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Learning design to support student-AI collaboration: perspectives of leading teachers for AI in education

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Abstract
Preparing students to collaborate with AI remains a challenging goal. As AI technologies are new to K-12 schools, there is a lack of studies that inform how to design learning when AI is introduced as a collaborative learning agent to classrooms. The present study, therefore, aimed to explore teachers' perspectives on what (1) curriculum design, (2) student-AI interaction, and (3) learning environments are required to design student-AI collaboration (SAC) in learning and (4) how SAC would evolve. Through in-depth interviews with 10 Korean leading teachers in AI in Education (AIED), the study found that teachers perceived capacity and subject-matter knowledge building as the optimal learning goals for SAC. SAC can be facilitated through interdisciplinary learning, authentic problem solving, and creative tasks in tandem with process-oriented assessment and collaboration performance assessment. While teachers expressed instruction on AI principles, data literacy, error analysis, AI ethics, and AI experiences in daily life were crucial support, AI needs to offer an instructional scaffolding and possess attributes as a learning mate to enhance student-AI interaction. In addition, teachers highlighted systematic AIED policy, flexible school system, the culture of collaborative learning, and a safe to fail environment are significant. Teachers further anticipated students would develop collaboration with AI through three stages: (1) learn about AI, (2) learn from AI, and (3) learn together. These findings can provide a more holistic understanding of the AIED and implications for the educational policies, educational AI design as well as instructional design that are aimed at enhancing SAC in learning.

Keywords AI in education · Student-AI collaboration · Distributed cognition · Learning design

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1 Introduction

One of the most profound areas of technological progress within the past decade has been in the development of artificial intelligence (AI) and its increased integration across multiple industries. The field of education is among those adopting and adapting to the opportunities and challenges of AI-enabled technologies, amid the broader incorporation of data, algorithms, and automation (Luckin et al., 2016). For instance, devices and programs that utilize AI can capture, aggregate, and analyze students' learning performance data in real-time from different sources to develop a student learning profile and automatically provide customized content, feedback, and learning parameters. These, in turn, provide more tailored and relevant learning opportunities and experiences that support students as they progress through the learning material (Peng et al., 2019; Cho et al., 2019). On the other hand, communicative AI such as conversational agents and embodied social robots interact with students, not limited to supporting students' cognitive development, serve as an empathic peer/tutor to support affective development such as improving learning interest, motivation, self-regulation, and sense of empathy and collaboration (Chin et al., 2014). In sum, AI is increasingly permeating the education ecosystem by increasingly interacting and collaborating with students, building and maintaining social relationships, and offering personalized instruction. This indicates that the educational field has integrated nonhuman agents as collaborative agents serving roles of tutors/teachers, assistants, advisors, and even learning peers (Lee & Kim, 2020; Kim et al., 2020).

Although interests and demands for students-AI collaboration (SAC) in learning, in general, are increasing, the integration of AI in classroom activities and the AI-related school curricula are complex and challenging in K-12 schools. In the absence of a specific roadmap for AI in Education (AIED), teachers face challenges in that they are not formally trained for AIED but have to teach about it in a jam-packed curriculum, without adequate and convenient infrastructure. Moreover, while AI applications differ from other technologies in that they explicitly aim to act as agents in the classroom environment by adaptively tapping into students' learning process, teachers face substantial pedagogical challenges in designing and facilitating how students interact, collaborate, and learn with AI in the classroom previously ruled by human-human (students and teachers) interaction only (Gunkel, 2012).

In recognition of teachers' beliefs and views will decide the actual curriculum at the ground level and are critical in the planning of educational practice for sustainability (Chiu, 2017), this study aims to examine the views of leading teachers in AIED on key considerations for the design and implementation of SAC in learning for K-12 schools. The findings of this study can develop a holistic understanding of learning design in the classroom where AI serves as a student's collaborator on a learning task.

2 Literature review

2.1 Student-AI collaboration

The ways that the role of AI in learning has been positioned as another emerging educational tool are mainly two-fold: (1) 'Learning with AI' and (2) 'Learning about AI' (Holmes et al., 2019). The former means the use of AI as a direct teaching and learning tool (e.g., adaptive or personalized learning management system, intelligent tutoring system (ITS), and AI speaker), while the latter refers to an approach that teaches AI as a learning content to develop the ability to design, develop, and utilize AI algorithms based on the understanding of AI (Baker & Smith, 2019). Although these studies offer a comprehensive understanding of the advancement of AI technology and the development of AI-related school curricula, it is claimed that such tool-centric conception of AI cannot fully discuss the potential of AI functionality, intended educational purpose of AI, as well as the potential risks of AIED in the educational system (Big Innovation Centre, 2020). In contrast to existing technologies, AI engages in more autonomous, personalized, and active interaction with students. Interactions with AI are dynamic rather than static, reflecting upon the communication and interactions being exchanged within a learning process and context. AI being autonomous, social, and reactive (Wooldridge & Jennings, 1995) makes the study of AI intriguing for AIED scholars and employs AI to serve roles as learning peers, tutors, and assistants that have been restricted to human students and teachers (Simmler & Frischknecht, 2020). This study, therefore, envisions AI as a subject in interaction on students' learning and shifts the attention that was previously focused on the advancement of AI technology and the development of AI-related school curricula to the nature and quality of social interaction between students and AI as collaborative learning partners/peers and its implications for the learning environment that can support the SAC for learning.

The current study adopts the theory of distributed cognition (DC) that has been found as an effective framework for a holistic understanding of the complex relations and interactions among heterogeneous agents (i.e., students, AI, and teachers), the multiple existing digital technologies, and practices in the classroom environment (Hutchins, 1995; Perkins, 1993; Nardi & O'Day, 1999). The notion of DC provides two important methodological insights. First, the unit of analysis should be expanded from the individual to the wider system. For instance, cognitive processes may be distributed across the members of a team; cognitive processes may involve coordination between internal and external (material or environmental) structure; processes may be distributed through time in such a way that the products of earlier events can transform the nature of later events (Hutchins, 1995). Second, the analysis looks for a range of mechanisms that can partake in the cognitive system rather than restricting itself to symbol manipulation and computation – e.g. the interplay between human memory, external representations, and the manipulation of objects (Hollan et al., 2000, p. 176). This gives some indication of the sorts of observations and phenomena that a DC analysis might highlight; this study has expanded on these by reference to the broader DC literature to present a set of components for SAC on

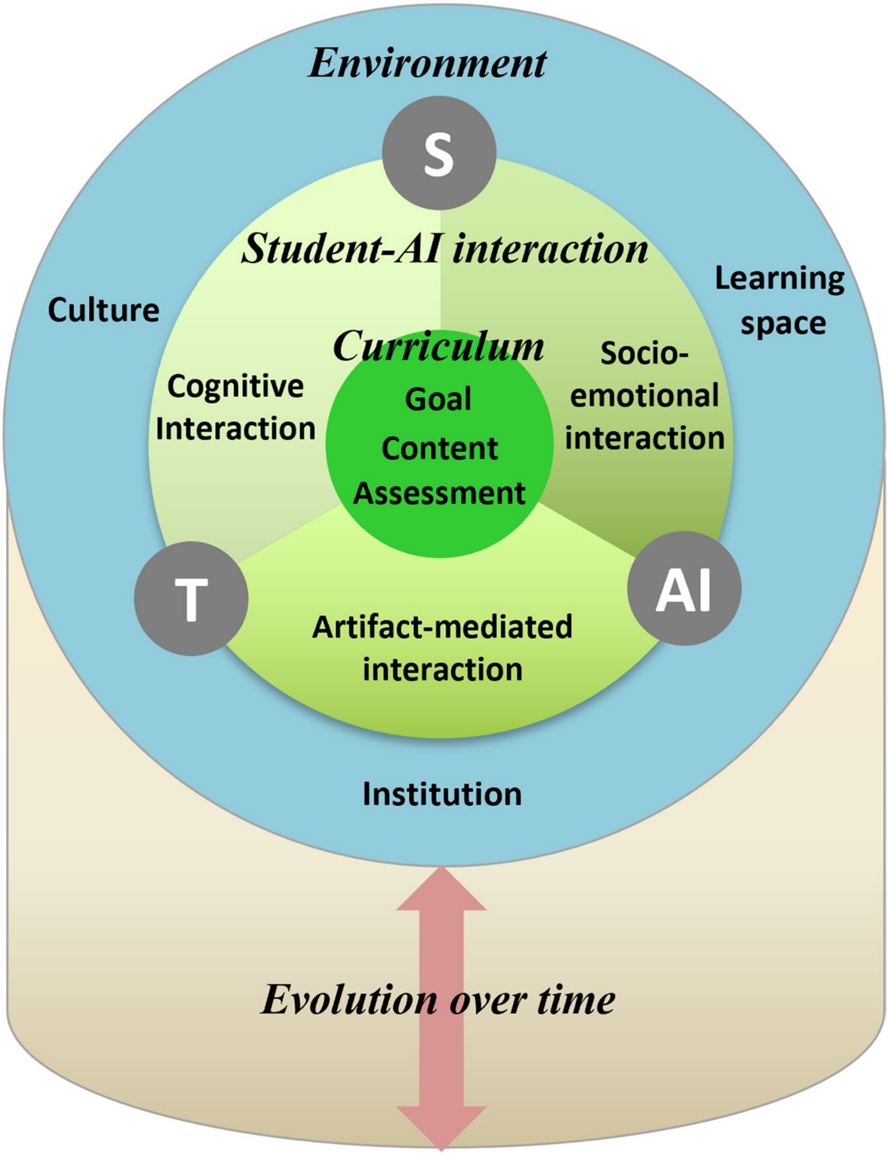

Fig. 1 Student-AI Collaboration Model

learning. The present study developed the SAC model composed of the four components that have been the focus of the work to date: (1) curriculum, (2) student-AI interaction, (3) environment, and (4) evolution over time (See Fig. 1).

