Creation and Evaluation of a Pretertiary Artificial Intelligence (AI) Curriculum

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Abstract*—*Contributions: **The Chinese University of Hong Kong (CUHK)-Jockey Club AI for the Future Project (AI4Future) co-created the first pretertiary AI curriculum at the secondary school level for Hong Kong and evaluated its efficacy. This study added to the AI education community by introducing a new AI curriculum framework. The prepposttest multifactors evaluation about students' perceptions of AI learning confirmed that the curriculum is effective in promoting AI learning. The teachers also confirmed the co-creation process enhanced their capacity to implement AI education.**

Background: **AI4Future is a cross-sector project that engages five major partners—CUHK's Faculty of Engineering and Faculty of Education, secondary schools, Hong Kong government, and AI industry. A team of 14 professors collaborated with 17 principals and teachers from six secondary schools to co-create the curriculum.**

Research Questions: **Would the curriculum significantly improve the student perceived competence, attitude, and motivation toward AI learning? How does the co-creation process benefit the implementation of the curriculum?**

Methodology: **The participants were 335 students and eight teachers from the secondary schools. This study adopted a mix-method with quantitative data measures at pre- and post-questionnaires and qualitative data emphasizes teachers' perspectives on the co-creation process. Paired *t*-tests and ANCOVAs, and thematic analysis were used to analyze the data.**

Findings: **1) students perceived greater competence and developed a more positive attitude to learn AI and 2) the co-creation process enhanced teachers' knowledge in AI, as well as fostered teachers' autonomy in bringing the subject matter into their classrooms.**

***Index Terms*—Artificial intelligence (AI) education, co-creation process, curriculum design, pretertiary education, teacher education.**

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I. Introduction

The EXPLOSIVE growth of artificial intelligence (AI) is increasingly transforming the way we live, learn, and work. To inspire more students to pursue AI in their studies and careers, it is necessary to develop a relevant and attractive curriculum at an early age and then follow through [1]. Therefore, teaching AI topics in schools is an important global strategic initiative in educating the next generation [2], [3]. However, AI topics have conventionally been taught in tertiary-level curricula. Naturally, the current literature review indicates that there is a lack of studies about AI curriculum design and development for pretertiary education [4], [5].

To create a pretertiary AI curriculum, a project named AI for the Future (AI4Future) was launched at The Chinese University of Hong Kong (CUHK). This is the first secondary school AI curriculum in Hong Kong. Leveraging CUHK's experiences in launching the first AI undergraduate degree program in Hong Kong in 2018, AI4Future is a collaborative project that engages five parties—CUHK's Faculty of Engineering and Faculty of Education, local secondary schools (refer to as "pioneering schools"), the local government (HKSARG Education Bureau), and the local AI industry to co-create a formal AI curriculum for junior secondary students. Paving the way for pretertiary AI education requires careful considerations especially of the needs of school teachers (who may or may not have previously studied AI), as well as the needs of the school students (who are learning the complex subject at a much younger age). This study presents a co-creation process that brings experts in AI and pedagogy and practitioners together to develop, implement, and evaluate a new pretertiary AI curriculum. Hence, this study should serve as a valuable reference for the academia, educators, industry, and government, as a first reference implementation of pretertiary AI education in Hong Kong. To date, there are no or few studies that evaluate the implementation of a formal AI curriculum for secondary education.

This article is structured as follows. Section II presents a summary of previous studies on AI education for schools in different regions and the needs of this project, as well as discusses several important elements for the school engineering curriculum. Section III introduces the purpose and methodology of this study. Section IV describes how the curriculum was co-created, and presents curriculum overview, framework, selected content, and activities. Section V presents the evaluation of the curriculum implementation and the teachers' views on the co-creation process. In Section VI, the results and main contributions of this study are discussed. Finally, the conclusions, limitations, and future research are outlined in Section VIII.

