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Critical thinking in higher education: Identifying the pedagogical practices and modes of engagement

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ABSTRACT

Critical thinking (CT) is widely recognized to be among the most essential skills for university graduates to successfully compete in the 21st century global economy; yet, much obscurity remains regarding its practical role in higher education. In fact, there is a need for an accepted educational plan with pedagogical guidelines that university instructors can lean on for integrating CT into subject instruction. Accordingly, this study aimed to identify the instructional design components recommended by instructors and students for promoting CT in higher education academic courses. The study involved ten higher education instructors and 342 undergraduate students in science and engineering. In order to address the research goal, the study followed the grounded theory approach in which the data was analyzed from a qualitative perspective. The data was collected through two research tools: semi-structured interviews and an online survey. The current study identified eight instructional design components for promoting CT. These components include four pedagogical practices: *explicit teaching of CT, integration of digital tools, collaborative learning* and *constructing questions*, as well as four modes of engagement: *critical engagement with information, comparing approaches to problem-solving, guided inquiry and experimentation* and *raising doubts and evaluating credibility*. The study introduces an adaptive model incorporating CT-enhanced pedagogical practices, for policymakers and instructional designers, to foster CT in science and engineering courses.

1. Introduction

Critical thinking (CT) is widely recognized in higher education to be among the most essential skills for university graduates to successfully compete in the 21st century global labor market (Barak & Shahab, 2023; Campo et al., 2023; Santos-Meneses & Drugova, 2023). It empowers individuals to actively engage as responsible citizens in democratic societies (Halpern, 1998; Pellegrino & Hilton, 2012). CT is a key skill that dates back to the Greek philosophers and has been readdressed by contemporary educational researchers (e.g., Barak et al., 2007; Ennis, 2018; Loes & Pascarella, 2017). CT encompasses a combination of cognitive skills – interpretation, analysis, inference, evaluation and self-regulation, along with the disposition to employ them effectively (Facione, 2015). Developing CT is an important goal across all fields of knowledge, particularly in science and engineering, where students are expected to process

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new information, evaluate its relevance, reliability and implications, and apply CT to solve complex problems (Ahern et al., 2019; Avsec & Savec, 2019). A number of frameworks have recommended the promotion of CT in higher education (e.g., OECD, 2021; Pellegrino & Hilton, 2012; Vincent-Lancrin et al., 2019). Yet, there remains a need for a widely accepted educational framework with guidelines that university instructors can rely on for integrating CT into subject instruction (Campo et al., 2023; Manalo, 2020). In fact, a review of the literature indicates that much obscurity still remains regarding CT and its practical role in higher education (Ahern et al., 2019; Barak & Shahab, 2023; Cortázar et al., 2021; Santos-Meneses & Drugova, 2023). This impedes the ability to construct an appropriate account of how to best foster CT skills among students (Ahern et al., 2019; Tosuncuoglu, 2018).

The need to advance CT skills in higher education has intensified due to digital technology, such as the integration of artificial intelligence (AI) tools in higher education. While these tools provide quick access to vast information and offer various potential opportunities to support learning, concerns have been raised regarding academic integrity and overreliance (Michel-Villarreal et al., 2023; Rusandi et al., 2023; Usher & Barak, 2024). Passive reliance on AI-generated content may undermine students' ability to critically evaluate information and explore alternative perspectives (Michel-Villarreal et al., 2023; Suriano et al., 2025; Usher & Barak, 2024). To meet these challenges, students must be equipped with the CT competencies that enable them to engage critically with new information and assess its outputs, so that they can constructively solve problems, draw reasonable conclusions, and make better decisions and judgements (Ahern et al., 2019; Cortázar et al., 2021; Santos-Meneses & Drugova, 2023).

In the context of science and engineering education, there is a growing body of research on CT (e.g., Ahern et al., 2019; Avsec & Savec, 2019; Forawi, 2016; Osman et al., 2016). Some studies examined the way CT is applied in engineering learning and/or students' everyday lives (Douglas, 2012; Osman et al., 2016). Other studies investigated perceptions and the utilization of CT (Ahern et al., 2019; Forawi, 2016). For example, a study conducted by Douglas (2012) identified five engineering practices that involve the application of CT: identifying a problem, organizing information, using prior knowledge, expressing an opinion, and making decisions. Similarly, a study conducted by Osman et al. (2016) pinpointed elements of CT and mathematical thinking that are used in real-world engineering practice. Forawi (2016) investigated perceptions and utilization of CT in American standard-based science education. The study identified CT as an important skill for establishing relationships between evidence and explanations as well as designing and conducting scientific experiments (Forawi, 2016). Ahern et al. (2019) reviewed 25 selected journal articles in order to examine the teaching strategies used in engineering to promote CT. It was found that most courses emphasize problem solving and the impact of real-world situations. More recently, Ma et al. (2023) examined "the relationship between students' and science teachers' CT" as well as "the relationship between CT and physics achievement".

The aforementioned studies on CT show a gap in the literature related to two points. Firstly, past studies with suggestions for pedagogical practices and modes of engagement that cater to developing CT competencies among higher education students have not been fully explored (Barak & Shahab, 2023; Bellaera et al., 2021). Secondly, studies focusing on CT often portray educators' viewpoints while there is a scarcity of studies that explore students' perspectives on the practices they believe foster the development of CT (Campo et al., 2023; Chen, 2017). Accordingly, the current study was designed to address these gaps by identifying the instructional design components recommended by instructors and students for promoting CT in higher education.

2. Literature review

CT has its roots in the teachings of Socrates and has since remained a central focus of Western philosophy (Dehghayedi & Bagheri, 2018). More modern definitions of CT stem from the 20th century philosopher John Dewey, who related to reflective thinking as a broader concept which encompasses what we now consider CT (Dwyer et al., 2014; Ennis, 2018). A review of the literature shows that numerous conceptualizations have been provided for CT over the years, (e.g. Dwyer et al., 2014; Ennis, 2018; Kuhn, 2019; Paul & Elder, 2007). Kuhn (1999) advanced a developmental model of CT in which individuals progress from absolutist to multiplist and then to evaluative conceptions of knowledge. While CT is regarded irrelevant at the multiplist stage, it emerges most fully at the evaluativist stage through evidence-based argumentation and metacognitive reflection. Complementing this developmental perspective, one of the prominent reference points on CT is that of the Delphi Report (Facione, 1990). The Delphi Report was developed by a cross-disciplinary panel of experts in the field of CT, under the sponsorship of the American Philosophical Organization. According to the report, CT is conceptualized as "purposeful self-regulatory judgement which results in interpretation, analysis, evaluation, inference, as well as explanation of the evidential, conceptual, methodological, criteriological or contextual considerations upon which a judgment is based" (Facione, 1990, p. 6). This report remains one of the leading documents on CT which serves as the basis for the work of science and engineering researchers till this day (e.g., Barak et al., 2007; Cortázar et al., 2021; Ma et al., 2023).