The SAC model consists of three participants: Student(S), AI, and Teacher(T). First, an individual student is considered an active learning agent in the SAC model. In fact, students in the early AIED literature, particularly in learning with ITS, were portrayed as passive recipients along with a specified learning path that AI guides. However, the recent study anticipates shifts in students' agency and roles over their learning through AIED whereby students learn as collaborators actively interacting with AI to achieve more optimized learning, or as leaders participating in learning and rethinking their growth within complex learning systems (Ouyang & Jiao, 2021).

Next, the model identifies AI as another learning agent, shifting its nature and role from a mere learning tool. Previous studies take note of AI's human-resemblance characteristics as a unique feature that distinguishes it from traditional educational tools (Huang, 2018), and expand the role of AI in learning (Simmler & Frischknecht 2020). For example, AI could be a teacher to properly diagnose learning processes and outcomes, provide personalized feedback and evaluate achievement (Chaudhry & Kazim, 2021). On the other hand, Fryer et al. (2017) demonstrate that the AI chatbot and students learn foreign languages together through peer relationships. Instead of fixing a conceptualization of interaction as a human-only process and the role of technology as a mediating tool, the model opens the theoretical possibility of AI as an interaction subject directly exchanging information with students in a learning process (Guzman & Lewis, 2020).

Alongside students and AI, teachers play a critical role in shaping and facilitating SAC and must be held accountable in classroom learning (Chaudhry & Kazim, 2021). In this regard, Utterberg and colleagues (2021) describe teachers as gatekeepers for AI adoption in the classroom, arguing that if teachers do not allow students to interact with AI in the classroom learning activity, AI is not likely to be embedded into the teaching curricula of school. In addition, although some anticipate that AI-assisted data-driven, evidence-informed decisions based on the collection and analysis of students' real-time learning data may diminish teachers' leadership, most literature argues that human teachers will remain the masterminds behind AI algorithms, considering the drawbacks of AI-assisted data-driven decision-making in intuition and value consideration (Wang, 2021). Taken together, teachers' pedagogical decision-making is best managed by reviewing and embracing a blend of data-driven, evidence-informed decision-making by AI and value-based moral decision-making by teachers to provide more effective instructional strategies (Zheng, 2020).

2.2 Curriculum: Learning goal, content and assessment

The curriculum, one of the core elements in the model, consists of learning goals, content, and assessment. While the acquisition of knowledge and skills in a specific domain has been the prime focus in the earlier literature (Ouyang & Jiao, 2021), the recent studies highlight the goal of AIED to cultivate high-level thinking such as problem-solving and creativity through collaboration with AI, rather than simply acquiring knowledge in the specific domain (Kafai & Burke, 2014). Particularly, improving computational thinking (CT), a set of skills including decomposition, abstraction, algorithm design, debugging, testing/simulation, heuristic reasoning, and generalization, is being accentuated to understand and use AI effectively to solve problems (Shute et al., 2017; NRC, 2010). Rodrigues et al. (2016) highlighted that CT can facilitate and support the mental processes that support the activity of learning in the school by demonstrating quantitative evidence on the correlation between primary school students' CT and academic performance in the school.

Although AIED calls for a multidisciplinary approach, STEM-related learning contents were widely implemented for several technical and practical reasons (Zawacki-Rtichter et al., 2019). Because AI's understanding of meaning and context through natural language processing is yet well advanced and much more difficult and expensive than interpreting mathematical expressions, humanities-related (e.g., arts, social sciences, etc.) learning contents have less been stressed in the AIED field (Olmos-Peñuela et al., 2015).

The assessment in AIED provides more formative feedback based on a sophisticated diagnosis of student understanding, engagement, and academic integrity (Zawacki-Richter et al., 2019). In contrast to the traditional assessment centered on formalized tests, the assessment in AIED analyzes and evaluates information from various pathways about students through speech recognition, language analysis, and behavioral pattern analysis (Vincent-Lancrin & van der Vlies, 2020).

2.3 Student-AI interaction: Cognitive, socio-emotional, and artifact-mediated interaction

Student-AI Interactions are divided into three types: cognitive, socio-emotional, and artifact-mediated interaction. First of all, cognitive interaction refers to task-focused interaction about the content or their learning process (Dillenbourg et al., 1995). This includes interactions about domain-focused content to be learned, such as the sharing, elaborating, and processing of knowledge (Hmelo-Silver & Barrows, 2008). For instance, a student talks with a chatbot about the characteristics of rocks suggested by a teacher, infers the types of rocks, and learns about different criteria for classifying rocks in a geology class.

Second, socio-emotional interaction involves "purposeful interchanges among group members that shape perceptions of emotions and socio-emotional climate" (Bakhtiar et al. 2017, p. 62). A range of studies investigated the effects of socio-emotional interaction between a student and AI on learning performance. For example, polite web-based tutors induce more learning than regular web-based tutors (McLaren et al., 2011). In addition, Hwang et al. (2020) found that an adaptive learning model using emotional and cognitive performance analysis was effective in elementary school students' mathematical learning outcomes by reducing their math anxiety.

Lastly, it should be noted that the core of AI is algorithms and engines. AI, therefore, interacts with students through artifacts such as interfaces. The characteristics of an AI system's interface and how students interact with AI through the interface are found to have a significant impact on learning with AI. For instance, Fu et al. (2020) presented that the AI's social presence, accurate speech recognition, and peer influence affect language learners' continuous interaction with AI-enabled automatic scoring applications.

2.4 Environment: Learning space, institution, and culture

The environments including learning space, institutional rules, and school culture play a crucial role in implementing SAC effectively. They are macro-level background elements for SAC. First, for AI to successfully embed into the classroom, an appropriate learning space has to be preemptively built. In this regard, the Korean government highlights distributing smart devices and establishing a wireless network environment for K-12 classrooms as a part of building an adequate learning space for AIED (MOE, 2021). In addition, digital infrastructure (i.e., learning platform) is considered to be essential for SAC (Wang & Cheng, 2021).

Second, institutional support is necessary for the budget/funding provision, the curriculum/pedagogy development, and legal/ethical guidelines in AIED. In particular, the time and cost of developing and introducing an appropriate methodology for implementing AIED pose a major challenge in public educational institutions (Zawacki-Richter et al., 2019). Without an upper-level institution's explicit directions and guidelines on curriculum and pedagogy for AIED, it would be challenging for schools to adopt AI, the new technology (Wang & Cheng, 2021). Furthermore, the introduction of AI in classrooms can cause several legal and ethical issues related to personal information and privacy, thus, institutional safeguards are needed to protect students from damage and disputes (Okoye et al., 2020).

Last but not least, school culture is a crucial environmental factor in SAC. The AIED has to be achieved through the collective will of the diverse stakeholders in the educational system. For instance, teachers are resistant to adopting new technology after they receive negative feedback from colleagues, students, and parents in school as well as due to their demanding schedules meeting various roles in schools. Therefore, it is crucial to build a collaborative school culture that supports professional dialogue on the need and importance of AIED and the utilization of AI for learning among varied stakeholders (Kim et al., 2021a).

2.5 Evolution over time

AI is not a static tool that does not change. Just as students learn and improve learning by interacting with AI, AI also learns and improves over time through interaction with students (Self, 1998). While a student learns effectively through interaction with the personalized AI, AI optimizes the student model by collecting the student's information and response to the AI's feedback and reflecting on them to derive more optimized analysis results (Tan & Cheah, 2021). In short, student learning growth and development go hand in hand with AI development, and vice-versa, which indicates that AI is not a mere tool.

After reviewing existing literature, the present study acknowledges the unique potential of AI and seeks a better understanding of the key considerations for the design and implementation of SAC in learning for K-12 schools toward a new AI-mediated educational environment. More precisely, the study aims to disclose and examine teachers' views on what (1) curriculum design (learning goals, contents, and assessment), (2) student-AI interaction during learning activity, and (3) learning environments (learning space, culture, and institution) are required and (4) how students would develop collaboration with AI over time based on the proposed SAC model (see Fig. 1). The research questions (RQs) set for the study are as follows:

(1) What curriculums are required in the SAC?
(2) What supports are needed in student-AI interactions?
(3) What learning environments should be established?
(4) How would SAC evolve over time?

3 Methods

3.1 Participant and context

In accordance with the 2015 revised national curriculum which reinforced software (SW) education as a mandatory subject, the Korean Ministry of Education and Ministry of Science and ICT have designated and operated 2011 SW leading schools via 17 metropolitan and provincial education offices as of December 2020. Among them, 247 schools are now selected as AI pilot schools, and 34 additional schools are designated as AI convergence curriculum-oriented high schools (KERIS, 2020).