II. Literature Review

A. AI Education in K–12 Schools

Literature indicates that the first idea of teaching AI to young students was delivered through LOGO programming and the Turtle robot [6], which was designed as learning activities, rather than a curriculum. Lee conducted a study of AI education in the primary and secondary schools [7]. The study indicated that over the last two years, Korea and the United States (AI4K12) proposed national curriculum standards for schools to design their curriculum and guidelines and policies such as teacher professional programs [8], [9]. It also reported that the European Union utilized courses and resources online to nurture population-wide AI literacy, rather than designating students or subjects at specific school levels. The curriculum content of these three regions (i.e., Korea, the United States, and the European Union) included fundamental concepts and applications of AI (e.g., machine learning and neural network). In India, the Central Board of Secondary Education (CBSE) introduced an AI curriculum as an elective subject that included the concept of AI and its ethics for Grade 9 students in 2019 [10], followed by focusing on teacher training to sustain AI education in schools [11]. This curriculum is supported by the Microsoft K12 education transformation framework. In Australia, courses with teaching and learning resources include foundation knowledge that every teacher needs to know for AI education were provided for school teachers [12]. Accordingly, all these studies have attempted to identify key AI content with focus on AI ethics and activities for young students, and to initiate the corresponding teacher education.

Universities in different regions also work on AI curricula for K–12 levels. For example, in 2018, East China Normal University collaborated with SenseTime, a technology company, to publish the first textbook series for high schools—Fundamentals of Artificial Intelligence [13]. The textbook has a strong technical focus, and is designed for students with a stronger STEM background. More recently, the Massachusetts Institute of Technology [14] examined different hands-on robot learning activities for kindergarten children by emphasizing the student learning process. In New South Wales, Australia, Macquarie University's School of Education and IBM worked together to propose an AI curriculum framework to bring AI into the P-12 classroom [15]. Instead of being a standalone subject, the curriculum was designed to complement other subjects to reflect AI's wide-ranging use cases and impacts. The framework mostly relied on ethics, critical thinking, and creativity, rather than requiring primary and secondary teachers to become knowledgeable in coding or robotics. Moreover, Sabuncuoglu from Koc University in Turkey reported on a design of a one-year curriculum for middle school. The curriculum used an interdisciplinary and inclusive approach to develop resources [16]. This study used observations to understand how the curriculum worked in schools. Accordingly, all these studies indicated the importance of school and university collaborations in AI curriculum development.

These AI education projects for schools align with the suggestions proposed in two systematic review studies of AI in education [17], [18]. Roll and Wylie have reviewed 47 papers and suggested research on AI in education should collaborate with teachers and support classroom practices [17]. Bozkurt *et al.* have examined AI studies in education from 1970–2020, and suggested that a stronger emphasis on the ethics of AI should be integrated into AI education [18].

As seen from the literature review, pretertiary AI education development for schools is still in an early stage. The initiatives launched above point toward the importance of a collaborative effort among universities, schools, and the industry. There is a lack of a comprehensive curriculum for AI in pretertiary education, because curriculum design necessarily involves the important elements of pedagogy and assessment. Furthermore, teacher training, as well as teacher involvement in the curriculum design, are crucial to the success of an AI curriculum. Rigorous research on curriculum effectiveness is largely lacking, but is most essential for continual refinement of curriculum created.

B. Drawing Reference to K–12 Engineering Education

Since the subject matter of AI is often subsumed under the engineering and computer science curricula in tertiary education, the curriculum in AI4Future draws reference to K–12 Engineering Education when designing a pretertiary AI curriculum. Literature suggests that key content for K–12 engineering programs should: 1) be interdisciplinary in its content; 2) include impact and ethical considerations; and 3) foster technical communication skills, engineering thinking, and techniques [19]–[21]. These are elaborated in the following.

1) Interdisciplinary Nature: A well-designed engineering program at the K–12 level should emphasize its interdisciplinary nature to address the absence of interdisciplinary connections in the school formal curriculum [10]–[19]. For example, the program should provide students with opportunities to apply developmentally appropriate mathematics in the context of solving engineering problems. One possible strategy is to allow students to study mathematical concepts through engineering [19].

2) Impact and Ethics: The program must expose students to contemporary societal problems that are increasingly complex and interdisciplinary in nature. Students should understand how their proposed solutions to the problems impact life and society locally, globally, economically, environmentally, etc., and also consider the possible ethical issues, safety issues, and impact on the individual and public [19].

3) Technical Communication Skills: The program should foster students' communication skills on technical matters. Students should be able to use technical language to explain the input, processes, and output of tools or solutions, and also be able to communicate their technical ideas in everyday language for those without a technological background [19], [22].