There is a general consensus among educationalists that the developing of CT competencies must constitute an indispensable part of the agenda of higher education (e.g. Avsec & Savec, 2019; Barak & Shahab, 2023; Bezanilla et al., 2019; Manalo, 2020). Research indicates that there is no single method which attributes to the success of CT teaching and learning (Santos-Meneses & Drugova, 2023; Todd et al., 2019). Instead, effective CT instruction depends on the well-planned use of diverse pedagogical practices and modes of engagement. The following section outlines several key recommendations from the literature for fostering CT in higher education.

One such pedagogical practice that arose in the literature is that making CT learning objectives explicit, including expected skills and dispositions, is crucial to improving students' competency and academic achievement (Cortázar et al., 2021; Ma et al., 2023; Santos-Meneses & Drugova, 2023). Teachers need a clear understanding of the concept, how it relates to learning and its value for themselves and their students (Dehghayedi & Bagheri, 2018). Moreover, instructors need to model CT and persistently incorporate this concept into their lesson designs and classroom activities so that the thinking process becomes systematic (Brookfield, 2020; Dehghayedi & Bagheri, 2018; Ma et al., 2023).

An additional recommended practice for promoting CT is the use of purposeful questioning. Research highlights that teacher-led questioning involving higher-level questions which go beyond memory recall and factual information, can effectively stimulate CT by requiring students to infer, analyze, and evaluate (Campo et al., 2023; Santos-Meneses & Drugova, 2023; Zhao et al., 2016). In addition, training students to effectively construct questions about items such as goals, assumptions, conclusions, implications and perspectives fosters their ability to critically engage with content (Paul & Elder, 2007; Kuhn, 2019; Rakedzon & Van Horne, 2024).

Another key practice for promoting CT is to incorporate the pedagogical practice of collaborative learning (Bezanilla et al., 2019; Campo et al., 2023; Ma et al., 2023; Santos-Meneses & Drugova, 2023). Defined as a method in which students work together in small groups to achieve shared learning goals, collaborative learning entails active engagement, knowledge construction and peer support (Cortázar et al., 2021; Loes & Pascarella, 2017). This practice is particularly effective in extending students' zone of proximal development (ZPD), allowing learners to engage in activities that might otherwise be beyond their capabilities (Cortázar et al., 2021; Wass et al., 2011). Digital tools and online environments play a vital role in supporting collaborative learning (Brookfield, 2020; Santos-Meneses & Drugova, 2023; Todd et al., 2019). For example, cloud-based applications such as Google Drive facilitate real-time collaborative writing and document creation, while platforms like Prezi enable the co-creation of dynamic presentations. These technologies not only enable teamwork but also promote critical and social competencies essential for deep learning (Barak, 2017). Research indicates that the interactivity facilitated by digital tools and web-based student interaction can have powerful effects on improving learners' CT skills (Brookfield, 2020; Santos-Meneses & Drugova, 2023; Todd et al., 2019).

In addition, digital tools enable interactive and reflective learning experiences, creating opportunities for students to immerse in meaningful dialogue, analyze diverse perspectives and refine their reasoning skills (Lin et al., 2021; Santos-Meneses & Drugova, 2023). For instance, online peer-review activities encourage students to critically evaluate their own and others' viewpoints and performance. This mutual feedback process fosters reflection, allowing both reviewers and recipients to identify strengths and weaknesses, gain a broader understanding of diverse perspectives and refine their thoughts (Barak, 2017; Bezanilla et al., 2019; Lin et al., 2021; Vincent-Lancrin, 2019). Moreover, online interactive peer-review practice creates a more engaging and reflective learning environment that significantly enhances students' CT abilities (Cortazar et al., 2021; Lin et al., 2021; Todd et al., 2019). Likewise, asynchronous online discussion forums and other forms of electronic interaction offer students time to think critically about their responses before sharing, thereby enhancing reflection and depth of thought (Jiang et al., 2024; Santos-Meneses & Drugova, 2023). Moreover, these forums provide a non-threatening learning environment, which is particularly beneficial for students whose cultural backgrounds or personalities favor less outspoken and confrontational communication (Jiang et al., 2024; Santos-Meneses & Drugova, 2023; Tan, 2017; Todd et al., 2019).

One significant form of discussion that fosters CT is argumentative discourse. It has been suggested by the literature that pedagogical strategies should incorporate practices that actively engage students in this form of discourse (Barak, 2017; Bezanilla et al., 2019; Campo et al., 2023; Kuhn, 2019; Santos-Meneses & Drugova, 2023). Graphic organizers, such as argument mapping templates and digital mind mapping tools, can effectively support argumentative discourse by helping students visually structure their reasoning and clarify the relationships between propositions (Dwyer et al., 2014; Halpern, 2014). These tools not only aid in the construction of coherent arguments but also encourage systematic self-reflection (Ghanizadeh, 2017; Jiang et al., 2024). A prominent example of an activity that engages students in argumentative discourse is debating, which has been shown to greatly enhance CT (Campo et al., 2023; Cortázar et al., 2021; Santos-Meneses & Drugova, 2023). Through debates, students are required to conduct in-depth research, pose insightful questions, identify contradictions, critically evaluate arguments, and construct evidence-based positions while engaging with diverse perspectives (Zhao et al., 2016).

The digital age, characterized by vast access to information and the advent of generative AI, has intensified the need for CT and digital literacy skills in education. These skills are essential for enabling students to navigate and critically evaluate extensive online content, distinguish fact from opinion, and identify biases or misinformation (Brookfield, 2020; OECD, 2021; Santos-Meneses & Drugova, 2023). To address these demands, educators should model explicit strategies for engaging with digital content critically and foster effective reading strategies (OECD, 2021; Suriano et al., 2025; Usher & Barak, 2024). For example, teachers can design activities that guide students in analyzing the reliability of generative AI outputs, such as ChatGPT, by encouraging reflective discussions about quality, accuracy and biases (Larson et al., 2024; Rusandi et al., 2023; Suriano et al., 2025).