A combination of a purposeful and snowball sampling strategy was employed to explore diverse views of AIED leading teachers about what should be supported to design and implement SAC in learning for the needs of different contexts of schools and students. Every participant works in either SW leading schools, AI pilot schools, or AI convergence curriculum-oriented high schools. This study initially conducted interviews with four leading teachers (P1, P3, S1, S5) from different regions/schools, years of teaching experience, and AIED experiences. Table 1 summarizes the information of 10 Korean teachers (5 primary and 5 secondary schools[1]) who participated in the study. This study received ethical approval from the university's Institutional Review Board and informed consent from all participants.

3.2 Data collection

The findings of this study are based on semi-structured interviews conducted with 10 teachers presented in Table 1 for approximately between 90 and 120 minutes. We first developed a semi-structured interview guide based on the SAC model proposed (see Fig. 1) with 15 questions related to the main components of the model. Due to the COIVID-19 pandemic situation, interviews were mostly conducted via videoconferences using the ZOOM, except face-to-face interviews with S1 and S2 because of their preference. The interviews were audio-recorded and then transcribed.

[1] While the Korean primary school is organized with six-year curriculums, the secondary school system consists of three years of middle school and three years of high school.

Table 1 Participants characteristics

Participant		Gender	Teaching experience	AIED experience
Primary school teacher	P1	F	14 years	AIED instruction, Academic research, AIED curriculum development
	P2	M	5 years	AIED instruction, Academic research, AIED curriculum development
	P3	M	5 years	AIED instruction, Academic research, Publication, AIED curriculum development, Consulting for an educational AI design
	P4	M	11 years	AIED instruction, Academic research, AIED curriculum development
	P5	F	17 years	AIED instruction, Academic research, Publication, AIED curriculum development, Consulting for an educational AI design
Secondary school teacher	S1	F	5 years	AIED instruction, Academic research, AIED curriculum development
	S2	M	17 years	AIED instruction, Academic research, Publication, AIED curriculum development, Consulting for an educational AI design
	S3	F	5 years	AIED instruction, Academic research, AIED curriculum development
	S4	F	15 years	AIED instruction, Academic research, Publication, AIED curriculum development, Consulting for an educational AI design
	S5	M	17 years	AIED instruction, Academic research, Publication, AIED curriculum development, Consulting for an educational AI design

3.3 Data analysis

A hybrid inductive and deductive thematic analysis (Braun & Clarke, 2006) was undertaken to identify themes related to the proposed framework. The first author generated initial codes through a repetitive reading of transcripts and conducted a deductive thematic analysis to develop initial themes based on the proposed framework. Then, a corresponding author reviewed all annotated transcripts to thoroughly examine codes and to identify any differences in interpretations. The analysis continued with an inductive approach to search for new emerging codes and themes not previously identified. The team reviewed codes and generated themes, combining existing themes or splitting some themes into subthemes. This process was repeated until the researchers reached an agreement on every theme. The team finally defined and named each theme that provided a full sense of the theme and its importance and translated the interview extracts regarding the themes from Korean to English.

We critically reflected on the translations to ensure that the 'voice' of the participants was maintained, so that those possible misunderstandings were avoided. To ensure the reliability of the data, we first confirmed the interview transcripts with every participant and they revised them when necessary. The analysis process and findings were discussed among the authors, and any disagreement was clarified.

4 Findings and discussion

Twenty-three themes were generated to address the four research questions. To be specific, a final set of 7 themes under RQ1, 6 themes under RQ2, 7 themes under RQ3, and 3 themes under RQ4 were determined (see Appendix 1).

4.1 Curriculum: Learning goal

4.1.1 Capacity building

Teachers considered developing capacities that help students to be future-proof citizens in the fast-changing society driven by digital and AI technologies as the prime learning goals in SAC on learning. First of all, teachers expected SAC could augment students' cognitive capacity that includes higher-order thinking (e.g., CT, critical thinking, creativity and imagination, and analytical thinking). To be specific, teachers considered that students should (1) engage in high-level cognitive processes involving problem-solving, divergent thinking, and reflection, (2) express ideas on learning tasks, and (3) solve problems in systematic ways (Kafai & Burke, 2014; Resnick, 2006) through interaction with AI. These findings reflect the experimental study by Lin et al. (2021), which provided quantitative evidence of the SAC's positive impacts on students' creativity, logical thinking, and problem-solving skills. They further highlighted that AI allowed students to better comprehend the problems within actual scenarios and help them plan and arrange a way to solve problems through various functions AI offers, such as analysis of AR sensors. The current study's findings shift the use of AI in students' learning from simply solving a problem for students or providing them the right answer (Skinner, 1958; Afzal et al., 2019) to engaging them in problem-solving, providing a variety of problem-solving experiences to propel them into new ways of thinking (Ouyang & Jiao, 2021). In addition, educating students in higher-order thinking means instilling the ability to collaborate effectively with AI as they conduct in-depth analysis to make decisions, evaluate the information received and processed by AI critically, and generate a broader range of solutions using AI.

Second, teachers aimed to facilitate the development of students' social capacity for collaboration with peers, communication (e.g., storytelling and public speaking, asking the right questions, and synthesizing messages), leadership (e.g., achievement orientation, grit, and persistence, and coping with uncertainty) through SAC. For instance, S3 commented:

It has proven very difficult to program machines to emulate our innate ability to manage and utilize emotions such as negotiation, conflict resolution, and having empathy for others. Students are not simply learning how to interact with AI but they are also learning things that AI will not be doing through AI-involved learning tasks with peers.

Teachers consider social skills as highly human abilities that may not be replaced by automation or AI. Meanwhile, they find the opportunity to utilize AI and learning activities/experiences with AI to help students possess AI-proof skills that add values beyond what can be done by automated systems and AI.

Parallel to these capacities, digital capacities that embrace the skills such as software use and development (e.g., programming literacy, computational and algorithmic thinking, data analysis, and statistics) and understanding digital systems (e.g., data literacy, tech translation, and enablement) as main learning objectives to be achieved through SAC.

4.1.2 Subject-matter knowledge building

Another learning goal that teachers sought to achieve through SAC was to guide students toward a better, more robust understanding of the subject-matter knowledge. However, teachers do not intend to solely transfer one specific subject knowledge, but also assist students in transforming/applying knowledge and skills into tangible products, feasible solutions, and new information. As P1's quotation illustrates in Appendix 1, SAC facilitates students to understand subject-matter knowledge by helping them to organize new information, link it to their existing knowledge, and retrieve information (Yeo & Lee, 2012).

4.2 Curriculum: Content

4.2.1 Interdisciplinary learning

Most teachers argued that it is essential to teach students algorithms, mathematical and statistical backgrounds within informatics/computer science subjects to build a strong foundation of knowledge in AI. However, they also highlighted that it is significant to make connections between SAC and cross-curricular subjects to better achieve the aforementioned learning goals. Teachers explained that an interdisciplinary learning approach can support students (1) to build a holistic understanding of AI itself ("*Students can better understand AI and technology itself by connecting it to its roots in linguistics, social science, economics, neuroscience, etc.",* S2) and (2) to improve their entire task performance with AI in various subjects ("*A more integrated curriculum that enhances students' consistent use of AI and diversifies experiences in AI for solving complex problems within a specific subject and across subjects"*, S3).

4.2.2 Authentic problems and tasks

Teachers highlighted the use of authentic tasks that allow students to construct and apply standard-driven knowledge to solve a real-world problem need to be foregrounded. Teachers developed various learning activities that make connections between subject-area knowledge and real-life problems through the student-AI team's task-focused interactions. For instance, students addressed their own classroom problems (e.g., a face detection of students running with outdoor shoes inside the classroom in home-economics, P4), daily life (e.g., a weekly meal plan for the family in home-economics; illustrated plant book making in science, P1), and global challenges (e.g., predicting the future of Antarctica's melting glaciers in social science and science, S4). Teachers support the notion of Cho et al. (2015) findings that an authentic task makes classroom work more relevant by serving as a bridge among the content learned in the classroom, why this knowledge is important in the world outside of it, and how real-world AI technologies work.

In line with this, it was worth noting that teachers implement such authentic tasks with AI by engaging students in the research process with both teachers and AI supporting them. Teachers highlight that SAC should build students' ability to (1) inquire (i.e., ask good questions, discuss and reformulate the problems), (2) research and reflect (i.e., identify and determine what needs to be learned and what resources are required to answer those questions), (3) evaluate (i.e., information gathering, filtering, and integration) and (4) communicate ideas and learning (Ai et al., 2008).

*The class sought to analyze the cause of the increasing suicide rate in the country. Students first analyzed public open data through data mining techniques. They then captured one particular suicide risk group and reasoned why. We had an open discussion about the characteristics of this group and the possible suicidal impulse experience this group may hav*e (S1).

4.2.3 Creative tasks

Teachers identified creative tasks (e.g., creating writing, drawing, and music composition) that can develop students' capabilities to develop ideas, make connections, create and make, and communicate and evaluate the creative outcomes, as another meaningful learning content and activities that SAC should be engaged (See P5's quotation in Appendix 1).