4) Engineering Thinking: In the K–12 setting, students should be empowered to believe that they can design and troubleshoot solutions to problems and develop new knowledge on their own [19]. They can learn from experience and failure, and suggest improvements over existing solutions. In other words, students should be able to use informed judgment to make decisions about their solutions [21].

5) Engineering Techniques: Students should learn and implement various techniques, processes, and skills in the program [19], [22]. Techniques refer to step-by-step procedures for specific tasks; processes refer to a series of actions taken to complete a final product; and skills are defined as the ability to perform specific tasks. Therefore, the program should provide students with tools throughout the process of building up their techniques and skills [19].

C. School Curriculum and Teacher Autonomy

A "school curriculum" refers to all experiences which are planned and guided by teachers, and learned by students, whether it is implemented inside or outside the classroom [23]. It is also a description of what, why, how, and when students should learn. How the curriculum is perceived and organized influences the process of teaching and learning [2], [23]. Curriculum design for schools is more complex compared to higher education. It involves considerations of how the new initiative translates into practice, and considerable variation in implementation can be expected from school to school [4]. In addition to the curriculum, teacher autonomy is also important—it refers to the teacher being able to take control of one's teaching, and is crucial to the teacher's motivation, engagement, and commitment in providing effective learning opportunities for students on the implementation of the curriculum [24]. This autonomy is an important aspect that is positively related to perceived self-efficacy and job satisfaction in the teaching profession [24]–[27]. It concerns the relations between the teachers' scope of action and the curriculum's role in providing directions, resources, and rules that may constrain or extend the learning environment [24], [27]. Accordingly, a curriculum that supports teacher autonomy can better optimize learning, especially through the teacher's support of the students' interests and needs. However, pretertiary teachers' perspective and experiences about teaching AI as a subject matter has rarely been studied [4].

III. This Study

As mentioned above, AI4future is the first of its kind in the development of pretertiary AI curriculum, and teachers' perspective plays a very important role in curriculum development. Therefore, this study aims to adopt a co-creation process to create and evaluate an AI curriculum for the junior secondary level (i.e., Grades 7–9), and understand the roles of the process in the implementation. Accordingly, the research questions (RQ) are as follows.

RQ1: Would the curriculum significantly improve the student perceived competence, attitude, and motivation toward AI learning?

RQ2: How does the co-creation process benefit the implementation of curriculum?

A. Background

There are two stages: 1) curriculum development and 2) implementation in AI4future. In the curriculum development stage, a designed-based research method was adopted since the method aims to design and develop educational technology innovations [27]–[29]. A collaborative team which involves a team of 14 professors with expertise in engineering and education together with some 15 postdoctoral fellows, research assistants, and undergraduate student helpers, working closely with 17 principals and teachers from six pioneering schools were established. The schools were purposefully selected from different districts of Hong Kong with varied social and economic characteristics; including girls', boys', and coeducational schools with different school banding (that is reflective of overall academic standards)—this aims to address the diverse learning needs of Hong Kong's secondary students. The selected schools have demonstrated that they have placed high emphasis in STEM education and also expressed that they have placed AI education in high priority for their students. This team formation bridges the gap between research on engineering and AI education. The professors from the two faculties authored the technical content based on their research specialization and then worked with the teachers to refine the learning outcomes and pedagogue the content in the year-long regular meetings (biweekly on Monday and Friday afternoons).

The implementation stage was conducted in the times of the COVID-19 pandemic. Hence, the teachers taught the AI topics in blended environments—both online and face-to-face modes, over a period of approximately three months. They also considered their school culture, teaching environments, and resources, and selected the relevant content, as well as fine-tune the content to create learning activities that are most fitting for their students' needs and interests. For example, while all the schools finished teaching Chapters 1 and 2, different schools were selected to cover different subsets from Chapters 4 to 12 in their lessons.

B. Method

A mix of quantitative and qualitative methods was adopted to collect data to answer the research questions [28]. Three hundred and thirty-five students in total, aged 12–16, and eight teachers from the pioneering schools are involved to evaluate the current curriculum and its co-creation process. To begin data collection, institutional ethical clearance was followed by participant consent. The students completed the online 30-min pre- and post-questionnaires; and the teachers participated in individual 60-min semi-structured interviews to express what they think about the co-creation process.

C. Measures

Apart from demographic data, the questionnaires included five variables to measure the students' perceived competence, attitude, and motivation toward AI. Perceived competence covers perceived AI knowledge (AIKG), AI readiness (AIRD).

