind for questions.	0.97	.324	.074
	7. I neither cared about the answers nor levels of critical thinking, I just wanted to complete the assignment.	0.00	.989	.001
	8. Other	0.19	.665	.032
3. Ask questions about topics/ answers I care about	1. I became competitive and wanted to ask questions to get me to higher levels of critical thinking.	0.01	.914	.008
	2. I cared about my level of critical thinking but I was more interested in the topic(s).	10.66***	.001	.245
	3. I wanted to test Ask.SMILE with tricky questions.	2.84	.092	.126
	4. I truly wanted to know the answer and did not really care about the level Ask.SMILE gave me.	8.81**	.003	.222
	5. I had problems coming up with questions.	2.15	.142	.110
	6. I neither cared about the answers nor levels of critical thinking, I just randomly put down what came to mind for questions.	0.00	.947	.005
	7. I neither cared about the answers nor levels of critical thinking, I just wanted to complete the assignment.	1.98	.160	.105
	8. Other	0.39	.534	.047
4. Ask random questions on a variety of topics	1. I became competitive and wanted to ask questions to get me to higher levels of critical thinking.	0.18	.670	.032
	2. I cared about my level of critical thinking but I was more interested in the topic(s).	0.52	.470	.054
	3. I wanted to test Ask.SMILE with tricky questions.	5.11*	.024	.169
	4. I truly wanted to know the answer and did not really care about the level Ask.SMILE gave me.	0.66	.415	.061
	5. I had problems coming up with questions.	2.72	.099	.124
	6. I neither cared about the answers nor levels of critical thinking, I just randomly put down what came to mind for questions.	0.55	.460	.055
	7. I neither cared about the answers nor levels of critical thinking, I just wanted to complete the assignment.	0.06	.800	.019
	8. Other	0.40	.526	.047

Table 5 (Continued).

Questioning technique	Questioning motivation	X	p	CV
5. Ask questions that challenge Ask.SMILE's assessment and feedback	1. I became competitive and wanted to ask questions to get me to higher levels of critical thinking.	3.87*	.049	.147
	2. I cared about my level of critical thinking but I was more interested in the topic(s).	4.13*	.042	.152
	3. I wanted to test Ask.SMILE with tricky questions.	1.25	.264	.084
	4. I truly wanted to know the answer and did not really care about the level Ask.SMILE gave me.	0.80	.371	.067
	5. I had problems coming up with questions.	0.24	.628	.036
	6. I neither cared about the answers nor levels of critical thinking, I just randomly put down what came to mind for questions.	1.95	.163	.105
	7. I neither cared about the answers nor levels of critical thinking, I just wanted to complete the assignment.	2.07	.150	.108
	8. Other	2.21	.137	.112
6. Ask the same question in different languages	1. I became competitive and wanted to ask questions to get me to higher levels of critical thinking.	11.36***	< .001	.253
	2. I cared about my level of critical thinking but I was more interested in the topic(s).	7.84**	.005	.210
	3. I wanted to test Ask.SMILE with tricky questions.	8.17**	.004	.214
	4. I truly wanted to know the answer and did not really care about the level Ask.SMILE gave me.	2.06	.152	.107
	5. I had problems coming up with questions.	0.03	.864	.013
	6. I neither cared about the answers nor levels of critical thinking, I just randomly put down what came to mind for questions.	0.97	.324	.074
	7. I neither cared about the answers nor levels of critical thinking, I just wanted to complete the assignment.	0.00	.989	.001
	8. Other	0.19	.665	.032
7. Other	1. I became competitive and wanted to ask questions to get me to higher levels of critical thinking.	0.01	.914	.008
	2. I cared about my level of critical thinking but I was more interested in the topic(s).	10.66***	.001	.245
	3. I wanted to test Ask.SMILE with tricky questions.	2.84	.092	.126
	4. I truly wanted to know the answer and did not really care about the level Ask.SMILE gave me.	8.81**	.003	.222
	5. I had problems coming up with questions.	2.15	.142	.110
	6. I neither cared about the answers nor levels of critical thinking, I just randomly put down what came to mind for questions.	0.00	.947	.005
	7. I neither cared about the answers nor levels of critical thinking, I just wanted to complete the assignment.	1.98	.160	.105
	8. Other	0.39	.534	.047

Note. X: $\chi^2(1, N = 178)$; CV: Cramér's V; & Cramér's V represents the effect size for Chi-square analyses and is interpreted as negligible (< .10), small (.10-.29), medium (.30-.49), or large ($\geq .50$)

Asking the same question but phrasing it differently every time

Chi-square tests revealed that PSTs who asked the same question but tended to phrase it differently every time were more likely to become competitive and wanted to ask questions to get me to higher levels of critical thinking, $\chi^2(1, N = 178) = 3.87, p = .049$, Cramér's $V = .15$, indicating a small association, and cared about their level of critical thinking but were more interested in the topic(s), $\chi^2(1, N = 178) = 4.13, p = .042$, Cramér's $V = .15$, indicating a small association.

Asking more hypothetical questions to get level 5

PSTs who asked more hypothetical questions to attain higher critical thinking levels were motivated by becoming competitive and wanting to ask questions to get me to higher levels of critical thinking, $\chi^2(1, N = 178) = 11.36, p < .001$, Cramér's $V = .25$, indicating a small association, caring about their level of critical thinking but being more interested in the topic(s), $\chi^2(1, N = 178) = 7.84, p = .005$, Cramér's $V = .21$, indicating a small association, and wanting to test Ask.SMILE with tricky questions, $\chi^2(1, N = 178) = 8.17, p = .004$, Cramér's $V = .21$, indicating a small association.

Asking questions on topics/answers students care about

PSTs who asked questions on topics that they cared about were more likely to care about their level of critical thinking but were more interested in the topic(s), $\chi^2(1, N = 178) = 10.66, p = .001$, Cramér's $V = .25$, indicating a small association, and truly wanting to know the answer and not really caring about the level Ask.SMILE gave them, $\chi^2(1, N = 178) = 8.81, p = .003$, Cramér's $V = .22$, indicating a small association.

Asking random questions on a variety of topics

PSTs who asked random questions on a variety of topics primarily tested Ask.SMILE with tricky questions, $\chi^2(1, N = 178) = 5.11, p = .024$, Cramér's $V = .17$, indicating a small association.

Asking questions that challenge Ask.SMILE's assessment and feedback

PSTs who asked questions that challenged Ask.SMILE's assessment and feedback were more likely to become competitive and want to ask questions to get them to higher levels of critical thinking, $\chi^2(1, N = 178) = 10.33, p = .001$, Cramér's $V = .24$, indicating a small association, and wanted to test Ask.SMILE with tricky questions, $\chi^2(1, N = 178) = 8.67, p = .003$, Cramér's $V = .22$, indicating a small association. In contrast, PSTs did not engage in this approach when they faced difficulties generating questions, $\chi^2(1, N = 178) = 5.34, p = .021$, Cramér's $V = .17$, indicating a small association.