4.3 Curriculum: Assessment

4.3.1 Process-oriented assessment

Teachers explained that various learning contents and activities are designed for students to have an opportunity to achieve the desired learning goals. Along with this, teachers highlighted that the assessment of SAC on the learning task performance should continually be conducted, while both teachers and students are actively involved in the assessment. Teachers, in particular, highlight the assessment aims to understand the process students undergo when given a task, rather than the outcome or product of a learning activity. In this regard, most teachers in the study conduct the assessment on two aspects: conceptual and procedural knowledge on both the subject-matter area and AI technology. For instance, S1 said:

In case when students developed prediction models for identifying areas at risk of earthquakes, the depth of students' understanding of subject knowledge and ability to locate it to define and construct variables that affect data collection, selection, and analysis and the adjustment of the model weight is central areas for assessment. So in this case, both I and the physics teacher examined students' performance.

It is interesting to capture that teachers perform co-assessment, whereby co-teachers discuss assessment, grading practice, share assessment responsibilities, and collaborate on ways to differentiate assessments based on learner needs (Conderman & Hedin, 2012). In doing so, teachers determine how well students have performed and plan the necessary language and content learning targets to help all students meet grade-level expectations (Dove & Honigsfeld, 2017).

4.3.2 Collaboration performance

Another significant assessment approach in SAC was related to the assessment of team learning performance. Teachers expressed that although some SAC-related learning activities and tasks are performed at an individual level, most work is accomplished by teams of individuals, either be small (i.e., a group of three) or large (i.e., a whole class). Teachers then recognize the importance of leveraging the collective knowledge and distributed resources (Johnson & Johnson, 2006) in achieving shared task goals not solely between an individual student and an AI but among students. Therefore, a scheme that is commonly used for assessing individual learning should be applied with caution. Team level learning is assessed both at the lower level through the acquisition of knowledge and member satisfaction, and at the higher level, such as enhanced work processes and level of behavioral changes. Along with this, team learning assessment is not limited to the performance among students, but includes interaction between students and AI, which is illuminated by S3:

Collaboration with peers is a key part to be assessed by criteria such as how they interact with other group members; contribute knowledge and resources to group discussion; provide constructive feedback to others and facilitate the group processes by follow-up, extension, and reframing. However, students' collaboration with AI is an equally important area to be assessed by examining how much and *various data they exchanged with AI, how many new models they have tried, and how they reduced the model's error.*

4.4 Student-AI interaction: Cognitive interaction

4.4.1 Teacher support for students

To enhance student-AI cognitive interaction during SAC, teachers expressed a range of supports and improvements needed both for students and AI. First of all, instruction on AI principles for students is found to be critical. Students need to develop a deep understanding of the core concepts of AI (i.e., definitions and types of AI and the knowledge of algorithms; Kim et al., 2021b) and establish a sensibility of AI's limitations, an understanding of what AI can and cannot do, the benefits and potential problems that the deployment of AI might entail to effectively regulate and orchestrate their learning task operation process. In particular, primary school teachers expressed a pressing need to guide students to explicitly identify what is and what is not AI, since many students conflate AI technologies with other non-AI technologies, and identify the unique characteristics of AI that may benefit or hinder their learning and action.

Second, given that data fuel AI supporting students' data literacy which can collect, process, analyze, evaluate and manage data to make data-based decisions (UNESCO, 2019a) is essential support alongside the instruction of AI principles. S1 well presents this view:

Students wondered why AutoDraw only recommends a series of western style hot dogs, sausages served on a toasted roll or a bun, not Korean-style hot dog on a stick! The class analyzed data AutoDraw learned from and found out that not sufficient image data of Korean hot dogs have been collected compared to the western hot dog. Groups of students then further discuss how to promote Korean culture and food.

Through her quotes, it can be seen that data literacy allows students to better understand AI's suggestions/recommendations particularly when there is uncertainty about AI's suggestion. Through reasoning and examining data, students actively exchange and reflect on knowledge and perspectives shaped in society with data that represent digital images of real phenomena, objects, and social processes. This guides students to be actively involved in meaning-making by contextualizing AI's suggestion into the learning task context and further developing solutions to address the task. In doing so, students become active agents from passive consumers of AI.

Third, teachers need to prompt students to reflect on SAC and enhance their skills for handling failure and their confidence during SAC through debugging AI models and error analysis whereby students interpret the significance of observed outcomes of the AI; analyze the logic of the model and test data, model prediction performance, and model features; evaluate where the logic of model data, prediction, and features break down; develop alternative ways to fix the breakdown; justify resolution for the breakdown; and examine and test their assumptions in iterative cycles of attempting a fix (DeLiema et al., 2020). Teachers mentioned a range of classroom activities and teaching strategies that surround debugging such as (1) comic-strip-like storyboard creation (students create their SAC experiences over time), (2) data visualization (students create a visual representation of how data was generated, when it was generated, who generated it and how it was stored) and (3) writing a journal specifically in response to debug and error analysis strategies performed in one-on-one or a small group.

4.4.2 AI offering an instructional scaffolding

Teachers expected AI could offer students scaffolding-driven interaction that provides them with detailed instructional support during learning task operation. Particularly, teachers highlighted that AI should take a proactive approach by anticipating students' learning difficulties and presenting a series of step-by-step questions that enhance students' understanding of subject knowledge (Albacete et al., 2018).

Students were given the assignment to research the moon using an AI speaker. But young students sometimes don't know what to ask and where to begin when they search for information. AI should more proactively interact with students by asking specific questions like "Do you know how crater looks like?" to scaffold the research process, instead of simply answering questions asked by students (P3).

4.5 Student-AI interaction: Socio-emotional interaction

4.5.1 Teacher support for building students-AI relationship

Instruction on AI ethics and AI experiences in daily life were found to be two crucial supports needed to enhance student-AI socio-emotional interaction. Teachers described that the AI ethics education aims to establish students' moral sensitivity toward AI in which students' ethical grounding can be embedded in the selection, design, deployment, and use of AI as well as decision-making driven by AI. Teachers particularly highlight that it is crucial to educate students not only about the possible ethical and emotional harm caused by AI or misuse of AI but also the importance of humans' ethical values on shaping technology, which in turn shapes individual lives and society.

Students should be fully aware of ethical challenges when AI is misused. At the same time, they should be mindful that they are the ones who shape and develop AI. AI will learn what they speak to AI and how they behave to AI and that learning results will come back to them (P5).

Teachers further pointed out that it is vital to provide students with AI experiences in daily life to enhance their awareness of AI, sensitivity to its applications, and become familiar with AI. In addition, teachers find the opportunity to build authentic connections between students' AI experiences and AI ethics instruction.

Students often imagine that AI exists only in the movie and assume that AI has nothing to do with them. So I often share examples of how AI is already used in our everyday lives, including Google search, smart home devices like smart *refrigerators, Netflix and Youtube recommendation engine, and even robot barista! We then further discuss how AI might impact their parents and their jobs in the future. Students actively say their opinions about how technology should be used and even talk about ethical and legal impacts* (P4).

4.5.2 AI attributes as a learning mate

First, teachers perceived that the element of gamification could positively enhance students' participation, engagement, and continuity in SAC and the SAC performance. This view is in line with earlier research which found gamification is an integral part of students-technology interaction to improve engagement, participation, and continuity of individuals to support learning processes and improve learning outcomes (Caporarello et al. 2019). In this regard, Dalmazzo and Ramirez (2017) utilized gamified interactions between students and an automatic tutoring system to provide students with adaptive learning guidance.

Second, teachers suggested that AI should be engaged in educationally meaningful socio-emotional interaction with students; AI should be designed with an understanding of students' affective domain in mind. For instance, P1 expressed:

Teaching is not simply about building students' knowledge. AI should interact educationally meaningfully with students, encourage them to overcome their difficulties and achieve the task, and motivate students to try once again when they insist that they would not be able to solve the problems. In this regard, educational AI engineers need a deep understanding of students' affective and psychology domains.

Their views are corroborated by existing studies suggesting that AI needs to be equipped with a theory of mind which would make it possible to recognize and understand emotions, infer intentions and predict behavior to build and maintain relationships, communicate effectively, and work collaboratively with humans to achieve common goals (Cuzzolin et al., 2020; Riedl, 2019).

4.6 Student-AI interaction: Artifact-mediated interaction

4.6.1 Intuitive interface of AI

Intuitive AI interface/hardware can even be suitable for students with no prior experience. In particular, primary school teachers expressed that the interface itself needs to be a powerful medium for expression and support students in working on the task without requiring additional manual books to figure out how the AI system works out.

In addition, teachers highlight that AI interface/hardware design should make the task execution process both by students and AI intuitive, particularly through interactive visualization. For instance, P1 said:

Synchronization is needed between students and the machine learning algorithms to create a framework for accessing knowledge and teaming up to direct the search for knowledge and eventually act for the shared goals. AI interface should integrate visual information production or processing panel to visualize the most *information-intensive pathway for exchanging information between students and artificial agents.*

4.6.2 Availability of diverse digital tools

Teachers expressed the need for an AI interface that is rich in the pool of digital tools to make the SAC process more interactive and learners more active and engaged in executing the task. Especially, teachers associate this need to create a classroom for accommodating a diverse range of skills, needs, and interests of students. Accordingly, students work and collaborate with AI in varied methods and strategies to execute the task. For instance, P3 shared students' use of AutoDraw in different cases as follows:

Students used AutoDraw's iconic images, screen-captured them, and worked on Powerpoint to further edit them with texts and other images to make a poster for nature protection in a science class. In Korean class, students downloaded their works on AutoDraw and worked on Word to write a story to make a book. In times of a whole-class discussion, students captured individual work and shared it on Miro, an online whiteboard and visual collaboration platform. Can't all of these works be done on Autodraw?