Perceived attitude refers to AI confidence (AICF), and the students' perception of the relevance of AI (AIRE). Motivation refers to the student's intrinsic motivation to learn AI (AIIM). These variables were intentionally selected as they provide important information about preparing secondary students with knowledge and confidence; and motivation to see learning AI as relevant so that they are ready for the era of AI. Each variable is measured with a 6-point Likert scale, adapted from previous studies with acceptable reliability and validity [30]–[32] (please refer to the Appendix). The items were also checked by three experienced educational researchers to make sure that the wording and language are understandable. The following elaborates on the 5 variables.

1) *AIKG*—We have proposed this new variable to measure. This variable measures the student's self-perception of the level of basic knowledge they have acquired for AI, and hence reflects on the quality of curriculum design. The variable has four items, e.g., "I have general knowledge about how AI is being used today."
2) *AIRD*—This variable is adopted from a previous study [28]. It measures the student's perception of the level of comfort in everyday use of various forms of AI technologies. Stronger perception indicates that the students hold a favorable viewpoint regarding the adoption of AI in applications. This variable consists of six items, with one example being "AI technology gives people more control over their own lives." The variable's original reliability was $\alpha = .88$.
3) *AICF* [30]—This variable measures the students' perceived confidence in learning the content of AI. The scale has five items, with an example being "I'm certain that I can succeed if I work hard enough in this AI class." The variable's adequate reliability $\alpha = .88$.
4) *AIRE*—This variable is adopted from a previous study [31]. It measures the students' perception of the relevance of learning AI. It has six items, with an example being "The things that I am learning in this AI class will be useful for me." The variable's reliability is $\alpha = .91$.
5) *AIIM*—This variable is adapted from the motivated strategies for learning questionnaire [32]. The variable has four items, with an example being "In this AI class, I prefer AI topics that arouse my curiosity, even if it is difficult to learn." The variable's reliability is $\alpha = 0.74$.

The above variables prove to be significant and relevant to measuring the learning outcomes in this study, as will be shown in the evaluation section.

IV. Curriculum Development

Given the boundary-less nature of AI technologies, and pretertiary AI education is a brand-new initiative (at least in Hong Kong), this project faces three unique challenges—the first is the creation of an AI curriculum that is foundational and specific, to enable a concrete grasp of the topic matter, while opening up broad intellectual horizons for the young students who have yet to decide on their interests and directions for long-term development. Every child is different. Not all are academically gifted; some will do better in one field than another; but all children should be supported and encouraged to achieve his or her potential. The second challenge lies in translation of this new initiative into practice with available manpower and resources, and there is a scarcity of AI talents in all sectors. The third challenge is that the needs in pretertiary AI education will vary from one school to another and our work must strive to fulfill all such needs.

To address these challenges, the project aims to design a clear curriculum structure that is modular and reconfigurable, to support flexible learning pathways as needed by various schools. Therefore, an AI curriculum for pretertiary education should make space for teachers to recognize each student's personal and cognitive capacities, and to adapt the curriculum to suit the students in their classes [4], [24], [25]. The curriculum should respect differences in ways that different children can best learn, therefore, should provide teachers with the flexibility to ensure that their treatment of the content is appropriate for their student's needs and capabilities. In other words, the curriculum should foster teacher autonomy in designing their own classroom activities/school-based curriculum in leading, assisting, and encouraging each student.

As the co-creation process took form and moved forward, two key observations were noted. First, regular meetings with content presentations and discussions among functional groups and subgroups began to facilitate teacher professional training for pretertiary AI education within the team. Second, iterative refinement of the curriculum content on per-topic and per-module bases involved revisions that spanned weeks. The revisions tightly integrated efforts from members working across secondary and tertiary education, and aimed to provide abundant options for teachers' selection and adaptation as the curriculum entered their classrooms. Such a practice supports teacher autonomy and places the needs of the students at the center of curriculum design.

This study used four components: 1) curriculum overview; 2) framework; 3) content; and 4) activities as a framework to analyze all the co-created data, including final curriculum documents, learning resources, and minutes of the meeting. The following four sections show the co-created curriculum: 1) overview; 2) framework; 3) activities; and 4) content approach.