Asking the same question in different languages

Finally, PSTs who asked the same question in different languages primarily due to competitive motivations to achieve higher levels of critical thinking, $\chi^2(1, N = 178) = 4.74, p = .029$, Cramér's $V = .16$, indicating a small association, and to test Ask.SMILE in innovative ways with challenging questions, $\chi^2(1, N = 178) = 5.14, p = .023$, Cramér's $V = .17$, indicating a small association.

Overall, the relationships between questioning techniques and questioning motivation suggest that PSTs' approaches to generating questions were shaped not only by the strategies they used, but also by the motivations underlying their engagement with Ask.SMILE. PSTs who were motivated by curiosity, competition, or interest in improving their critical thinking were more likely to engage in exploratory and adaptive questioning approaches, such as asking hypothetical questions, rephrasing questions, and challenging the AI system's responses. In contrast, PSTs who reported difficulty generating questions appeared less likely to engage in these more exploratory questioning strategies. These findings suggest that question-generation approaches in AI-supported learning environments may be associated with both questioning motivation and strategic questioning behaviors.

Satisfaction With Ask.SMILE

Table 6 shows the results of a series of ANOVA exploring dissidences in PST satisfaction with Ask.SMILE based on their questioning techniques and questioning motivation. Examination of descriptive statistics (skewness = -0.74, kurtosis = 0.18), together with visual inspection of group distributions and Q-Q plots, suggested acceptable normality of the satisfaction variable; Levene's test additionally supported the assumption of homogeneity of variance. There were no significant differences in PSTs' satisfaction based on questioning techniques they used. However, differences in satisfaction with Ask.SMILE emerged based on questioning motivation. Specifically, PSTs who became competitive and wanted to ask questions to get to higher levels of critical thinking ($M = 4.29, SD = 0.68$) reported significantly higher satisfaction with Ask.SMILE compared to those who did not exhibit this competitive approach ($M = 3.89, SD = 0.78$), $F(1, 176) = 10.11, p = .002, \eta^2 = .05$. In contrast, PSTs who had problems coming up with questions ($M = 4.01, SD = 0.81$) expressed significantly lower satisfaction with Ask.SMILE than those who found question generation less challenging ($M = 4.26, SD = 0.69$), $F(1, 176) = 4.00, p = .047, \eta^2 = .02$. According to conventional interpretations of η^2 , these effects were in the small range, suggesting meaningful but modest associations between questioning motivation and satisfaction with Ask.SMILE. Importantly, these findings suggest that PSTs who approached Ask.SMILE with greater curiosity, competitiveness, and interest in critical thinking tended to report more positive experiences with the platform, whereas PSTs who struggled with question generation reported lower satisfaction. These patterns suggest that PSTs' questioning motivation and prior experiences generating questions may be associated with how they experience AI-supported critical thinking tools or platforms.

Table 6. Results of ANOVA for satisfaction with Ask.SMILE based on approaches and techniques to asking questions, $N = 178$

	Yes				No				LEVENE		ANOVA		
	<i>N</i>	<i>M</i>	<i>SD</i>	95% CI	<i>N</i>	<i>M</i>	<i>SD</i>	95% CI	<i>F</i> (1, 176)	<i>p</i>	<i>F</i> (1, 176)	<i>p</i>	η^2
Questioning techniques													
1. Ask the same question but phrase it differently every time	126	4.21	0.75	[4.07, 4.34]	52	4.15	0.69	[3.96, 4.34]	0.32	.573	0.24	.625	.00
2. Ask more hypothetical questions to get level 5	118	4.21	0.67	[4.09, 4.33]	60	4.14	0.83	[3.93, 4.36]	2.95	.088	0.34	.561	.00
3. Ask questions on topics/answers I care about	108	4.21	0.76	[4.06, 4.35]	70	4.16	0.68	[4.00, 4.32]	0.40	.529	0.16	.689	.00
4. Ask random questions on a variety of topics	106	4.12	0.79	[3.97, 4.27]	72	4.29	0.63	[4.14, 4.43]	3.46	.065	2.20	.140	.01
5. Ask questions that challenge Ask.SMILE's assessment and feedback	94	4.26	0.75	[4.10, 4.41]	84	4.12	0.70	[3.96, 4.27]	0.90	.343	1.65	.200	.01
6. Ask the same question in different languages	26	4.05	0.92	[3.68, 4.42]	152	4.21	0.69	[4.10, 4.32]	7.14	.008	1.09	.297	.01
7. Other	4	4.00	0.82	[2.70, 5.30]	174	4.19	0.73	[4.08, 4.30]	0.19	.667	0.28	.600	.00
Questioning motivation													
1. I became competitive and wanted to ask questions to get me to higher levels of critical thinking	134	4.29	0.68	[4.17, 4.40]	44	3.89	0.78	[3.66, 4.13]	0.50	.480	10.11**	.002	.05
2. I cared about my level of critical thinking but I was more interested in the topic(s)	103	4.22	0.74	[4.07, 4.36]	75	4.15	0.72	[3.99, 4.32]	0.03	.862	0.35	.553	.00
3. I wanted to test Ask.SMILE with tricky questions	80	4.30	0.72	[4.14, 4.46]	98	4.10	0.73	[3.95, 4.24]	0.18	.676	3.69	.057	.02
4. I truly wanted to know the answer and did not really care about the level Ask.SMILE gave me	53	4.08	0.80	[3.86, 4.30]	125	4.24	0.69	[4.11, 4.36]	0.88	.349	1.85	.176	.01
5. I had problems coming up with questions	49	4.01	0.81	[3.78, 4.25]	129	4.26	0.69	[4.14, 4.38]	1.17	.280	4.00*	.047	.02
6. I neither cared about the answers nor levels of critical thinking, I just randomly put down what came to mind for questions	13	3.82	0.52	[3.51, 4.13]	165	4.22	0.73	[4.11, 4.33]	2.72	.101	3.65	.058	.02
7. I neither cared about the answers nor levels of critical thinking, I just wanted to complete the assignment	3	4.11	0.84	[2.03, 6.20]	175	4.19	0.73	[4.08, 4.30]	0.00	.998	0.04	.852	.00
8. Other	10	4.10	0.77	[3.55, 4.65]	168	4.19	0.73	[4.08, 4.31]	.00	.971	0.16	.691	.00

Note. CI: Confidence interval; LEVENE: Levene's test of homogeneity of variance; & η^2 represents the effect size for ANOVA analyses and is interpreted as negligible ($< .01$), small (.01-.059), medium (.06-.139), or large ($\geq .14$).