4.7 Environment: Learning space

4.7.1 Flexible classroom design

Teachers expressed that SAC can take place not only in the digital learning environment but also in the actual classroom. To support new ways of learning that may occur in SAC, classroom spaces should embrace adaptability (students-adaptable space) and convertibility (repurposing space like a classroom becoming a computer lab, art studio, or gym) which promotes effective collaboration amongst students as well as SAC.

SAC-related learning activities can take place in different subjects. The classroom should be flexible enough to turn to a science lab where students can work on simulation with AI on a laptop from a music studio where students collaboratively work on song-making with AI and their peers (P1).

4.7.2 Digital learning environment

Adequate digital infrastructure should be equipped to facilitate SAC. To do so, teachers first mentioned that the school should be equipped with secured wireless networks to connect and facilitate real-time interactions among students, teachers, AI, and other mobile devices via broadband to cloud-based tools and platforms. Moreover, the security and privacy of networks are increasingly important in learning, secure authentication and access control should be an integral component of the school wireless networks architecture (Zhu et al., 2020).

Second, the 1:1 device to student ratio is found to be essential. To support students' consistent and immediate access to digital content, simultaneous online collaboration inside/outside the classroom resources, and systematic collection of students' data for personalized learning, teachers consider providing school-owned one-to-one devices, rather than bring your own device (BYOD) policy. The BYOD system makes it virtually impossible for teachers to monitor whether all students can access the same material at the same speed as each other, and also causes problems when outdated devices fail. In addition, teachers prefer portable and lightweight devices over desktop PC, meaning that a dedicated computer lab is not needed to access technology.

Third, a cloud-based learning platform that collects, analyzes, and processes data generated from various interactions (i.e., between students-AI, AI-other existing digital tools, students-students, students-teachers-AI) is required to adapt and personalize to each learner to give the optimal learning environments. It should, however, be noted that teachers underline that the newly developed AI system should make synergy and combination with other existing digital learning applications such as LMS, digital textbooks, and educational administration systems. S4 well reflects this view:

Such a platform will generate an immense volume of data. If the outputs and data cannot be transferred automatically into the existing NEIS[2] *system, who will then take this job? Me, an informatics teacher? That will add another work for teachers, while AI should automate teachers' repetitive tasks.*

4.8 Environment: Institution

4.8.1 Systematic AIED policy

The prerequisites for successful AI applications at the ground level are not only technical in nature. The establishment of long-term systematic AIED policy nationwide that add a value of AI applications in education and implement AIED strategically were found to be the most-in-demand by teachers.

First of all, a system-wide vision and strategic priorities that the nation aspires to achieve with AIED need to be formulated. In particular, teachers advised that the government needs to shape the AIED vision based on an in-depth understanding of students' learning and development processes and of the impacts that AI will make on learning rather than simply highlight international education trends and market demand. Teachers then expected the government to communicate with them about what are and what are not desirable outcomes of AI-enhanced learning to increase their understanding of how to address SAC in the learning context, and complement and augment student capabilities through SAC. Following the aforementioned suggestion, there is a need for a master plan to inform about a coherent curriculum that

[2] NEIS stands for the National Education Information System. NEIS sought to centralize the personal data of students from primary and secondary schools across the country. Twenty-seven categories of personal information, including data on students' academic records, medical history, counseling notes, and family background, are consolidated in NEIS servers maintained by local education agencies.

clearly defines sets of learning objectives across the school and grade level, utilizing AI in education management to support personalized resources and outcomes, and assessment methodologies on multiple dimensions of competencies and outcomes driven from student-AI interaction during learning.

At the other spectrum, teachers emphasized that the government should set inter-sectoral governance and coordination mechanism to make concerted effort among different stakeholders (i.e., students, teachers, parents, policymakers, researchers, and EdTech providers) and maximize their cross-sector collaboration and resource sharing to truly build 'educational AI' and ensure safe and effective implementation of AIED. S1 highlights this view as follows:

Government-schools-research institution-Edtech companies all need to work closely to develop AI itself as well as implement AIED. Especially, AIED collaboration councils consisting of stakeholders and other experts should be established to facilitate virtuous circles of collaboration. Schools need to voice their demands and preference in AI development and necessary educational programs to external stakeholders on an ongoing basis and they can provide useful feedback throughout the implementation of a change initiative.

Her quotes indicate that teachers call for the establishment of a central governing board supporting and overseeing the policy implementation, a coordination body to manage the partners and collaboration, and a team of representatives charged with implementing the policy (UNESCO, 2019b).

4.8.2 Flexible school system

Teachers anticipate that AI will accelerate personalized learning as its technology develops rapidly. In this context, they suggest that students are better grouped according to competencies within the subject in the school. To do so, teachers emphasized that the school systems should shift from generic 'education level' to an emphasis on subjects. For instance, P3 said:

AI works with students at a level appropriate to their domain knowledge. Although students in the same class work on the same AI platform to solve math problems, one works at an advanced level and the other one works at the beginner level. For teachers to better orchestrate and support students at their level, the school system needs to allow students to selectively learn necessary subjects according to their level of domain specific knowledge and their preference.

4.8.3 Teacher capacity building in AIED

The government needs to plan training programs and continuous supports to develop teachers' AI knowledge that is rapidly evolving and to enable them to apply AI to their practice. Although participating teachers are all leading teachers in AIED, they expressed a strong need to update them with the latest AI knowledge and curriculum design capacity from experts in different fields, including AI engineering, statistics, mathematics, and education, to be able to interpret the output of an AI and translate it into meaningful feedback to students during SAC process as well as apply AI in an educationally meaningful way.

Students often come up with challenging questions that require a deep understanding of mathematics, statistics, and new techniques in AI. So I decided to attend open lectures at universities and workshops run by an EdTech company to learn (S1).

4.9 Environment: Culture

4.9.1 Culture of collaborative learning

Teachers perceived that it is essential to establish a culture of collaborative learning as the basis to drive a profound implementation of SAC. Throughout the interviews, teachers expected students to develop, through teaching and learning AIED, the skills and attitudes that enable collaboration with peers and technologies, which is well reflected in the assessment area as well. They, however, experienced barriers in forming a collaborative learning culture among colleague teachers although it is most pertinent for co-design, implementation, and assessment of AI learning. Particularly, secondary school teachers pointed out that portraying teaching and learning AI as the learning boundary of one specific subject such as informatics or science and technology blocks dialogue among teachers in a wide-area subject. In this regard, teachers suggest supporting teachers' professional learning communities composed of different subject teachers to understand the broader values of individual subjects, share information and knowledge openly and identify effective AIED practices across the subjects.

4.9.2 Safe to fail

For the goals of SAC to be achieved, teachers highlighted creating a safe to fail environment that supports learning from failure, and developing students' mindset of 'have a go' needs to be embedded in the classroom. Teachers criticized existing schoolwork and assessment practices that have been performed toward attaining higher scores on a school's standardized exams and solving standard problems within the classroom. Such classroom culture does not easily allow to make failures and appreciate problems or their alternative solutions. In contrast, teachers expected students to frame and value failure as an integral part of learning instead of a hindrance that slows their pace of work through SAC on learning tasks. For instance, P5 said:

I strongly encourage students to make mistakes, or even allow them to experience failure during SAC. Creating such an atmosphere and culture is important for them to treat failure as productive and try different ways to solve problems with AI and their friends. Also, they learn to appreciate or analyze the feedback that failure offers.

This notion is supported by the study of Nachtigall et al. (2020) arguing that a culture of trial and error scaffolded by teachers helps failure to become a learning opportunity.

4.10 SAC co-evolution

Teachers anticipated that students would develop collaboration with AI through three principal stages: (1) learn about AI, (2) learn from AI, and (3) learn together. First of all, students begin with little understanding of AI itself, the goals of SAC on learning tasks, and the collaboration process. Therefore, at this stage, teachers mainly focus on developing students' understanding of AI, directing them in the procedural use of AI through step-by-step task execution and fostering a positive attitude toward AI. Students are not likely to relate SAC to the scope outside of the instructional setting in a specific domain.

In the second stage, students experiment and apply SAC for building knowledge and solving authentic problems and real-life tasks. In doing so, students develop strategic ways of working and interacting with AI and formulate supportive relationships. At this stage, teachers need to design learning activities that require the use of knowledge from different subject domains for SAC whereby students can actively test and examine exploration and independent use of AI.

Although teachers expressed the final stage as a seemingly far-fetched scenario, but envision it as a plausible pathway with rapid technological change. At the final stage, teachers expected that AI would serve diverse roles in learning and teaching and bring new forms of school systems that resonated with OECD (2020)'s notion of future school scenario 3: schools as learning hubs. In this scenario, personalized learning will be strengthened within a framework of collaborative work. Students interact with AI for higher-order learning activities in the context of broader learning ecosystems, leveraging resources of external institutions (e.g., museums, libraries, technological hubs, etc.).