Additional recommended modes of engagement for promoting CT include engaging students in authentic problem-solving and project-based learning activities (Bezanilla et al., 2019; Campo et al., 2023; Ma et al., 2023). These activities encourage students to create, apply and evaluate solutions, while fostering skills like logical reasoning and evidence-based decision-making (Todd et al., 2019; Brookfield, 2020). The OECD suggests science activities where students analyze multiple approaches to a problem, assess their strengths and limitations, and reflect on alternative solutions (Vincent-Lancrin, 2019). Case studies and multimedia simulations further immerse students in real-world scenarios, while encouraging critical analysis and the practical application of knowledge (Barak, 2017; Brookfield, 2020; Campo et al., 2023; Todd et al., 2019). Project-based learning has been recognized as an effective learner-centered mode of engagement that promotes CT by engaging students in collaborative investigations of complex real-world open-ended problems (Barak & Yuan, 2021; Cortazar et al., 2021). It cultivates analytical reasoning, creativity, and evidence-based decision-making, while enhancing students' understanding of scientific and engineering principles (Barak & Yuan, 2021; Wengrowicz et al., 2018). Similarly, inquiry-based instruction and guided experimentation have been presented in the literature as an effective way to promote scientific reasoning and CT by engaging students in exploring concepts, testing hypotheses and refining their understanding (Avargil et al., 2012; Barak et al., 2007; Kuhn, 2019).

These recommendations offer sporadic insights into CT instruction. Therefore, there is a need to develop a comprehensive CT-enhanced instructional framework that synthesizes recommendations alongside evidence provided by instructors and students for effective CT integration in science and engineering education curriculums (Cortázar, 2021; Ennis, 2018; Tosuncuoglu, 2018).

3. Methodology

3.1. Research goal and questions

The goal of this study was to identify the instructional design components recommended by instructors and students for promoting CT in science and engineering education academic courses.

This goal raised the following research questions:

1. What are the pedagogical practices recommended for promoting CT in higher education?
2. What are the modes of engagement recommended for promoting CT in higher education?

3.2. Participants

The study was conducted at a research university which offers degrees in science and engineering. Participants were deliberately selected from these disciplines, where CT is widely recognized as an indispensable skill for learning and professional practice (Ahern et al., 2019; Avsec & Savec, 2019; Osman et al., 2016). The study involved 10 higher education instructors and 342 undergraduate students. The instructors, comprising seven females and three males, all held master's or doctorate degrees and had teaching experience ranging from 10 to 38 years. The student participants, aged 18 to 30, comprised 36 % females and 64 % males. The instructors were recruited through personal contacts to capture a diverse range of academic disciplines and teaching backgrounds. The students were recruited through a combination of online listservs and snowball sampling (Creswell, 2018).

To ensure ethical conduct, the participants signed an informed consent form that described the research, explaining that participation is voluntary and that they can withdraw at any time with no negative consequences. Responses were analyzed collectively, ensuring that names and personal information were anonymized. All research records were securely stored in a locked file, and the study received approval from the IRB.

3.3. Methods and tools

In order to address the research goal, the study followed the grounded theory approach (Corbin & Strauss, 2014), in which the data was analyzed from a qualitative perspective. The data was collected through two research tools: semi-structured interviews and an online survey. The semi-structured interviews included 10 instructors and 34 students who had already accumulated academic experiences. The interviews were carried out face-to-face in a private setting and were approximately 20 min. Notes were taken and the participants' comments were audio-recorded and later transcribed in detail. The interview questions were:

- What examples can you provide of learning activities that you incorporated / experienced in previous science and engineering courses that you feel contributed to the development of CT?
- What specific pedagogical practices do you recommend courses integrate to promote CT?
- What specific modes of engagement do you recommend courses integrate to promote CT?

The online survey was administered among 308 students to provide a broader sample with additional insights including the three open-ended questions described above. Both the interviews and online survey were based on participants' self-report, providing details about their own thoughts and experiences related to CT. Self-report has been a useful method in psychology and education for measuring facets of students' learning as it allows participants to describe their own experiences (Pekrun, 2020). Qualitative content analysis was conducted via inductive analysis methods (Willig, 2013) according to the following steps: 1. The participants answers to the interviews and online survey were compiled into a file; 2. Two researchers read the file rigorously and marked relevant segments that indicate, explicitly or inexplicitly, pedagogical practices and modes of engagement for promoting CT that were apparent in the participants' responses; 3. The marked segments were assigned to categories which emerged from the text.

In order to ensure research reliability and trustworthiness, the study included three types of triangulation: data, methodological and investigator (Denzin, 2006). First, the data triangulation involved data collected from different stakeholders, including instructors and students. Second, the methodological triangulation entailed a mixture of data collection tools: interviews and an online survey with three open-ended questions. Third, the investigator triangulation involved several researchers who are experts in science and engineering education, holding MSc and PhD degrees. Initially, independent coding by the two main researchers reached about 90 % agreement, after which the researchers discussed the text excerpts in dispute, resolved gaps, and reached full agreement. Three more experts, validated the data analysis and interpretation process after they were presented with a representative sample of the text excerpts, reaching full agreement (Cohen's kappa = 1.00).

4. Findings

This segment presents findings related to the recommended instructional design components of a CT-enhanced instructional framework for science and engineering education. In particular, it relates to the pedagogical practices participants believe contribute to the fostering of CT, followed by the modes of engagement considered to incorporate CT components in science and engineering education. All names are pseudonyms.

4.1. Pedagogical practices for promoting CT

An analysis of the interview transcripts and online survey indicated the existence of four pedagogical practices that participants believe contribute to the fostering of CT: *explicit teaching of CT, integration of digital tools, collaborative learning* and *constructing questions*.
a) Explicit teaching of CT

The first pedagogical practice which surfaced is that higher education courses should explicitly nurture CT. Students are under the impression that instructors do not incorporate activities that openly and clearly aim to promote CT in science or engineering lessons. According to Z.Y., a science student, *"Perhaps instructors include some activities which develop CT, but this is not done directly nor often enough. I haven't experienced someone who has formally brought it up." Instructors should speak more openly about it."* M.N., an engineering student found that *"CT is somewhat encouraged but not always with us being aware. It isn't given a name. Giving it a name will raise awareness about its importance."* b) Integration of digital tools

The second pedagogical practice which emerged is that higher education courses should integrate more digital tools for the purpose of promoting CT. Currently, not all instructors do so. For example, Ms. Lisa, an instructor with 13 years' experience admitted *"I don't use technology because I think that it is more distracting than helpful. I prefer to hold discussions and write on the board."* Other instructors often utilize digital tools for presenting and drilling course material rather than fostering CT. Mr. Ross, an instructor with 10 years' experience, claims *"I mainly utilize technology to present the course material, like with PowerPoint slides, or show videos with simulations so that students can visualize processes."* Y.Z., an engineering student, added that *"Some instructors incorporate online practice quizzes to review for exams and entertain students. However, these quizzes include basic questions that do not require higher order thinking."*

Digital integration should go beyond incorporating activities which just demand recalling information that students have learned. They should include questions that develop CT, prompting deeper analysis and evaluation. Dr. Anna, an instructor with 13 years' experience, provided an example of how her course fosters CT through digital platforms.