Applications of Ask.SMILE into Future Classrooms

There were 178 PSTs responding to the open-ended survey question of how they would utilize Ask.SMILE in their future classrooms. These PSTs reported diverse plans for integrating Ask.SMILE into their future classrooms, among which enhancing student questioning practices and critical thinking development ranked the highest. Whether used collaboratively through group activities or individually, Ask.SMILE was recognized as a versatile resource. In addition to utilizing it to enhance the design of one's lesson plans, these PSTs viewed it as a viable tool for creating an inclusive, innovative, and intellectually stimulating learning environment across various subjects. Lastly, the PSTs in this study indicated that they would use Ask.SMILE as a critical thinking and content comprehension assessment tool, as well as a resource for learner writing support. **Table 7** illustrates three areas of application of Ask.SMILE reported by the PSTs, followed by themes and indicators.

Table 7. Application of Ask.SMILE to future classrooms

Areas of application	Themes	Indicators
Cognitive development (student thinking)	Development of questioning skills and critical thinking	<ul style="list-style-type: none"> • Support student question-asking practices and critical thinking development • 47 • Improve question-asking skills • 36 • Ask meaningful, thoughtful, deep, and critical questions • 23 • Coach asking advanced/high-level questions with examples • 21 • Ask questions by student ability and show different question levels • 15 • Practice how questions are made and refine question-asking skills • 12 • Ask questions in different ways to explore responses • 10 • Have students ask questions and elaborate on the responses • 8
		<ul style="list-style-type: none"> • Use for research, brainstorming, and exploration activities • 13 • Use as a game to encourage asking more questions • 6 • Promote student engagement through games and rewards (e.g., Level 5 questions) • 4 • Use in discussion boards to facilitate student interaction • 3
Pedagogical applications (instructional practices)	Classroom engagement and inquiry-based learning	<ul style="list-style-type: none"> • Build course content, lessons, and better questions • 15 • Use for research questions and brainstorming in lesson planning • 15 • Incorporate in course assignments • 3
	Instructional and lesson design	<ul style="list-style-type: none"> • Test critical thinking skills and question asking ability • 11 • Ask reflective questions to show understanding (e.g., end-of-lesson reflection) • 7 • Measure different types and levels of questions • 4
Assessment and feedback provider	Assessment of critical thinking & understanding	<ul style="list-style-type: none"> • Assist essay writing by asking meaningful questions • 8 • Support writing by asking questions in different ways • 6 • Support argument development • 5 • Apply across subject areas (e.g., science, history, English) • 5
	Academic skill development (e.g., writing and argumentation)	

Cognitive development (student thinking)

Theme. Development of questioning skills and critical thinking: This is one of the main areas of application of Ask.SMILE reported by the participants. Under this theme, PSTs emphasized the platform's role in supporting students' development of questioning skills and critical thinking. Many PSTs reported planning to leverage the platform to guide students in crafting thoughtful and critical inquiries to eventually enhance their metacognitive processes. The PSTs envisioned using Ask.SMILE to encourage learners to elevate their inquiries and explore more thought-provoking topics using Ask.SMILE's feedback on the questions. They also suggested using this feedback to teach students how to rephrase their questions and develop critical thinking through an iterative process. As an example, one participant shared "I would have students practice their critical thinking skills through trying to find ways to get a Level 4 or 5 through adjusting their questions." Another noted "I would like to use Ask.SMILE in my future classroom to allow my students to practice better levels of questioning. It really helps practice the necessary skills and thought process that is required to formulate deeper level thinking." These reflections show how Ask.SMILE enables iterative question refinement, encouraging students to elevate their inquiries from simple recall to deeper analysis and synthesis.

PSTs also emphasized the tool capacity in helping students ask questions in different ways, explore the responses, and differentiate their questioning approaches based on their cognitive levels and abilities. Using these refinement processes iteratively allows PSTs to deepen their lines of inquiry, explore deeper and more meaningful questions, ultimately strengthening their critical thinking skills.

Ask.SMILE is particularly valued for its ability to enhance critical thinking in writing assignments and other subject areas by the PSTs. They reported planning to incorporate the tool to guide students in crafting meaningful questions that inspire compelling essay topics and argument development. As an example, one participant explained:

I may incorporate Ask.SMILE to teach students the different ways to ask a critical thinking question. Maybe specifically in the English portion of the class to showcase how to receive a particular response based on how you ask a question. (student participant)

Besides writing, the PSTs planned to use Ask.SMILE across subject areas such as history, science, and English to prompt reflective and analytical questioning, which fosters deeper engagement with content and supports higher-order thinking across disciplines.

Pedagogical applications (instructional practices)

Theme 1. Classroom engagement and inquiry-based learning: Beyond cognitive development, PSTs identified Ask.SMILE as a valuable tool to promote classroom engagement and inquiry-based learning. Participants described using the platform to support student-centered activities such as research, brainstorming, and discussion-based learning. For instance, one participant wrote: "Ask.SMILE would be a good tool for discussion boards. Students can ask a question for their peers to answer but put it in Ask.SMILE in order to have a good critical discussion." In regards to promoting independent thinking and inquiry-driven learning, one participant indicated, "I think I could see myself using Ask.SMILE to challenge myself to ask open-ended questions that encourage independent thought and reflection so my students have a better opportunity to share their knowledge and explore concepts even further."

Several PSTs highlighted the potential of gamifying Ask.SMILE to motivate student engagement. For example, one participant suggested using the tool as a game to encourage students to generate higher-level questions, while another proposed rewarding student for achieving level 5 questions. Additionally, Ask.SMILE was viewed as an effective tool for facilitating online discussions and fostering collaborative inquiry, where students could pose questions for peers to answer, and explore the topic in depth through their back and forth interaction. As one participant noted, "Students can ask a question for their peers to answer... in order to have a good critical discussion." And another suggested, "I would use Ask.SMILE during discussion boards so students can ask critical thinking questions and encourage students to think critically and ask questions that stimulate deeper understanding." And another elaborated, "I would use it when having students do peer reviews. By having students practice the depth of their questions, they can introduce these practices on their peer's work to enhance it." Finally, the tool was also recognized for its role in supporting hypothesis generation, as one participant noted, "I think I would use it if my students had an assignment where they had to come up with a theory or hypothesis. They could utilize Ask.SMILE to see if their theory or hypothesis was good."