Someday in the future, a form of Minerva school would become apparent in the realm of public education whereby students are taught subject knowledge online both by human teachers and AI teachers while they are actively performing in diverse problem-solving projects, engage in a whole community offline, and develop higher-order thinking (S3).

5 Conclusion

Through situating the teachers' views on the nexus of theory and practice, the study provided a better understanding of how to design and support SAC in four dimensions: (1) curriculum, (2) student-AI interaction, (3) learning environments, and (4) SAC development. Nonetheless, we emphasize that this study's findings are preliminary to understand SAC in the learning context. The study, therefore, is not target-bound but steps into a point for discussion and suggestions to better design SAC for students' meaningful learning.

First of all, teachers in the study designed SAC on a learning task in their class while they aimed to augment students' competencies that go well beyond the knowledge and skills typically measured by schools' standardized tests. These competencies include improved understanding of complex concepts in the subject, connections among ideas, processes, and learning strategies, as well as the development of problem-solving, visualization, data management, communication, and collaboration skills. These findings echo with the concept of intelligence augmentation (IA) coined by Engelbart (1962), highlighting that AI should be developed to supplement or support human intelligence rather than attempt to imitate/replicate or replace human cognitive functions and operate independently. In support of this argument, this study calls for educational AI developers to understand the importance of students' capacities (e.g., creativity) that need to be nurtured through the interaction with AI (Hassani et al., 2020; Zheng et al., 2017). Educational AI that interacts with students should better be developed to help them to do more than they are currently capable of doing. AI should encourage students to fully accomplish learning tasks on their own (to be autonomous learners) by externalizing their ideas, extending their perspective through a massive volume of data analysis, and providing new experiences enhancing their affective domain in learning (e.g., learning motivation, the joy of learning, and self-efficacy). For instance, Grammarly, the writing correction AI software, can help academic authors excel in writing skills by suggesting better ways of phrasing sentences rather than merely detecting and replacing the grammar errors by an author.

In line with the IA-directed AI development in education, this study directs teachers to pay more attention to instructional strategies for integrating AI to improve students' thinking skills (e.g., CT, critical thinking, creativity and imagination, and analytical thinking), rather than merely focusing on coding/programming and creating neural networks. Although teachers in this study highlighted a digital capacity such as programming literacy and data analysis, their underlying notion around understanding AI operations and concepts and applying them to gather, evaluate, and use information was meant to enhance students' higher-order thinking. Along this way, teachers actively support students with CT-related activities (e.g., debugging AI models and error analysis) to better understand AI, interact with AI and solve problems collaboratively with AI. This reflects that the teachers perceive CT as a cornerstone for students' cognitive development as well as a logical way of thinking for learning and acting with AI. In support of the existing studies highlighting that using technology for drill and practice generally has been found to be less effective than using technology for more constructivist purposes such as writing, research, collaboration, analysis, and publication (Warschauer & Matuchniak, 2010), this study recommends teachers' training programs to enable teachers to build substantial understanding and experience on subject-specific AI applications integrated with CT and AI-driven instructional design. While discussions on CT skills were narrowly positioned within the field of computer science or STEM-related subjects (Barr & Stephenson, 2011; Lee et al., 2020), this study moves CT forward to be extensible and embedded across disciplines. Yet, its concept, components, and detailed skills should be well understood and contextualized within a subject-specific context, its learning goals, and learning activities together with a range of different teaching and learning approaches underpinning AI of each subject. The development of teachers' instructional competencies would help students to augment high-level thinking with AI and have educationally meaningful interaction with AI. Furthermore, this study's findings highlighted the importance of co-design for AIED curriculum planning and co-assessment on SAC performance on learning tasks. In this regard, teacher educators should develop a necessary toolkit/guideline of resources and activities for structuring co-design of AIED curriculum among teachers from various subjects and provide support and make improvements along the way.

Furthermore, this study found a strong need for a system-wide policy that orchestrates top-down and bottom-up reflection. Teachers expressed that top-down reflection needs to orchestrate what learning the nation expects AI to support, what education system we sought to build, and what roles that different stakeholders are expected to play to achieve desired goals of AIED by taking into account evidence about areas of both the AI's strengths and weakness in students' learning. In this regard, educational policymakers are called upon to specifically and explicitly address questions related to shaping a newly developing educational system by adopting AI, incorporate the best and safeguarding against the unknown or harmful dimension if such are found, and offer a structured format to those reflections with the expectation of actionable outcomes. On the other hand, policy should support bottom-up coordination to maximize cross-sector collaboration and resource sharing among different stakeholders in which schools' ongoing needs and challenges are discussed and educationally meaningful AI and pedagogical practices can then be designed via academia-public-private collaborative research and development (R&D). In this regard, promoting opportunities for sustained investment in AIED R&D and for transitioning advances into practices at the ground level is on the call (Big Innovation Centre, 2020; UNESCO, 2021).

Although the present study can provide a springboard for other scholars and practitioners to further examine SAC in learning, there are a few limitations to be addressed in the future study. First, this study examined teachers' perceptions among 10 leading teachers in AIED, which may somewhat limit the generalizability of our results. Therefore, future research needs to apply the proposed framework in the study on a larger scale. Second, while this study proposes a new model to design and examine SAC in the K-12 learning context, more research is needed to validate, further refine and enrich the proposed model by applying and evaluating it on diverse subject classes and different school contexts. For instance, participating teachers in the study anticipated that SAC might evolve over time from the stage of becoming familiar with AI to solving diverse learning tasks with AI, which then leads to disruptive changes in the education system. Reflecting on these findings, future studies can expand this area of research by analyzing current AIED learning design from the SAC co-evolution perspective, what instructional support and AI technologies need to be developed to support gradual evolution between students and AI, and what aspects of the educational system need to be adjusted to meet with the changes driven by SAC co-evolution in learning.

Appendix 1 Summary of emergent themes

Category		Themes	Sub-themes	Exemplary quotes
Curriculum (RQ1)	Learning goal	T1. Capacity building	Cognitive capacity	*The essential tool required to solve a complex problem of the future that students will face is thinking ability. As iron sharpens iron, students evolve collective intelligence with their friends so as with AI. They are learning how to address problems appropriately both to a human friend and AI, and they also need to critically evaluate solutions generated both by humans and AI.* (S5)
			Social capacity	*AI-involved learning tasks mostly require teamwork. During the collaboration process, they divide roles, take responsibility for a mistake, respect each other opinions, and successfully work toward a common goal with peers*. (S3)
			Digital capacity	*Students are learning AI thinking that goes beyond what computational thinking offers. They become familiar with data processing and ideas behind deep learning and cognitive computing*. (S2)

Category		Themes	Sub-themes	Exemplary quotes
		T2. Subject-matter knowledge building		*Students seemed not well understanding the concept of variation. But their understanding of the ideas and concepts of variation taught in the class were reinforced through the composition-activity with AI like Google Doodles and AIVA*. (P1)
	Content	T3. Interdisciplinary learning		*Students learn about and expose to AI in informatics very few times, go to the next class and come back to the informatics class after new weeks with empty-minded of AI. A more integrated curriculum that enhances students' consistent use of AI and diversifies experiences in AI for learning*. (S3)
		T4. Authentic problems and tasks		*Students developed an AI model of predicting the future of Antarctica's melting glaciers after some trial and error with peers and AI*. (S4)

Category		Themes	Sub-themes	Exemplary quotes
		T5. Creative tasks		*There were moments that students wondered about AI's suggestions and felt disappointed about its inability to recognize their drawing, but it was interesting to see how they were developing stories by connecting their sketch and AI's suggestion.* (P5)
	Assessment	T6. Process-oriented assessment		*Students are not AI developers so their technical skills are not the main area of assessment. I pay more attention to how they understand and apply the content knowledge in a subject domain to solve problems as well as the process of data collection and processing.* (P2)
		T7. Collaboration performance		*How they helped teammate each other and performed individual roles in completing the tasks are also assessed.* (P5)
Student-AI Interaction (RQ2)	Cognitive interaction	T8. Teacher support for students	Instruction on AI principles	*Teaching AI principles, concepts and mechanisms is important to decide what to expect from AI and what they should do with AI.* (S3)
			Data literacy	*The ability to contextualize and interpret data allows students to critically question AI suggestions.* (S2)

Category		Themes	Sub-themes	Exemplary quotes
			Debugging AI model and error analysis	*Students improve both techniques and domain knowledge as they reflect and reason about what was wrong during SAC*. (S5)
		T9. AI offering an instructional scaffolding		*AI should more pro-actively interact with students by asking specific questions to scaf-fold the research process, instead of simply answering questions asked by students*. (P3)
	Social interaction	T10. Teacher sup-port for building students-AI relationship	AI ethics educa-tion	*Establishing their ethical grounding is crucial in high-lighting the risks of Educational efforts might be beneficial in high-lighting the risks of malicious intent or adversarial data input.* (S4)
			AI experiences in daily life	*As they interact with the classroom AI speaker and robot vacuum cleaner, they become more aware that AI has assimilated into their everyday life than they have assumed. They then take more seriously about the challenges it posed and consider how they might make a difference to make responsible engagement with AI*. (P4)