> "I upload videos and short articles to my course site for students to review independently. Afterwards they respond to questions in a forum or participate in online quizzes which include questions that demand looking at things from different perspectives and thinking beyond what appears in the text or video. The questions do not drill students on whether they remember the material, but aim to genuinely promote CT."

Students can also use the forums to provide their peers with constructive feedback. Ms. Ariella, an instructor with 14 years' experience, shared how her students *"reflect on classmates' presentations in a forum. They are instructed to comment on what they learned and what they believe should be improved, and this requires CT." Furthermore,* H.Z., a science student, claimed that the Internet and Google Docs can be employed to nurture CT: *"When learning theories in science education, students can access information on the Internet, summarize the main ideas in a shared Google Doc and then collaborate online with a group of classmates to compare what they have learned."* c) Collaborative learning

The third pedagogical practice for promoting CT is incorporating collaborative learning in higher education courses. An engineering student asserted in the online survey that *"holding group discussions and sharing thoughts and ideas is one of the most effective ways to develop CT."* These discussions can transpire in pairs, small groups or whole-class settings, where students compare scientific strategies and concepts through oral and written communication. Mr. Herman, an instructor with 30 years' experience, illustrated this practice, noting how students *"compare approaches or methods together, while identifying similarities and differences"* before solving problems.

The role of justification and persuasion also emerged as central to collaborative learning. One science student, T.S., reflected that *"in math and science courses, we often had to choose one formula or method and argue why it was the best choice"*. In a bio-enterprise class, Y. L., an engineering student, explained that students *"presented plans for novel ideas and attempted to convince classmates that their ideas are worthy."* Structured debates provide a particularly effective format for this kind of engagement. A.M., an engineering student, described how his instructor encouraged students to adopt different positions on a topic and support them with evidence: *"We were posed with a dilemma, weighed the pros and cons, and shared our opinion while explaining our reasoning to the group. This practice exposes you to new perspectives and reveals gaps in understanding."*

Another form of collaborative learning entails providing formative feedback to peers. X.O., an engineering student, explained that in some courses *"when someone designs something, our teachers will ask us to evaluate the advantages and disadvantages of their design."* Finally, students also highlighted how teamwork enhances logical reasoning. As a science student noted in the online survey, "*teamwork and collective thinking can improve students' thinking ability, especially their logical reasoning."* H.Z., another science student, illustrated this point by describing how lab collaboration unfolds this practice: "*We conduct experiments together, collaboratively decide on the protocol, discuss our findings and future directions."* d) Constructing questions

The fourth pedagogical practice recognized as a fundamental element of CT is training students to effectively construct questions, as emphasized by eight of the instructors. This practice fosters students' engagement by prompting deeper analysis, comparison, evaluation and inquiry as they navigate learning experiences. According to Ms. Miley, an instructor with 26 years' experience: *"Creating an environment where students compose and answer complex questions encourages them to think at a higher level. This is essential to the process of cultivating CT*." Similarly, Izak, with 30 years' of teaching experience, pointed out the role of questioning in *"verifying comprehension and determining that one's personal ideas are logically sound"*. Ross, an instructor with 10 years' experience, added that CT *"involves not automatically accepting facts but questioning whether the information you receive is accurate and not based on misinformation."*

4.2. Modes of engagement embedding CT components

An analysis of the interview transcripts and online survey regarding the participants' previous experiences in science and engineering courses, indicated the existence of four modes of engagement that participants believe contribute to the fostering of CT. The following section presents selected examples of activities related to each of the four modes: '*critical engagement with information*', '*comparing approaches to problem solving', 'guided inquiry and experimentation'* and '*raising doubts and evaluating credibility'*. a. Critical engagement with information

One mode of engagement that the participants perceived promotes CT is *critical engagement with information*. This involves immersing deeply in scientific texts and multimedia resources to interpret and analyze content. It embraces such activities as organizing information, paraphrasing, holding discussions and active reading or listening, often integrating digital tools to enhance comprehension and interaction. Participants first noted activities that encourage engagement through competition. M.D., a science student, portrayed how some instructors conclude learning units with "*individual and group competitions in which online quizzes or PowerPoints with complex questions are incorporated to assess knowledge and encourage students to think deeply"*.

> Participants also emphasized organizing and structuring information systematically as a means of engaging with information and achieving better understanding. Tanya, an instructor with 36 years' experience, explained that she provides opportunities for her *"students to classify information … in graphs or tables"*. An engineering student in the online survey further illustrated this idea by recalling being *"instructed to read articles and organize the data into a timeline, including the topic and reason for the following study", facilitating a clearer* relationship between studies.

Summarizing information was also identified as central to promoting CT. For instance, Tanya directs her students to restate ideas in their own words, emphasizing that "*this entails not only repeating what was read, but also interpreting it. I ask students what the author really wants to say. It is not just paraphrasing but giving an additional flavor which is beyond the words."*

Activities that foster CT through critical reading or listening were also highlighted. These involve engaging with scientific articles and educational videos while responding to complex open and closed-ended questions designed to stimulate analysis and reasoning. For example, G.R., a science student, described how students are directed to identify *"the purpose and main ideas of research articles, author's claims, and justifications for these claims"*. From an instructional perspective, Sharon, an instructor with 38 years' experience, stressed the value of inference questions, asserting that *"students need to be trained to predict what will happen next."* b. Comparing approaches to problem solving

A second mode of engagement that the participants considered prominent for cultivating CT is *comparing approaches to problem solving*. This involves evaluating different methods or approaches, understanding their strengths and weaknesses and choosing the most efficient one. Izak, an instructor with 30 years' experience, portrayed how this promotes CT in his computer science courses: *"I present a collection of problems, guiding students to distinguish between the main and subordinate ones. We then explore various coding methods and discuss why certain approaches are more effective than others, while weighing the advantages and disadvantages."*

Parallel examples were provided by students. N.S., an engineering student, portrayed how he has been trained to compare possible actions when working on a project: *"Our project includes simulator tasks consisting of a sequence of actions, each with multiple alternatives, where you need to choose the best option for the project."* In mathematics, M.B., a science student, depicted how students *"look at the similarities between different methods that were previously learned and compare them with new approaches to identify which is best to solve the equation*".