Theme 2. Instructional and lesson design: PSTs proposed several ideas on how to use Ask.SMILE for students to practice and refine their questioning skills through lesson planning, assignment creation, and gamification activities. envisioned integrating Ask.SMILE into building course content, develop lesson ideas, and design assignments that incorporate structured questioning activities. As an example, one participant shared that students could experiment with generating their own questions, evaluate the usefulness of the feedback provided by the tool, draw their own conclusion whether to use Ask.SMILE or not.

I would use Ask.SMILE in my future classroom as a learning method. I would allow students to experiment and come up with their own questions. They either will think more critically about their questions or think about how the data is being helpful or not. In addition, it would allow my students to collect data on if Ask.SMILE is reliable or not. I would ask them to come up with an answer on why students should use Ask.SMILE or not. They would have to provide evidence to support their answers. (student participant)

This sentiment demonstrates that Ask.SMILE's feedback mechanisms help students improve their questioning skills and analytical abilities. Participants who raised this idea perceived the value of fostering a deeper understanding of how to construct meaningful inquiries and knew how to maneuver the tool to gain the purpose. On that note, a participant reflected, "The feedback provided to the students will help them improve their question-asking skills over time." Another indicated that he would "change up my question to get my students to think a little harder when we are doing certain activities." Yet, another mentioned using it in an assignment, "where my students have to come up with a theory or hypothesis. They could utilize Ask.SMILE to see if their theory or hypothesis was good."

By integrating Ask.SMILE into lesson plans, teachers can motivate students through gamified activities and structured feedback loops, encouraging them to aim for higher-level questions. As one participant aptly

noted, "I would have students practice their critical thinking skills through trying to find ways to get a level 4 or 5 rating through adjusting their questions." This iterative process of question refinement fosters both critical thinking and intrinsic motivation, preparing students for success in academic and real-world contexts.

Interestingly, some participants indicated using Ask.SMILE "when having students do peer reviews. By having students practice [adjusting] the depth of their questions, they can introduce these practices on their peer's work to enhance it." AI tools like Ask.SMILE will undoubtedly find many additional uses on paired and collaborative team projects in the coming decade.

Importantly, PSTs also emphasized the adaptability of Ask.SMILE for different instructional contexts and student populations. They described tailoring questioning activities to align with learning objectives, cognitive levels, and student interests. For instance, more complex questioning tasks could be assigned to middle and high school students, while simpler, more engaging activities could be designed for younger learners. These reflections highlight the potential of Ask.SMILE to support differentiated instruction and responsive teaching practices.

Additionally, PSTs recognized Ask.SMILE as a versatile tool to cater to students' diverse needs and interests in a certain topic to further enhance their engagement in the classroom. One participant explained, "I believe I would use Ask.SMILE in my future classroom not only for critical thinking purposes but to understand what comes to students' minds when asking (topic-wise, if they are interested in the assignment, etc.)." This sentiment highlights how Ask.SMILE can help teachers design lessons peculiar to their students' interests, promoting meaningful and relevant learning experiences. Another student elaborated on using Ask.SMILE to support their reflective learning as a means "to challenge myself to ensure I'm asking open-ended questions that encourage independent thought and reflection so my students have a better opportunity to share their knowledge and explore concepts even further."

Finally, student teachers stated they could use Ask.SMILE to assess and gauge their teaching strategies. By using Ask.SMILE's assessment and feedback on students' critical thinking levels, the teachers can design lesson plans and assignments that align with their learners' interests and cognitive abilities. This data-driven approach ensures that instruction remains both challenging and accessible to all students and allows them to thrive. Through the incorporation of Ask.SMILE into lesson plans to enact question-asking practice and critical thinking development, teachers are increasingly equipped to inspire curiosity, enhance problem-solving skills, and prepare students for academic and real-world success.

Assessment and feedback provider

Theme 1. Assessment of critical thinking and understanding: Another key area of application identified by PSTs was the use of Ask.SMILE for assessment purposes. One significant utilization is content comprehension assessment, where PSTs envision having their students use the platform to ask reflective questions to show their understanding at the end of a lesson. Through the question levels and feedback received from the Ask.SMILE system, teachers can assess students' critical thinking levels, identify their strengths and weaknesses as well as interest areas and learning processes to personalize their teaching strategies accordingly. As an example, one participant wrote:

I would use Ask.SMILE to check for understanding. Students would be asked to create questions ranging from level 3-5 after having completed required readings. In doing so students are ensuring that they are asking higher level questions. Additionally, I could incorporate Ask.SMILE for any assignment that requires students to ask questions. Using this tool will help students develop higher level thinking questions. Ask.SMILE would ideally be a supportive tool for students. (student participant)

Recognizing the diverse needs and capacities of their students, the PSTs envisioned adapting Ask.SMILE differently for different age groups. For middle and high school students, these PSTs planned to deepen intellectual engagement by assigning more complex critical thinking tasks such as collaboratively analyzing questions in groups, testing their ideas, and refining their approaches based on feedback, whereas, for elementary students, the tasks could be more fun and simpler. The participants reported that the adaptability

feature of Ask.SMILE made it a versatile resource for cultivating critical thinking across varied learning contexts with various age groups of learners. For example, one participant reported:

Ask.SMILE provided me with constructive criticism on how to better structure the questions I asked. I could see this being helpful in devising more thought-provoking questions, allowing for more critical thinking from students. The rating system could be helpful in helping the instructor decide if the question is fit for the targeted age group/subject matter. (student participant)

Another explained:

In my own classroom, and if I had access to the data, I would probably use this tool as a response tool! I would have my students ask questions on this tool and this would allow me to see what I need to cover more in depth, and I feel that this can be used for any subject! I can also have my students do a research project on a topic, and I would have them formulate questions in which the class would have to go over with the teacher! (student participant)

Lastly, the PSTs concur with the fact that Ask.SMILE serves as a valuable resource for young learners' academic writing support and subject-specific integration. These future teachers plan to use the tool to assist students with essay writing by empowering them to ask meaningful questions, crafting strong thesis statements, and structuring arguments effectively. Beyond writing, the platform is integrated into subjects like science, history, and English to promote inquiry-based learning and subject-specific critical thinking. As an example, one participant wrote:

As a future elementary teacher, I would use Ask.SMILE in class to help my students in writing. For example, having them ask questions in different ways so that they can see the different scores they get and how they can better the way they word phrases. (student participant)

Yet, another shared:

I would be teaching a younger group of kids so I would want them to pick a topic by asking questions on Ask.SMILE. Once they get a question that was ranked as a number 3, they would write their paper on that. I do not want it to be a number 5 because I feel as if my number fives would be very hard to research. That is why they would only need a level 3. (student participant)

And another:

I would highly recommend Ask.SMILE if students needed help with theoretical questions, like to help them out with their writing, it would help them improve with paraphrasing questions when it [sic] needs to understand a certain problem or help them with any writing information. (student participant)

Theme 2. Academic skill development (e.g., writing and argumentation): In addition to assessment, PSTs recognized Ask.SMILE as a valuable resource for supporting academic skill development, especially writing and argumentation. Participants described using the tool to help students generate ideas, refine questions, and structure their writing more effectively. For instance, PSTs proposed students using Ask.SMILE to develop essay topics, construct arguments, and improve the clarity and coherence of their writing. One participant indicated that students could experiment with asking questions in different ways to observe how changes in phrasing affect the quality of responses and feedback. Another suggested that students could use the tool to develop hypotheses or theories and evaluate their strength based on the feedback received.