Category		Themes	Sub-themes	Exemplary quotes
		T11. AI attributes as a learning mate	Gamification	*Educational AI should make students feel interesting and fun of learning and entertaining learning process.* (P3)
			Understanding of students' psychological characteristics	*I let one of my students struggle with the math, with little or no success at school tests, to work with the AI math platform after the class. He didn't seem to like it since he was left alone to do extra works. But after some hours with AI, he became delighted by being told by AI that he is clever enough doing the math really well and is improving on his math scores*. (P5)
	Artifact-mediated interaction	T12. Intuitive interface of AI		*A kind of AI that students mostly experience in school is an algorithm-based AI, not the physically embodied AI in a robot. They can't interact with their bodies with AI. So I think the interface serves as a bridge between students and AI. Designing an interface that helps students understand the AI task performance process would less puzzle and complicate them on the task execution process*. (P2)

Category		Themes	Sub-themes	Exemplary quotes
		T13. Availability of diverse digital tools		*Can't a function of Word, PowerPoint, video-production, or many others be together?* (P3)
Environment (RQ3)	Learning space	T14. Flexible classroom design		*Desks and chairs should be moveable first. Depending on the type of SAC-related learning activity, students may perform it individually or be engaged in group work, or even flexibly switch from one another*. (S1)
		T15. Digital learning environment	1:1 device to student ratio	*When a student opens their designated device, their account appears straight away and they only need to input their password to access the AI platform. This is so much easier and faster than using shared devices*. (P4)
			Secured wireless network	*Without Wi-Fi at school, students cannot access and store their works in the cloud-based AI platform. Students are buffered in data processing which delays the interaction and task process with AI. Also, they cannot quickly and easily share their works with peers*. (S5)

Category		Themes	Sub-themes	Exemplary quotes
			Cloud-Based Learning platform	*Cloud-based learning platform that offers a wide range of learning tools and adequately collects and analyzes data generated through interactions between friends, teachers, communities, and technologies in learning is essential.* (S2)
	Institution	T16. Systematic AIED policy	A system-wide vision and strategic priorities	*The clear goals and direction of AIED need to be set so that teachers can be committed to aspired learning goals that AI can make for students.* (S4)
			A master plan for curriculum design, use of AI in education management, and assessment	*A sort of roadmap on what to be taught to students needs to be shared with every school. Otherwise, students who were offered AIED in a specific school can only be advantageous.* (P5)
			Interdisciplinary planning and inter-sectoral governance	*The private sector needs more consideration of the pedagogical aspect of AI design rather than concentrating on the need for commercial advantage and quick profit. There is no room for collaboration among schools, industry, and academia.* (P2)

Category		Themes	Sub-themes	Exemplary quotes
		T17. Flexible school system		*If the school aims to use AI to best support personalized learning, school structures and curricular approaches should allow students to have a choice in subjects and pursue areas of strength and interest to create a personalized learning path and make connections across learning with AI and human teachers.*
		T18. Teacher capacity building in AIED		*Most teachers in my school do not feel comfortable designing and teaching with digital tools and AI. I think it would be a great burden if I am told to teach English one day. More training needs to be offered to teachers to know about how to utilize AI and apply it in their classes*. (S5)
	Culture	T19. Culture of collaborative learning		*The reason that I employed peer assessment is that I wanted students to listen actively to their peers' practice on SAC and learn from them. This needs to go the same for teachers. We need to establish a collaborative atmosphere to design the lesson with other teachers and reflect on each other's practice*. (S4)

Category	Themes	Sub-themes	Exemplary quotes
	T20. Safe to fail		*We have a class rule of not blaming friends for making an error when they work on building an AI model in the group. Instead, we ask each other what have you learned from making errors and fixing errors*. (S1)
Co-evolution (RQ4)	T21. Learn about AI		*At first, students come into the class unknown of AI. As we don't expect students who don't even know how to bounce the ball to compete in a basketball match, students need to learn from the basic concept and principle of AI and apply AI to solve the structured problems*. (P4)
	T22. Learn from AI		*As students gradually develop their skills to control and appropriately address the errors generated from the AI model, they are more deeply engaged in learning with AI by solving real-world problems together with AI, and also reviewing and critiquing the AI suggested outcomes*. (S5)
	T23. Learn together		The entire community is connected and actively engaged in supporting students' learning via AI. (P5)

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References

Ai, R., Bhatt, M., Chevrier, S., Ciccarelli, R., Grady, R., Kumari, V., Li, K., Nazarli, N., Rahimi, H., Roberts, J., Sachs, J., Schepmyer, A., Wang, M., & Wong, H. (2008). Choose your own inquiry. , University Press of America.

Afzal, S., Dempsey, B., D'Helon, C., Mukhi, N., Pribic, M., Sickler, A., Strong, P., Vanchiswar, M., & Wilde, L. (2019). The personality of AI systems in education: Experiences with the Watson tutor, a one-on-one virtual tutoring system. *Childhood Education, 95*(1), 44–52.

Albacete, P., Jordan, P., Lusetich, D., Chounta, I. A., Katz, S., & McLaren, B. M. (2018, June). Providing proactive scaffolding during tutorial dialogue using guidance from student model predictions. In *international conference on artificial intelligence in education* (pp. 20-25). Springer, Cham.

Baker, T., & Smith, L. (2019). Educ-AI-tion rebooted? Exploring the future of artificial intelligence in schools and colleges. .

Barr, V., & Stephenson, C. (2011). Bringing computational thinking to K-12: What is involved and what is the role of the computer science education community? *Acm Inroads, 2*(1), 48–54.

Bakhtiar, A., Webster, E. A., & Hadwin, A. F. (2017). Regulation and socio-emotional interactions in a positive and a negative group climate. *Metacognition and Learning, 13*(1), 57–90.

Big Innovation Center. (2020). AI in education: Embedding AI tools into teaching curricula. Big Innovation Centre.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*, 77–101.

Caporarello, L., Magni, M. & Pennarola, F. (2019). One game does not fit all. gamification and learning: Overview and future directions. In A. Lazazzara, R. C. D. Nacamulli, C. Rossignoli, & S. Za (Eds.), *Organizing for digital innovation* (pp. 179–188). Lecture notes in information systems and organisation. Springer International Publishing.

Chaudhry, M. A., & Kazim, E. (2021). Artificial intelligence in education (AIEd): A high-level academic and industry note 2021. *AI and Ethics*.

Chin, K. Y., Hong, Z. W., & Chen, Y. L. (2014). Impact of using an educational robot-based learning system on students' motivation in elementary education. *IEEE Transactions on Learning Technologies, 7*(4), 333–345.

Chiu, T. K. (2017). Introducing electronic textbooks as daily-use technology in schools: A top-down adoption process. *British Journal of Educational Technology, 48*(2), 524–537.

Cho, Y. H., Kim, K. H., & Han, J. Y. (2019). Student perception of adaptive collaborative learning support through learning analytics. *The Journal of Educational Information and Media, 25*(1), 25–57.

Cho, Y., Caleon, I., & Kapur, M. (Eds.) (2015). Authentic problem solving and learning in the 21st century. Springer.

Conderman, G., & Hedin, L. (2012). Purposeful assessment practices for co-teachers. *Teaching Exceptional Children, 44*(4), 18–27.

Cuzzolin, F., Morelli, A., Cîrstea, B., & Sahakian, B. J. (2020). Knowing me, knowing you: Theory of mind in AI. *Psychological Medicine, 50*, 1057–1061.

Dalmazzo, D., & Ramirez, R. (2017). Air violin: A machine learning approach to fingering gesture recognition. In *Proceedings of the 1st ACM SIGCHI international workshop on multimodal interaction for education* (pp. 63–66). MIE 2017. New York, : ACM.

DeLiema, D., Dahn, M. Flood, V. J., Asuncion, A., Abrahamson, D., Enyedy, N., Steen, F. F. (2020). Debugging as a context for collaborative reflection on problem-solving processes. In E. Manolo (Ed.), Deeper learning, communicative competence, and critical thinking: Innovative, research-based strategies for development in 21st century classrooms (pp. 209–228). : Routledge.

Dillenbourg, P., Baker, M. J., Blaye, A., & O'Malley, C. (1995). The evolution of research on collaborative learning. In H. Spada & P. Reimann (Eds.), *Learning in humans and machine: Towards an interdisciplinary learning science* (pp. 189–211). Elsevier.

Dove, M. G., & Honigsfeld, A. (2017). *Co-teaching for English learners: A guide to collaborative planning, instruction, assessment, and reflection*. Corwin Press.

Engelbart, D. (1962). Augmenting human intellect: A conceptual framework. Summary report. *Stanford Research Institute, on Contract AF, 49*(638), 1024.

Fryer, L. K., Ainley, M., Thompson, A., Gibson, A., & Sherlock, Z. (2017). Stimulating and sustaining interest in a language course: An experimental comparison of Chatbot and human task partners. *Computers in Human Behavior, 75*, 461–468.

Fu, S., Gu, H., & Yang, B. (2020). The affordances of AI-enabled automatic scoring applications on learners' continuous learning intention: An empirical study in China. *British Journal of Educational Technology, 51*(5), 1674–1692.

Gunkel, D. J. (2012). *The machine question: Critical perspectives on AI, robots, and ethics*. MIT Press.

Guzman, A. L., & Lewis, S. C. (2020). Artificial intelligence and communication: A human–machine communication research agenda. *New Media & Society, 22*(1), 70–86.