Students also are trained to explore problems presented in the literature and critically examine the methodologies and solutions proposed by researchers as presented in the following example. B.Y., an engineering student, described how his professor guided students *"to trace the development of modern problem-solving theories, and examine various theories proposed from the past to the present, while assessing their suitability and identifying their limitations."* c. Guided inquiry and experimentation

A third mode of engagement for fostering CT, as identified by the students, was *guided inquiry and experimentation*. This involves hands-on experiments where students test hypotheses, analyze data, discuss their findings and draw conclusions in lab reports. Y.H., an engineering student, explained why she believes that lab experiments promote CT: *"In lab reports I present how the process was performed, discuss my conclusions and the steps that led me to the conclusions. I think that these steps involve CT."* Similarly, B.Y., an engineering student, finds that experiments promote CT because: *"We predict what will happen in the experiment and make hypotheses. For example, in the engineering industry, we make predictions about the performance of a material in the lab, like if the material will crack."* A science student wrote in the online survey that he finds that the main thing related to CT that is included in his science classes is the *"discussion at the end of a chemistry experiment report where we express criticism towards the course of the experiment, and consider which factors caused disruption or inaccuracy during the process."* d. Raising doubts and evaluating credibility

A fourth mode of engagement that the participants deemed promotes CT is *raising doubts and evaluating credibility*. This involves recognizing misinformation, identifying biases in information and evaluating the credibility of sources. Sharon, an instructor with 38 years' experience, explained that in her classes: *"When reading, students identify if the text is accurate, if there is bias and if it is reliable. I tell them to look at the source of the information and the author's motives."*

Students are also taught to be skeptical and question what they are reading. Herman, an instructor with 30 years' experience, guides his students to examine *"the methodology of articles and verify that they are scientifically sound."* An engineering student commented in the online survey that: *"some lecturers provoke students to reflect on what we are reading, ask questions and doubt. We comment in a forum when we disagree."*. Another means of developing this skill is by the deliberate use of mistakes to provoke critical reflection. Lisa, an instructor with 13 years' experience claimed: *"Sometimes I deliberately propose a math condition that is incorrect in order to train* *my students to make judgements and not automatically accept results."* A.N., a science student, described how his class developed a program to evaluate the reliability of information: *"In an artificial intelligence project, we try to detect fake news through machine learning."*

5. Summary and discussion

Based on the experience of instructors and students, this study identified eight instructional design components for promoting critical thinking in science and engineering education. These components include four pedagogical practices and four modes of engagement, as depicted in Fig. 1.

Fig. 1 summarizes the four modes of engagement: *critical engagement with information, comparing approaches to problem solving, guided inquiry and experimentation* and *raising doubts and evaluating credibility*. The circular arrangement of these modes illustrates their equal importance in promoting critical thinking, ensuring a well-rounded learning experience. The model also presents four key pedagogical practices believed to foster critical thinking: *explicit teaching of critical thinking, integration of digital tools, collaborative learning* and *constructing questions*. The model suggests that critical thinking should be explicitly taught through the modes of engagement, while integrating digital tools, collaborative learning, neither or both simultaneously. At the center of the four modes, constructing questions is depicted as a pedagogical practice that intertwines with each mode, emphasizing its continuous presence and essential role in enhancing critical thinking across all modes of engagement. This relationship is reciprocal, as questioning both drives engagement in a mode and emerges from it, fostering an ongoing cycle of reflection and learning.

Both instructors and students recognized the pedagogical practices *integration of digital tools and collaborative learning* as effective means of promoting critical thinking, aligning with previous studies on critical thinking methodologies. The literature advocates for the use of digital tools to create engaging critical thinking enhanced environments (e.g. Barak & Shahab, 2023; Brookfield, 2020; Cortázar et al., 2021; Santos-Meneses & Drugova, 2023). Likewise, *collaborative learning,* has been widely acknowledged as beneficial for critical thinking development. For example, Cortázar et al. (2021) advocated for fostering critical thinking through collaborative work in an online project-based course while Lin et al. (2021) proposed interactive peer-reviews to enhance critical thinking in a digital learning environment. The findings of the current study are unique in that they demonstrate the importance of the presence of these