DISCUSSION

As discussed in the first half of this paper, one of the unique aspects of this particular study is in using Ask.SMILE with PSTs who have decades of future life experiences in which to implement generative AI tools like it in their own teaching. These PSTs now have firsthand knowledge of how to implement such tools to foster learning environments of inquiry, question asking, and general pedagogical experimentation and

innovation. Along with this knowledge, they now have a powerful, free tool for fostering learner critical thinking skills. And they witnessed such critical thinking happen. They have seen distinct growth in their ability to formulate higher-order questions aligned with Bloom's taxonomy's criteria on critical thinking. These six different cognitive levels can now be targeted one-by-one or in unison.

While there were fewer than 200 participants in this study from a single teacher preparation program out of more than 2,300 (American Association of Colleges for Teacher Education [AACTE], 2022) and there is an estimate of 5.7 million practicing K-12 teachers and over 54 million K-12 students across the United States (United States Census Bureau, 2025), this study offers insights into the question asking process with a freely available and easy to navigate and use tool that can readily be implemented in schools and universities worldwide. While this study represents just 178 of the more than 500,000 PSTs enrolled across the United States (AACTE, 2022), they are of sufficient number to begin to understand how teachers might rely on AI tools like Ask.SMILE in the classroom, especially for its use as a feedback provider (Phan et al., 2026) and improving student-question generation to improve their critical thinking skills (Phan & Zhu, 2026). It would not be very difficult to imagine many of them demonstrating and training others about this tool and the iterative process of question generation. It is also important to understand how receiving and processing AI-driven feedback allows PSTs to reflect on the outputs, including identifying gaps in their reasoning and refining their questioning techniques. Unlike previous research on Ask.SMILE that was used with conference participants (Kim et al., 2025), the outcomes of this particular study with PSTs indicates that Ask.SMILE not only serves as a self-assessment tool but also as an interactive learning environment that cultivates metacognitive awareness, a crucial skill for future educators, especially when incorporating inquiry-based forms of learning and instruction.

At its core, the present study highlights the broader educational value of SGQ practices supported by such AI-based tools like Ask.SMILE. By exposing future educators to AI-supported questioning frameworks, the study equips them with strategies to facilitate dynamic, student-centered learning environments. This finding is particularly relevant in modern classrooms, where critical thinking and problem-solving are prioritized to meet 21st century educational goals. Teachers can use Ask.SMILE to scaffold questioning skills progressively, encouraging students to elevate their inquiries from factual recall to more complex, analytical and creative questions. However, as Kim et al. (2025) pointed out, while users find it highly valuable, there is a need for the Ask.SMILE tool to continue to evolve beyond a question evaluation to include new features that might support user reflection, question answer generation, and more explicit feedback on the relevance of user questioning to the subject matter.

In terms of classroom applications or relevant uses outside of traditional classrooms, the PSTs in this study reported strong intentions to integrate Ask.SMILE into their future instructional practices. But learner intentions all-too-often do not get realized in the real world. A follow-up study might explore actual behaviors in the classroom after these PSTs graduate and find their way into a diverse set of K-12 classrooms. For example, the study participants envisioned using the Ask.SMILE tool for a wide range of activities, including lesson planning, student engagement, and formative assessment. As such, it would be valuable to find out if these PSTs would employ Ask.SMILE to guide students in brainstorming essay topics, testing their content comprehension, and improving their reflective thinking, among many other typical tasks. Additionally, the ability to tailor questions to individual students' abilities allows educators to differentiate instruction, helping ensure that all learners are appropriately challenged. This adaptability makes a generative AI tool such as Ask.SMILE a highly versatile and valuable resource for diverse subject areas including science, history, and writing and for different age groups.

Furthermore, the competitive and reflective nature of Ask.SMILE encourages PSTs to engage actively with learning materials, fostering a sense of ownership over their inquiry processes. Future teachers can leverage this feature to motivate learners through gamified activities (Buckner & Kim, 2014; Kim & Lee, 2020), where students strive to craft thoughtful, high-level questions to achieve better feedback ratings (Phan & Zhu, 2026). This dynamic interaction not only enhances students' critical thinking but also nurtures their creativity and intrinsic motivation to learn. Moreover, the real time, human-like feedback provided by Ask.SMILE can reduce the burden on teachers while still offering students personalized, constructive guidance to improve their questioning techniques.

At the same time, the present findings should be interpreted with consideration of factors that may have influenced PSTs' experiences with Ask.SMILE beyond the questioning process itself. For example, the gamified structure of the platform, including critical thinking levels and competitive elements, as well as the immediate AI-generated feedback, may have contributed to PSTs' engagement and satisfaction with the activity. Because these features were integrated simultaneously within the learning experience, it is difficult to determine the extent to which observed responses were attributable specifically to AI-supported question generation versus the combined influence of gamification and immediate feedback. Future research should further examine the relative contributions of these instructional and technological features.

Although the relationships between questioning motivation and satisfaction with Ask.SMILE were statistically significant, the observed effect sizes were within the small range. These findings, therefore, suggest modest, yet meaningful, associations that warrant further investigation.

Limitations and Implications for Future Research

This study presents several limitations that may affect the generalizability and depth of the findings. First, the participant group consisted solely of PSTs from a single teacher education program, potentially limiting the applicability of results to other educational contexts, geographic areas, or populations. Additionally, the study relied on a convenience sample that was heavily represented by female students and Liberal Studies majors. Therefore, the findings should be interpreted with caution and may not fully generalize to broader PST populations, teacher education programs, or institutional and disciplinary contexts. Expanding future research to include a more diverse range of programs, as well as a wider range of in-service teachers, would provide a more comprehensive understanding of the implementation and effectiveness of Ask.SMILE in different educational settings. Additionally, the reliance on self-reported data introduces potential biases, including selective memory and a tendency toward socially desirable responses, which may compromise the reliability and accuracy of the findings.