Hassani, H., Silva, E. S., Unger, S., TajMazinani, M., & Mac Feely, S. (2020). Artificial intelligence (AI) or intelligence augmentation (IA): What is the future? *Ai, 1*(2), 143–155.

Hmelo-Silver, C. E., & Barrows, H. S. (2008). Facilitating collaborative knowledge building. *Cognition and Instruction, 26*(1), 48–94.

Hollan, J., Hutchins, E., & Kirsh, D. (2000). Distributed cognition: Toward a new foundation for human-computer interaction research. *ACM Transactions on Computer-Human Interaction (TOCHI), 7*(2), 174–196.

Holmes, W., Bialik, M., & Fadel, C. (2019). *Artificial intelligence in education: Promises and implications for teaching and learning*. Center for Curriculum Redesign. The Center for Curriculum Redesign.

Huang, S. P. (2018). Effects of using artificial intelligence teaching system for environmental education on environmental knowledge and attitude. *EURASIA Journal of Mathematics, Science and Technology Education, 14*(7), 3277–3284.

Hutchins, E. (1995). How a cockpit remembers its speeds. *Cognitive Science, 19*(3), 265–288.

Hwang, G. J., Sung, H. Y., Chang, S. C., & Huang, X. C. (2020). A fuzzy expert system-based adaptive learning approach to improving students' learning performances by considering affective and cognitive factors. *Computers and Education: Artificial Intelligence, 1*, 100003.

Johnson, D. W., & Johnson, R. T. (2006). Cooperation and the use of technology. In D. H. Jonassen (Ed.), *Handbook of research on educational communications and technology* (2 ed.), (pp. 785–811). , Lawrence Erlbaum Associates.

Kafai, Y. B., & Burke, Q. (2014). *Connected code: Why children need to learn programming*. , MIT Press.

KERIS (2020). 2020 White paper on ICT in education Korea. Office Korea Education and Research Information Service.

Kim, J., Merrill, K., Xu, K., & Sellnow, D. D. (2020). My teacher is a machine: Understanding students' perceptions of AI teaching assistants in online education. *International Journal of Human–Computer Interaction, 36*(20), 1902–1911.

Kim, J., Pak, S., & Cho, Y. H. (2021a). The role of teachers' social networks in ICT-based instruction. *The Asia-Pacific Education Researcher*. https://doi.org/10.1007/s40299-020-00547-5

Kim, S., Jang, Y., Kim, W., Choi, S., Jung, H., Kim, S., & Kim, H. (2021b, May). Why and what to teach: AI curriculum for elementary school. In *Proceedings of the AAAI Conference on Artificial Intelligence* (Vol. 35, No. 17, pp. 15569–15576).

Lee, I., Grover, S., Martin, F., Pillai, S., & Malyn-Smith, J. (2020). Computational thinking from a disciplinary perspective: Integrating computational thinking in K-12 science, technology, engineering, and mathematics education. *Journal of Science Education and Technology, 29*(1), 1–8.

Lee, S. S., & Kim, J. (2020). An exploratory study on student- intelligent robot teacher relationship recognized by middle school students. *Journal of Digital Convergence, 18*(4), 37–44.

Lin, Y. S., Chen, S. Y., Tsai, C. W., & Lai, Y. H. (2021). Exploring computational thinking skills training through augmented reality and AIoT learning. *Frontiers in Psychology*, 12.

Luckin, R., Holmes, W., Griffiths, M. & Forcier, L. B. (2016). Intelligence unleashed*.* An argument for AI in Education. .

McLaren, B. M., DeLeeuw, K. E., & Mayer, R. E. (2011). Polite web-based intelligent tutors: Can they improve learning in classrooms? *Computers & Education, 56*(3), 574–584.

Ministry of Education. (2021). 2021 education Informatization implementation plan. Korean Ministry of Education.

Nachtigall, V., Serova, K., & Rummel, N. (2020). When failure fails to be productive: Probing the effectiveness of productive failure for learning beyond STEM domains. *Instructional Science, 48*(6), 651–697.

Nardi, B. A., & O'Day, V. (1999). Information ecologies: Using technology with heart*.* MIT Press.

National Research Council. (2010). Report of a workshop on the scope and nature of computational thinking. The National Academies Press.

OECD. (2020). Back to the future of education: Four OECD scenarios for schooling. OECD Publishing.

Okoye, K., Nganji, J. T., & Hosseini, S. (2020). Learning analytics for educational innovation: A systematic mapping study of early indicators and success factors. *International Journal of Computer Information Systems and Industrial Management Applications, 12*, 138–154.

Olmos-Peñuela, J., Benneworth, P., & Castro-Martínez, E. (2014). Are sciences essential and humanities elective? Disentangling competing claims for humanities' research public value. *Arts and Humanities in Higher Education, 14*(1), 61–78.

Ouyang, F., & Jiao, P. (2021). Artificial intelligence in education: The three paradigms. *Computers and Education: Artificial Intelligence, 2*, 100020.

Peng, H., Ma, S., & Spector, J. M. (2019). Personalized adaptive learning: An emerging pedagogical approach enabled by a smart learning environment. *Smart Learning Environments, 6*(1), 9.

Perkins, D. (1993). Person plus: A distributed view of thinking and learning. In G. Salomon (Eed.), *Distributed Ccognitions: Psychological and Educational Considerations* (pp. 88–110). Cambridge University Press.

Resnick, M. (2006). Computer as paintbrush: Technology, play, and the creative society. In D. Singer, R. Golikoff, and K. Hirsh-Pasek (Eds.), *Play=learning: How play motivates and enhances children's cognitive and social-emotional growth* (pp.192–208). Oxford University Press.

Riedl, M. O. (2019). Human-centered artificial intelligence and machine learning. *Human Behavior and Emerging Technologies, 1*(1), 33–36.

Rodrigues, R. S., Andrade, W. L., & Campos, L. M. S. (2016, October). Can computational thinking help me? A quantitative study of its effects on education. In *2016 IEEE Frontiers in Education Conference (FIE)* (pp. 1–8). IEEE.

Self, J. A. (1998). The defining characteristics of intelligent tutoring systems research: ITSs care, precisely. *International Journal of Artificial Intelligence in Education, 10*, 350–364 https://telearn.archives-ouvertes.fr/hal-00197346

Simmler, M., & Frischknecht, R. (2021). A taxonomy of human–machine collaboration: Capturing automation and technical autonomy. *AI & SOCIETY, 36*(1), 239–250.

Skinner, B. F. (1958). Teaching machines. *Science, 128*(3330), 969–977.

Shute, V. J., Sun, C., & Asbell-Clarke, J. (2017). Demystifying computational thinking. *Educational Research Review, 22*, 142–158.

Tan, D. Y., & Cheah, C. W. (2021). Developing a gamified AI-enabled online learning application to improve students' perception of university physics. *Computers and Education: Artificial Intelligence, 2*, 100032.

UNESCO. (2019a). *Steering AI and advanced ICTs for knowledge societies a rights, openness, access, and multi-stakeholder perspective*. UNESCO Publishing.

UNESCO. (2019b). *Beijing consensus on artificial intelligence and education*. UNESCO Publishing.

UNESCO. (2021). *AI and education: Guidance for policy-makers*. UNESCO Publishing..

Utterberg Modén, M., Tallvid, M., Lundin, J., & Lindström, B. (2021). Intelligent tutoring systems: Why teachers abandoned a technology aimed at automating teaching processes. *Hawaii International Conference on System Sciences*.

Vincent-Lancrin, S., & van der Vlies, R. (2020). *Trustworthy artificial intelligence (AI) in education: Promises and challenges*. OECD Education Working Papers, 218.

Wang, T., & Cheng, E. C. K. (2021). An investigation of barriers to Hong Kong K-12 schools incorporating artificial intelligence in education. *Computers and Education: Artificial Intelligence, 2*, 100031.

Wang, Y. (2021). Artificial intelligence in educational leadership: A symbiotic role of human-artificial intelligence decision-making. *Journal of Educational Administration, 59*(3), 256–270.

Warschauer, M., & Matuchniak, T. (2010). New technology and digital worlds: Analyzing evidence of equity in access, use, and outcomes. *Review of Research in Education, 34*(1), 179–225.

Wooldridge, M., & Jennings, N. R. (1995). Intelligent agents: Theory and practice. *The Knowledge Engineering Review, 10*(2), 115–152.

Yeo, J., & Lee, Y. J. (2012). Knowledge advancement in environmental science through knowledge building. In K. C. D. Tan, & M. Kim (Eds.). *Issues and Challenges in Science Education Research* (pp. 317–332). Springer.

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).

Zheng, G. (2020). The optimization and application of blended teaching based on artificial intelligence. *2020 3rd International Conference on Advanced Electronic Materials, Computers and* Software Engineering (AEMCSE).

Zheng, N. N., Liu, Z. Y., Ren, P. J., Ma, Y. Q., Chen, S. T., Yu, S. Y., Xue, J. R., Chen, B. D., & Rui, Y. (2017). From artificial intelligence to augmented intelligence. *IEEE Multimedia, 24*(1), 4–5.

Zhu, T., Xiong, P., Li, G., Zhou, W., & Philip, S. Y. (2020). Differentially private model publishing in cyber physical systems. *Future Generation Computer Systems, 108*, 1297–1306.