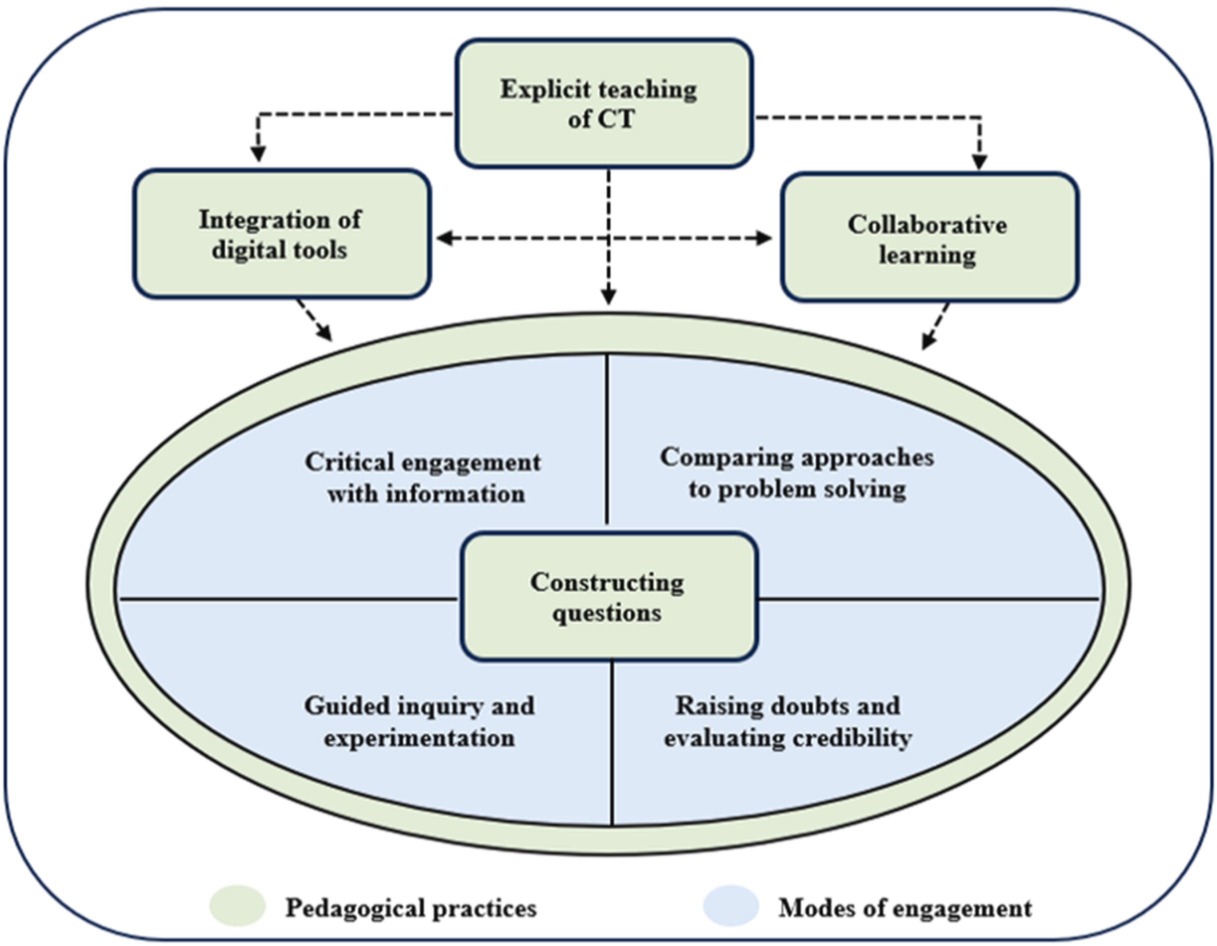

Fig. 1. A model summarizing the instructional design components for promoting CT.

two pedagogical practices, together or separately, in the context of explicit teaching of critical thinking in academic courses.

From a teaching perspective, recent literature highlights the importance of explicitly articulating critical thinking objectives in course design, ensuring students understand the skills and dispositions being developed (e.g. Bellaera et al., 2021; Cortázar et al., 2021; Ma et al., 2023; Santos-Meneses & Drugova, 2023). From a learning perspective, the literature shows that training students to construct questions enhances their ability to critically engage with content (Bezanilla et al., 2019; Paul & Elder, 2007; Kuhn, 2019; Rakedzon & Van Horne, 2024). The current study addresses both perspectives, highlighting the importance of *explicit teaching of critical thinking* and *constructing questions* as essential for fostering critical thinking. However, despite the importance of explicit teaching, in practice, the promotion of critical thinking is often not explicitly embedded in curricula or instructional practices (Barak et al., 2007; Bellaera et al., 2021; Santos-Meneses & Drugova, 2023). One possible explanation for this omission is that instructors may assume that critical thinking development occurs implicitly through subject learning rather than requiring deliberate pedagogical strategies (Bellaera et al., 2021; Santos-Meneses & Drugova, 2023). In addition, instructors may be primarily focused on delivering subject-specific content and meeting curricular demands, leaving little time to explicitly teach 21st-century competencies such as critical thinking (Santos-Meneses & Drugova, 2023; Tan, 2020). In the case of constructing questions, while this pedagogical practice was recognized by the instructors, it was less acknowledged by students. A possible explanation could be that students perceive questioning as a spontaneous act rather than a structured skill that is associated with critical thinking. Moreover, students may be hesitant to raise questions in class, particularly if they come from cultural backgrounds where questioning authority figures is less encouraged (Rakedzon & Van Horne, 2024; Tan, 2020). Given the significance of these pedagogical practices, it is recommended that instructors invest intentional efforts to embed critical thinking development and effective questioning strategies explicitly into pedagogical design in order for students to receive the opportunities needed to cultivate these practices.

While both the instructors and students acknowledged the significance of the *integration of digital tools* for fostering critical thinking, some participants contended that these tools were primarily utilized for presenting and drilling course material, rather than fostering critical thinking. Effective digital integration should extend beyond incorporating activities which simply demand recalling information. They should include opportunities to develop critical thinking, by prompting deeper analysis and evaluation (Barak & Shahab, 2023; Bezanilla et al., 2019). For instance, online discussion forums and cooperative writing through Google Docs can provide settings for students to collaboratively analyze problems, exchange opinions and provide peers with constructive feedback. Forums have the additional benefit of providing a non-threatening learning environment, which is particularly beneficial for students whose learning styles or cultural backgrounds favor less outspoken and confrontational ways of communication (Brookfield, 2020; Santos-Meneses & Drugova, 2023; Tan, 2017; Todd et al., 2019). Moreover, artificial intelligence is a groundbreaking technology, that when effectively incorporated into lessons, can enhance critical thinking skills (Larson et al., 2024; Rusandi et al., 2023). However, unquestioningly relying on AI-generated content without verifying its accuracy against reliable sources may hinder critical thinking rather than fostering it (Michel-Villarreal et al., 2023; Suriano et al., 2025).

Regarding the modes of engagement: critical engagement with information, comparing approaches to problem-solving as well as raising doubts and evaluating credibility were identified as promoting critical thinking, corresponding with prior studies on critical thinking methodologies. For example, Kuhn (2019) proposed a dialogic concept of critical thinking, incorporating activities and techniques that actively engage students in argumentative discourse. Suriano et al. (2025) emphasized the importance of fostering active engagement and in-depth understanding to promote the critical analysis of information provided by AI-based chatbots. While these studies and others (e.g., Brookfield, 2020; Jiang et al., 2024) provide valuable insights, they often focus on one methodology, or a few select elements and offer sporadic insights into critical thinking instruction. By integrating multiple pedagogical practices and modes of engagement, this study provides a more holistic approach to promoting critical thinking in science and engineering education.

Similarly, *guided inquiry and experimentation,* was recognized in the study as essential for fostering critical thinking. This finding aligns with previous literature on critical thinking methodologies that portray inquiry-based instruction as an effective way to promote scientific reasoning and critical thinking (Avargil et al., 2012; Barak et al., 2007; Kuhn, 2019; Ma et al., 2023). Interestingly, while this mode of engagement was raised by the students, it was less acknowledged by the instructors. The differences between student and instructor perceptions suggest that students experience *guided inquiry and experimentation* as thought-provoking, reinforcing their role in developing critical thinking skills. In contrast, instructors may simply view these activities as explorative components of scientific and engineering practice (Barak et al., 2007; Ma et al., 2023). It is possible that they conceptualize critical thinking as a skill more closely tied to activities such as evaluating arguments, questioning assumptions and assessing credibility.