Additionally, while the study captured immediate responses and reflections on Ask.SMILE usage, it did not include longitudinal tracking to determine how PSTs implement the tool in real-world classroom settings over time. Along these same lines, we were unable to explore how users might experiment with different approaches to employing Ask.SMILE as they become increasingly adept at using it. Just how might learner metacognitive awareness play a role in effectively deploying such AI technology? This lack of follow-up data raises questions about the sustained effectiveness and long-term adoption of Ask.SMILE in K-12 environments. Variations in participants' familiarity and comfort with AI tools may have also influenced their ability to fully engage with the platform, creating uneven experiences that were not fully accounted for.

Future research should aim to explore the long-term impact of Ask.SMILE on teaching practices and student outcomes in diverse educational settings. Longitudinal studies that track how PSTs implement and adapt Ask.SMILE in their classrooms can provide valuable insights into the tool's sustainability and effectiveness. Additionally, incorporating observational and case study methods would allow researchers to capture the nuanced ways in which AI tools influence classroom dynamics, instructional strategies, and student engagement over extended periods.

Another promising avenue for future research is investigating the intersection of equity and accessibility in AI-supported education. Studies could examine how to ensure equitable access to AI tools like Ask.SMILE across schools with varying resources, particularly in underserved communities and those in the Global South (Kim et al., 2008; Kim & Lee, 2020; Zhang et al., 2020). Moreover, researchers could explore strategies for bridging the gap in AI proficiency among educators, such as targeted professional development and scaffolding. Finally, future research should delve deeper into the relationship between students' critical thinking growth and their satisfaction with AI tools, as well as the effectiveness of different questioning techniques in fostering higher-order cognitive skills. Addressing these areas would provide a more comprehensive understanding of the pedagogical potential of AI in education.

CONCLUSIONS

This study demonstrates the transformative potential of integrating AI-based tools like Ask.SMILE into teacher education programs to enhance critical thinking and SGQ practices. By encouraging PSTs to generate,

evaluate, and reflect on their questions, the data in this study revealed that Ask.SMILE supported the development of higher-order cognitive skills and fostered metacognitive awareness. The AI-driven feedback and ranking system allowed participants to iteratively refine their questioning techniques, improving both their critical thinking abilities and their understanding of the role of inquiry in learning. This process not only helped the PSTs in this study assess their own learning but also equipped them with strategies to scaffold similar skills in their future students. However, although some statistically significant relationships emerged between questioning motivation and satisfaction with Ask.SMILE, the practical significance of these effects was relatively modest and should therefore be interpreted cautiously.

In addition, the study highlights the practical implications of Ask.SMILE for classroom instruction. PSTs reported plans to implement the tool as a versatile resource to foster student engagement, support content comprehension, and enhance reflective thinking across various subjects and grade levels. By leveraging Ask.SMILE's ability to provide immediate feedback and assess critical thinking levels, educators can create more dynamic, student-centered learning environments. This finding aligns with 21st century educational priorities, where fostering inquiry-based learning and problem-solving skills are essential for preparing students to navigate complex real-world challenges.

Suffice to say, the pedagogical possibilities are seemingly endless. Clearly, pedagogical experimentation with generative AI in general and Ask.SMILE, more specifically, has only just begun. Additionally, the findings should be interpreted within the specific institutional and cultural context of this study, which was conducted within a single teacher education program in the United States. Teacher preparation structures, attitudes toward AI, educational technologies, and classroom questioning practices may differ substantially across institutional, disciplinary, and international contexts. Therefore, additional research across more diverse educational settings and cultural contexts is critical to better understand the broader applicability of these findings. Given the potential impact of such studies on human learning and inquiry across age groups and educational sectors, there is some urgency to additional research on Ask.SMILE and similar generative AI tools and platforms.

Overall, the results of this study suggest that Ask.SMILE has far-reaching implications for teacher education and K-12 classrooms specifically. It bridges the gap between traditional teaching methods and modern technology by empowering PSTs to embrace AI tools that enhance critical thinking and inquiry-based learning. By equipping future educators with skills to implement SGQ practices, Ask.SMILE promotes reflective teaching, student engagement, and deeper learning outcomes; such a tool aligns educational curricula with the evolving demands of the 21st century. Future research could further explore the longitudinal impact of AI-supported questioning tools on student achievement and critical thinking development across different educational contexts.

In conclusion, the results underscore the importance of incorporating AI tools like Ask.SMILE into teacher preparation programs to bridge the gap between traditional pedagogies and emerging technologies. By equipping PSTs with the ability to use AI tools and systems such as Ask.SMILE to facilitate inquiry and critical thinking, they are better positioned to cultivate curiosity, creativity, and deeper learning in their classrooms. Future research should explore the long-term impact of these tools on teaching practices and student outcomes, as well as address issues of equity, accessibility, and teacher readiness to maximize the benefits of AI in education. Researchers might also experiment with pedagogical variations across different subject matter disciplines, age levels, and educational sectors.

With such a freely available technology tool for bolstering the level of cognitive complexity of classroom discourse at the ready, we have potentially entered an exciting new era of teaching and learning. Perhaps most importantly, in this era, there is newfound hope that AI-based learning technology can elevate levels of classroom discourse, and, in turn, enhance literacy skills and cognitive processes of learners from the Global South to the Global North. Let the questions rain. Let the questioning culture reign.

Author contributions: **TP:** data curation, formal analysis, investigation, methodology, project administration, resources, visualization, writing – original draft, writing – review & editing; **MAY-L:** data curation, formal analysis, methodology, visualization, writing – original draft; **CJB:** resources, writing – original draft, writing – review & editing. All authors approved the final version of the article.

Funding: The authors received no financial support for the research and/or authorship of this article.

Ethics declaration: The data analyzed in this study were originally collected as part of normal educational practices and were not initially intended for research purposes. Following completion of the courses, the secondary analysis of the archived course data was approved as exempt by the California State University, Fresno Departmental Human Subjects Review Committee (IRB Protocol #2436, Artificial Intelligence and Student Critical Thinking). Because the data were originally collected for instructional rather than research purposes, informed consent for research participation was not obtained. Prior to analysis, all identifying information was removed from the dataset, analyses were conducted using only de-identified data, and all findings are reported in aggregate form to protect participant confidentiality.

AI statement: During the preparation of this work, the authors used ChatGPT in order to improve language and readability. After using this tool/service, the authors reviewed and edited the content as needed and took full responsibility for the content of the published article.

Declaration of interest: The authors declared no competing interest.

Data availability: Data generated or analyzed during this study are available from the authors on request.

REFERENCES

- AACTE. (2022). Colleges of education: A national portrait. *American Association of Colleges for Teacher Education*. <https://aacte.org/wp-content/uploads/2022/03/Colleges-of-Education-A-National-Portrait-Executive-Summary.pdf>
- Aflalo, E. (2021). Students generating questions as a way of learning. *Active Learning in Higher Education*, 22(1), 63-75. <https://doi.org/10.1177/1469787418769120>
- Aguilar, O. G., Mortimer, E. F., & Scott, P. (2010). Learning from and responding to students' questions: The authoritative and dialogic tension. *Journal of Research in Science Teaching*, 47, 174-193. <https://doi.org/10.1002/tea.20315>
- Ali, F., Choy, D., Divaharan, S., Tay, H., & Chen, W. (2023). Supporting self-directed learning and self-assessment using TeacherGAIA, a generative AI chatbot application: Learning approaches and prompt engineering. *Learning: Research and Practice*, 9(2), 135-147. <https://doi.org/10.1080/23735082.2023.2258886>
- Anderson L, W., & Krathwohl D. R. (2001). *A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives*. Pearson Longman.
- Anistyasari, Y., Ekohariadi, E., Yani, M. T., Wiriawan, O., & Hidayati, S. C. (2024). An artificial intelligence-based tool for student-generated questions. *E3S Web of Conferences*, 513, Article 040018. <https://doi.org/10.1051/e3sconf/202451302003>
- Becker, R. R. (2000). The critical role of students' questions in literacy development. *The Educational Forum*, 64(3), 261-271. <https://doi.org/10.1080/00131720008984763>
- Bozkurt, A. (2023). Generative artificial intelligence (AI) powered conversational educational agents: The inevitable paradigm shift. *Asian Journal of Distance Education*, 18(1), 198-204.
- Buckner, E., & Kim, P. (2014). Integrating technology and pedagogy for inquiry-based learning: The Stanford mobile inquiry-based learning environment (SMILE). *Prospects*, 44(1), 99-118. <https://doi.org/10.1007/s11125-013-9269-7>
- Chin, C., & Brown, D. E. (2002). Student generated questions: A meaningful aspect of learning in science. *International Journal of Science Education*, 24(5), 521-549. <https://doi.org/10.1080/09500690110095249>
- Chin, C., & Osborne, J. (2008). Students' questions: A potential resource for teaching and learning science. *Studies in Science Education*, 44(1), 1-39. <https://doi.org/10.1080/03057260701828101>
- Chiu, T. K.F., Xia, Q., Zhou, X., Chai, C. S., & Cheng, M. (2023). Systematic literature review on opportunities, challenges, and future research recommendations of artificial intelligence in education. *Computers and Education: Artificial Intelligence*, 4, Article 100118. <https://doi.org/10.1016/j.caeai.2022.100118>
- Crompton, H., & Burke, D. (2024). The educational affordances and challenges of ChatGPT: State of the field. *TechTrends*, 68, 380-392. <https://doi.org/10.1007/s11528-024-00939-0>
- Davey, B., & McBride, S. (1986). Effects of question-generation training on reading comprehension. *Journal of Educational Psychology*, 78(4), 256-262. <https://doi.org/10.1037/0022-0663.78.4.256>
- Digital Education Council. (2024). AI or not AI: What students want. Digital Education Council global AI student survey 2024. *Digital Education Council*. <https://www.digitaleducationcouncil.com/post/digital-education-council-global-ai-student-survey-2024>
- Ennis, R. H. (1985). The logical basis for measuring CT skills. *Educational Leadership*, 43(2), 44-48.

- Ennis, R. H. (1987). A taxonomy of critical thinking dispositions and abilities. In J. B. Baron, & R. J. Sternberg (Eds.), *Teaching thinking skills: Theory and practice* (pp. 9-26). W.H. Freeman.
- Facione, P. A. (1990). *Critical thinking: A statement of expert consensus for purposes of educational assessment and instruction: Executive summary, The Delphi report*. California Academic Press.
- Holbeck, R. (2025). Helping students develop AI prompting skills for critical thinking. *Faculty Focus*. <https://www.facultyfocus.com/articles/teaching-with-technology-articles/helping-students-develop-ai-prompting-skills-for-critical-thinking/>
- Hou, X., Chang, Z., Lu, Z., Wenli, C., Wan, L., Feng, W., Hu, H., & Guo, Q. (2025). *EduThink4AI: Bridging educational critical thinking and multi-agent LLM Systems*. arXiv.
- Hsu, H. Y., & Kim, P. (2016). Preservice teachers' uses of SMILE to enact student-generated questioning practices. *International Journal of Innovation in Education*, 3(2-3), 110-121. <https://doi.org/10.1504/IJIE.2016.081547>
- IBM Corp. (2023). IBM SPSS statistics for Macintosh, version 29.0.1.0. *IBM Corp.* <https://www.ibm.com/support/pages/downloading-ibm-spss-statistics-2901>
- Kasneji, E., Seßler, K., Küchemann, S., Bannert, M., Dementieva, D., Fischer, F., Gasser, U., Groh, G., Günemann, S., Hüllermeier, E., Krusche, S., Kutyniok, G., Michaeli, T., Nerdel, C., Pfeffer, J., Poquet, O., Sailer, M., Schmidt, A., Seidel, T., ... Kasneji, G. (2023). ChatGPT for good? On opportunities and challenges of large language models for education. *Learning and Individual Differences*, 103, Article 102274. <https://doi.org/10.1016/j.lindif.2023.102274>
- Khasawneh, E., Hodge-Zickerman, A., York, C. S., Smith, T. J., & Mayall, H. (2023). Examining the effect of inquiry-based learning versus traditional lecture-based learning on students' achievement in college algebra. *International Electronic Journal of Mathematics Education*, 18(1), Article em0724. <https://doi.org/10.29333/iejme/12715>
- Kim, M., & Adlof, L. (2024). Adapting to the future: ChatGPT as a means for supporting constructivist learning environments. *TechTrends*, 68, 37-46 (2024). <https://doi.org/10.1007/s11528-023-00899-x>
- Kim, P. (2024). Trends of AI in education and new competencies for the future at the exploring the ethical use of AI TIP Conference [Video]. *YouTube*. <https://youtu.be/DsUEhxlNku8?si=h2vXfm-P2zNfdg5o>
- Kim, P., & An, J. Y. (2016). New evaluation vector through the Stanford mobile inquiry-based learning environment (SMILE) for participatory action research. *Healthcare Informatics Research*, 22(3), 164-171. <https://doi.org/10.4258/hir.2016.22.3.164>
- Kim, P., & Lee, J. (2020). Evolution of online learning environments and the emergence of intelligent MOOCs. In K. Zhang, C. J. Bonk, T. C. Reeves, & T. H. Reynolds (Eds.), *MOOCs and open education in the Global South: Challenges, successes, and opportunities* (pp. 329-341). Routledge.
- Kim, P., Miranda, T., & Olaciregui, C. (2008). Pocket school: Exploring mobile technology as a sustainable literacy education option for underserved indigenous children in Latin America. *International Journal of Educational Development*, 28(4), 435-445. <https://doi.org/10.1016/j.ijedudev.2007.11.002>
- Kim, P., Wang, W., & Bonk, C. J. (2025). Generative AI as a coach to help students enhance proficiency in question formulation. *Journal of Educational Computing Research*, 63(3), 565-586. <https://doi.org/10.1177/07356331251314222>
- King, A. (1997). ASK to THINK-TEL WHY: A model of transactive peer tutoring for scaffolding higher level complex learning. *Educational Psychologist*, 32(4), 221-235. https://doi.org/10.1207/s15326985ep3204_3
- Li, Z., Wang, C., & Bonk, C. J. (2024). Exploring the utility of ChatGPT for self-directed online language learning. *Online Learning*, 28(3), 157-180. <https://doi.org/10.24059/olj.v28i3.4497>
- McGivney, E., & Kim, P. (2016). Using technology to teach the art of asking questions. *Stanford Social Innovation Review*. <https://doi.org/10.48558/89AT-W123>
- Mollick, E. (2024). *Co-intelligence: Living and working with AI*. Penguin.
- Palincsar, A. S., & Brown, A. L. (1984). Reciprocal teaching of comprehension-fostering and comprehension-monitoring activities. *Cognition and Instruction*, 1(2), 117-175. https://doi.org/10.1207/s1532690xci0102_1
- Paul, R., & Elder, L. (2006). *Critical thinking: Tools for taking charge of your learning and your life*. Pearson Prentice Hall.
- Phan, T., & Zhu, M. (2026). Asking better questions with AI: Exploring student inquiry, critical thinking growth, and the interpretive role of Ask.SMILE. *TechTrends*. <https://doi.org/10.1007/s11528-026-01192-3>