6. Conclusions and research limitations

Three main conclusions were drawn from the study. First, to ensure students have meaningful opportunities to develop critical thinking, it is recommended that instructors explicitly embed clear critical thinking objectives into pedagogical design. Second, to optimize digital tools' role in fostering critical thinking, effective integration should extend beyond activities that focus on basic comprehension or rote learning. Instead, opportunities should be provided to cultivate higher order thinking, by prompting deeper analysis and evaluation. Third, the instructors emphasized the importance of training students to construct questions, recognizing their role in fostering deeper thinking and cognitive engagement. Given their significance across all modes of engagement, instructors should intentionally teach and model effective questioning strategies, reinforcing questioning as a fundamental aspect of critical thinking.

Adhering to previous work on critical thinking (Facione, 1990, 2015), this study presents insights regarding the instructional design components recommended by university instructors and students for promoting critical thinking in science and engineering education.

The study's theoretical contribution is the creation of an adaptive model with explicit critical thinking pedagogical practices that include digital technology and social interactions while integrating the four modes of engagement in academic courses for science education, policy makers and instructional designers. The practical contribution is the suggested design components for fostering critical thinking in science and engineering courses. This study employed a rigorous approach to data collection and analysis; however, its focus on a single research university may limit the generalizability of the findings. As a case study, this research provides in-depth, context-specific insights valuable for understanding complex phenomena within their real-life context (Creswell, 2018; Stake, 1995), and can serve as a foundation for further research at additional universities. Moreover, future research could explore the development of learning activities which integrate the aforementioned design components within a CT-enhanced instructional framework. This includes assessing their effectiveness in promoting critical thinking across diverse courses and cultural contexts.

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Ethics approval

The authors confirm that the study was conducted according to the university's ethical guidelines, approved by the institutional review board (IRB) and the Office of the Chief Scientist at the Ministry of Education. The study was performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

CRediT authorship contribution statement

Carmella Shahab: Writing – original draft, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Miri Barak:** Writing – review & editing, Validation, Supervision.

Declaration of Competing Interest

The authors reported no declarations of interest.

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Data availability

Data will be made available on request.

References

Ahern, A., Dominguez, C., McNally, C., O'Sullivan, J. J., & Pedrosa, D. (2019). A literature of critical thinking in engineering education. *Studies in Higher Education, 44*(5), 816–828.

Avargil, S., Herscovitz, O., & Dori, Y. J. (2012). Teaching thinking skills in context-based learning: Teachers' challenges and assessment knowledge. *Journal of Science Education and Technology, 21*, 207–225.

Avsec, S., & Savec, V. F. (2019). Creativity and critical thinking in engineering design: The role of interdisciplinary augmentation. *Global Journal of Engineering Education, 21*(1), 30–36.

Barak, M. (2017). Science teacher education in the twenty-first century: A pedagogical framework for technology-integrated social constructivism. *Research in Science Education, 47*(2), 283–303. https://doi.org/10.1007/s11165-015-9501-y

Barak, M., Ben-Chaim, D., & Zoller, U. (2007). Purposely teaching for the promotion of higher-order thinking skills: A case of critical thinking. *Research in Science Education, 37*, 353–369.

Barak, M., & Shahab, C. (2023). The conceptualization of critical thinking: Toward a culturally inclusive framework for technology-enhanced instruction in higher education. *Journal of Science Education and Technology, 32*, 872–883.

Barak, M., & Yuan, S. (2021). A cultural perspective to project-based learning and the cultivation of innovative thinking. *Thinking Skills and Creativity, 39*, Article 100766. https://doi.org/10.1016/j.tsc.2020.100766

Bellaera, L., Weinstein-Jones, Y., Ilie, S., & Baker, S. T. (2021). Critical thinking in practice: The priorities and practices of instructors teaching in higher education. *Thinking Skills and Creativity, 41*. https://doi.org/10.1016/j.tsc.2021.100856

Bezanilla, M. J., Fernandez-Nogueira, D., Poblete, M., & Galindo-Dominguez, H. (2019). Methodologies for teaching-learning critical thinking in higher education: The teacher's view. *Thinking Skills and Creativity, 33*, 1–10.

Brookfield, S. (2020). Teaching for critical thinking. *International Journal of Adult Education and Technology, 11*(3), 1–21. https://doi.org/10.4018/ijaet.2020070101

Campo, L., Galindo-Dominguez, H., Bezanilla, M., Fernandez-Nogueira, D., & Poblete, M. (2023). Methodologies for fostering critical thinking skills from university students' points of view. *Education Sciences, 13*, 132. https://doi.org/10.3390/educsci13020132

Chen, L. (2017). Understanding critical thinking in Chinese sociocultural contexts: A case study in a Chinese college. *Thinking Skills and Creativity, 24*, 140–151.

Corbin, J. M., & Strauss, A. (2014). *Basics of qualitative research: Techniques and procedures for developing grounded theory* (4thEd.). London: Sage.

Cortázar, C., Nussbaum, M., Harcha, J., Alvares, D., López, F., Goñi, J., & Cabezas, V. (2021). Promoting critical thinking in an online, project-based course. *Computers in Human Behavior, 119*. https://doi.org/10.1016/j.chb.2021.106705

Creswell, J. W. (2018). *Research design: Qualitative, quantitative, and mixed methods approaches* (5th Ed.). Thousand Oaks, CA: SAGE Publications.

Dehghayedi, M., & Bagheri, M. S. (2018). EFL teachers' learning and teaching beliefs: Does critical thinking make a difference? *International Journal of Instruction, 11*(4), 223–240.
Denzin, N. (2006). *Sociological methods: A sourcebook* (5thEd.). New Brunswick, N.J.: Aldine Transaction.
Douglas, E. P. (2012). Defining and measuring critical thinking in engineering. *Procedia – Social and Behavioral Sciences, 56*, 153–159.
Dwyer, C. P., Hogan, M. J., & Stewart, I. (2014). An integrated critical thinking framework for the 21st century. *Thinking Skills and Creativity, 12*, 43–52.
Ennis, R. (2018). Critical thinking across the curriculum: A vision. *Topoi, 37*, 165–184.
Facione, P. A. (1990). *Critical thinking: A statement of expert consensus for purposes of educational assessment and instruction - The Delphi report*. Millbrae, CA: California Academic Press.
Facione, P. A. (2015). *Critical thinking: What it is and why it counts*. Hermosa Beach, CA: Measured Reasons LLC.
Forawi, S. A. (2016). Standard-based science education and critical thinking. *Thinking Skills and Creativity, 20*, 52–62.
Ghanizadeh, A. (2017). The interplay between reflective thinking, critical thinking, self-monitoring, and academic achievement in higher education. *The Journal of Higher Education, 74*, 101–114.
Halpern, D. F. (1998). Teaching critical thinking for transfer across domains: Disposition, skills, structure training, and metacognitive monitoring. *American Psychologist, 53*(4), 449–455.
Halpern, D. F. (2014). *Thought and knowledge: An introduction to critical thinking* (5th ed.). New York: Psychology Press.
Jiang, L., Liang, F., & Wu, D. (2024). Effects of technology-aided teaching mode on the development of CT skills of EFL students in higher vocational colleges: A case study of English argumentative writing. *Thinking Skills and Creativity, 53*, Article 101594. https://doi.org/10.1016/j.tsc.2024.101594
Kuhn, D. (1999). A developmental model of critical thinking. *Educational Researcher, 28*(2), 16–25. http://www.jstor.org/stable/1177186.
Kuhn, D. (2019). Critical thinking as discourse. *Human Development, 62*, 146–164.
Larson, B. Z., Moser, C., Caza, A., Muehlfeld, K., & Colombo, L. A. (2024). Critical thinking in the age of generative AI. *Academy of Management Learning & Education, 23*(3), 373–378. https://doi.org/10.5465/amle.2024.0338
Lin, H., Hwang, G., Chang, S., & Hsu, Y. (2021). Facilitating critical thinking in decision making-based professional training: An online interactive peer-review approach in a flipped learning context. *Computers & Education, 168*, Article 104266. https://doi.org/10.1016/j.compedu.2021.104266
Loes, C. N., & Pascarella, E. T. (2017). Collaborative learning and critical thinking: Testing the link. *The Journal of Higher Education, 88*(5), 726–753.
Ma, X., Zhang, Y., & Luo, X. (2023). Students' and teachers' critical thinking in science education: Are they related to each other and with physics achievement? *Research in Science & Technological Education, 41*(2), 734–758.
Manalo, E. (Ed.). (2020). *Deeper learning, dialogic learning, and critical thinking: Research-based strategies for the classroom*. London: Routledge.
Michel-Villarreal, R., Vilalta-Perdomo, E. L., Salinas-Navarro, D. E., Thierry-Aguilera, R., & Gerardou, F. S. (2023). Challenges and opportunities of generative AI for higher education as explained by ChatGPT. *Education Sciences, 13*(9). https://doi.org/10.3390/educsci13090856
OECD. (2021). *21st-Century Readers: Developing literacy skills in a digital world*. Paris: PISA, OECD Publishing. https://doi.org/10.1787/a83d84cb-en
Osman, S., Abu, M. S., Mohammad, S. B., & Mokhtar, M. B. (2016). Identifying pertinent elements of critical thinking and mathematical thinking used in civil engineering practice in relation to engineering education. *The Qualitative Report, 21*(2), 212–227.
Paul, R., & Elder, L. (2007). *Critical thinking competency standards*. Dillon Beach, CA: Foundation for Critical Thinking.
Pellegrino, J. W., & Hilton, M. L. (Eds.). (2012). *Education for life and work: Developing transferable knowledge and skills in the 21st century*. Washington, D.C.: The National Academies Press. National Research Council.
Pekrun, R. (2020). Commentary: Self-report is indispensable to assess students' learning. *Frontline Learning Research, 8*(3), 185–193.
Rakedzon, T., & Van Horne, C. (2024). Curious is as curious does": Fostering question-asking in a Sino-Foreign engineering school - A case study. *Sustainability, 16*, 7308. https://doi.org/10.3390/su16177308
Rusandi, M. A., Ahman, S. I., Khairun, D. Y., & Mutmainnah. (2023). No worries with ChatGPT: Building bridges between artificial intelligence and education with critical thinking soft skills. *Journal of Public Health, 45*(3), e602–e603. https://doi.org/10.1093/pubmed/fdad049
Santos-Meneses, L. F., & Drugova, E. A. (2023). Trends in critical thinking instruction in 21st-century research and practice: Upgrading instruction in digital environments. *Thinking Skills and Creativity, 49*, Article 101383. https://doi.org/10.1016/j.tsc.2023.101383
Stake, R. E. (1995). *The art of case study research*. London: Sage.
Suriano, R., Plebe, A., Acciai, A., & Fabio, R. A. (2025). Student interaction with ChatGPT can promote complex critical thinking skills. *Learning and Instruction, 95*. https://doi.org/10.1016/j.learninstruc.2024.102011
Tan, C. (2017). Teaching critical thinking: Cultural challenges and strategies in Singapore. *British Educational Research Journal, 43*(5), 988–1002.
Tan, C. (2020). Conceptions and practices of critical thinking in Chinese schools: An example from Shanghai. *Educational Studies, 4*, 331–346.
Todd, C. L., Ravi, K., & McCray, K. (2019). Cultivating critical thinking skills in online course environments: Instructional techniques and strategies. *International Journal of Online Pedagogy and Course Design, 9*(1), 19–37. https://doi.org/10.4018/IJOPCD.2019010102O
Tosuncuoglu, I. (2018). Place of critical thinking in EFL. *International Journal of Higher Education, 7*(4), 26–32.
Usher, M., & Barak, M. (2024). Unpacking AI ethics education for science and engineering students. *International Journal of STEM Education, 11*, 35. https://doi.org/10.1186/s40594-024-00493-4
Vincent-Lancrin, S., Gonzalez-Sancho, C., Bouckaert, M., Luca, F. D., Fernandex-Barrerra, M., Jacotin, G., Urgel, J., & Vidal, Q. (2019). Fostering students' creativity and critical thinking: What it means in school. *Educational Research and Innovation*. Paris: OECD Publishing. Retrieved August 10th 2019 from: Https://www.oecd.org/en/publications/fostering-students-creativity-and-critical-thinking_62212c37-en.html.
Wass, R., Harland, T., & Mercer, C. (2011). Scaffolding critical thinking in the zone of proximal development. *Higher Education Research and Development, 30*(3), 317–328.
Wengrowicz, N., Dori, Y. J., & Dori, D. (2018). Metacognition and meta-assessment in engineering education. In Y. J. Dori, Z. R. Mevarech, & D. R. Baker (Eds.), *Cognition, metacognition, and culture in stem education. innovations in science education and technology: 24. Cognition, metacognition, and culture in stem education. innovations in science education and technology* (pp. 191–216). Cham: Springer.
Willig, C. (2013). *Introducing qualitative research in psychology* (3rdEd.). Berkshire, England: McGraw-Hill Education.
Zhao, C., Pandian, A., & Singh, M. K. M. (2016). Instructional strategies for developing critical thinking in EFL classrooms. *English Language Teaching, 9*(10), 14–21.