- Phan, T., Zheng, X., & Zhu, M. (2026). Comparative analysis of AI-generated and peer feedback on student-generated questions in teacher education. *AI Enhanced Learning*, 2(1), 99-121. <https://doi.org/10.70725/493067ulyywm>
- Quintana, C., Reiser, B., Davis, E. A., Krajcik, J., Golan, R., Kyza, E., Edelson, D., & Soloway, E. (2002). Evolving a scaffolding design framework for designing educational software. In P. Bell, R. Stevens, & T. Satwicz (Eds.), *Proceedings of the 5th International Conference for the Learning Sciences*. Erlbaum.
- Rogoff, B. (1990). *Apprenticeship in thinking: Cognitive development in a social context*. Oxford Academic. <https://doi.org/10.1093/oso/9780195059731.001.0001>
- Rudolph, J., Tan, S., & Tan, S. (2023). ChatGPT: Bullshit spewer or the end of traditional assessments in higher education? *Journal of Applied Learning & Teaching*, 6(1), 342-363. <https://doi.org/10.37074/jalt.2023.6.1.9>
- Schroeder, R. (2024). The AI augmented professor of 2024. *Inside Higher Ed*. <https://www.insidehighered.com/opinion/blogs/online-trending-now/2024/05/08/ai-augmented-professor-2024>
- Seeds of Empowerment. (2025). SMILE LLM project brief: Phi-2 model deployment on Raspberry Pi 5 using llama.cpp. Seeds of Empowerment. <https://www.seedsofempowerment.org/smile-llm/>
- Shi, Z., Castellucci, G., Filice, S., Kuzi, S., Kravi, E., Agichtein, E., Rokhlenko, O., & Malmasi, S. (2025). Ambiguity detection and uncertainty calibration for question answering with large language models. In *Proceedings of the 5th Workshop on Trustworthy NLP* (pp. 41-55). ACL Anthology. <https://doi.org/10.18653/v1/2025.trustnlp-main.4>
- Singer, J., Marx, R. W., Krajcik, J., & Chambers, J. C. (2000). Constructing extended inquiry projects: Curriculum materials for science education reform. *Educational Psychologist*, 35(3), 165-178. https://doi.org/10.1207/S15326985EP3503_3
- Terada, Y. (2020). *Using student-generated questions to promote deeper thinking*. Edutopia.
- United States Census Bureau. (2025). Back to school: August 2025. *United States Census Bureau*. <https://www.census.gov/newsroom/stories/back-to-school.html>
- Vendrell, M., & Johnston, S. K. (2026). Scaffolding critical thinking with generative AI: Design principles for integrating large language models in higher education. *Computers and Education: Artificial Intelligence*, 10, Article 100572. <https://doi.org/10.1016/j.caeai.2026.100572>
- Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Harvard University Press.
- Wang, C., Li, Z., & Bonk, C. J. (2024). Understanding self-directed learning in AI-assisted writing: A mixed methods study of postsecondary learners. *Computers & Education: Artificial Intelligence*, 6, Article 100247. <https://doi.org/10.1016/j.caeai.2024.100247>
- Wertsch, J. V. (1991). *Voices of the mind: A sociocultural approach to mediated action*. Harvard University Press.
- Wu, L., Liu, Y., How, M. L., & He, S. (2023). Investigating student-generated questioning in a technology-enabled elementary science classroom: A case study. *Education Sciences*, 13(2), Article 158. <https://doi.org/10.3390/educsci13020158>
- Yu, F. Y., & Wu, W. S. (2020). Effects of student-generated feedback corresponding to answers to online student-generated questions on learning: What, why, and how? *Computers & Education*, 145, Article 103. <https://doi.org/10.1016/j.compedu.2019.103723>
- Yu, F. Y., Chang, Y. L., & Wu, H. L. (2015). The effects of an online student question-generation strategy on elementary school student English learning. *Research and Practice in Technology Enhanced Learning*, 10, Article 24. <https://doi.org/10.1186/s41039-015-0023-z>
- Zawacki-Richter, O., Marín, V. I., Bond, M., & Gouverneur, F. (2019). Systematic review of research on artificial intelligence applications in higher education – Where are the educators? *International Journal of Educational Technology in Higher Education*, 16(1), Article 39. <https://doi.org/10.1186/s41239-019-0171-0>
- Zhang, K., Bonk, C. J., Reeves, T. C., & Reynolds, T. H. (Eds.). (2020). *MOOCs and open education in the Global South: Challenges, successes, and opportunities*. Routledge. <https://doi.org/10.4324/9780429398919>
- Zhi, J., Kumar, H., & Lee, M. (2026). Investigating the effects of LLM use on critical thinking under time constraints: Access timing and time availability. In *Proceedings of the 2026 CHI Conference on Human Factors in Computing Systems* (pp. 1-21). ACM. <https://doi.org/10.1145/3772318.3791796>