A. Overview of the Co-Created Curriculum

Fig. 1 is an infographic that encapsulates the overall curriculum. The curriculum began at the core of the illustration, with the introduction of AI and the key drivers of its recent, rapid advancements, namely, big data, machine learning, and cloud computing. Another core emphasis is on ethical considerations in the use of AI applications, as well as related societal impact.

The middle circle in pink illustrates our coverage of various branches in AI, including perceptual machine intelligence such as "see" and "hear," human language technologies such as, "speak," "read and write," machine reasoning, use of simulation for problem-solving, and how machines can generate content "creatively." The outer circle in green shows various

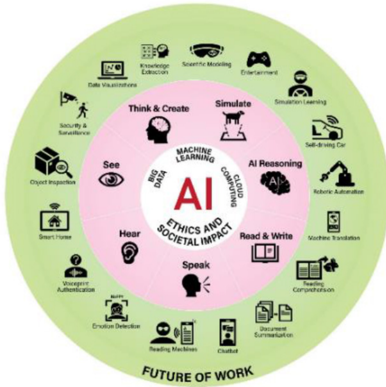

Fig. 1. Infographic providing an overview of the new AI curriculum.

TABLE I
CURRICULUM FRAMEWORK

✓ Beginner Unit (BU) ✓ Intermediate Unit (IU) ✓ Advanced Unit (AU)

Modules \ Teaching Units (✓)	Awareness	Ethics and Impact	Knowledge	Interactions	Empowerment
1. Introduction to AI	✓	✓	✓	-	-
2. Fundamentals of AI	✓	✓	✓	✓	-
3. "See the World"	✓	✓	✓	✓	✓
4. "Hear"	✓	✓	✓	✓	✓
5. "Speak"	✓	✓	✓	✓	✓
6. "Read"	✓	✓	✓	✓	✓
7. "AI Reasoning"	✓	✓	✓	✓	✓
8. "Simulate"	✓	✓	✓	✓	✓
9. "Think and Create"	✓	✓	✓	✓	✓
10. Societal Good, Social Impact and Challenges of AI	✓	✓	✓	✓	✓
11. AI and Ethics	✓	✓	✓	-	✓
12. AI and Future of Work	✓	✓	✓	-	✓

possible applications that are supported by AI, many of which carry important societal implications, especially for the future of work

B. Curriculum Framework

The project has designed a curriculum framework with 12 chapters and five levels of depth address the pedagogy introduced as illustrated in Table I. The first column lists the various topics, organized as chapters, ranging from the introduction and fundamental concepts (chapters 1 and 2), various branches of AI, e.g., computer vision, speech, and language processing (chapters 3–9), as well as societal impact, ethical use, and transformation of the future of work (chapters 10–12). These chapters aim to capture breadth and comprehensiveness, and allow teachers to pick and choose appropriate content that fits their teaching objective(s). For example, a teacher may only cover chapters on introduction and society, and perhaps chapters on selected (but not all) branches of AI (e.g., computer vision and machine reasoning, only chapters 3 and 7), yet the curriculum remains coherent and self-contained.

Furthermore, each chapter is organized into five modules: 1) awareness; 2) knowledge; 3) interaction; 4) empowerment; and 5) ethics (AKIEE), as elaborated in Table II. These modules can be categorized into the beginner, intermediate, and advanced levels, as color-coded in Table II with green, yellow, and purple, respectively. This module-based, level-up design not only allows flexibility in content selection for the classroom, but also caters for capacity building by offering a clear

TABLE II
ELABORATION ON CURRICULUM MODULES

Chapters	Descriptions
Awareness	Awareness of the history, background and development of various types of AI technologies (corresponding to different subsets of intelligence: machine perception, understanding, reasoning, etc.)
Knowledge	Identification of key concepts and the impact of AI through eye-catching, illustrative applications, especially usage contexts of local relevance.
Interaction	Experimentation of AI technologies in AI Lab
Empowerment	Acquisition of the abilities to design, develop and integrate component AI technologies into end-to-end systems.
Ethics & Impact	Exploration of AI topics and case studies to promote social good, illustrate transformative effects to the future of work, and reflect on ethical use of AI.

path to the development of student AI techniques and skills. In addition, the five modules are intended to cover the key elements referred to in K–12 engineering education mentioned in Section II.

C. Curriculum Content That Fosters Local and Global Understanding

Student relevance is very important in learning AI. The classroom activities were created such that the tasks enable learning "from local explanations to global understanding." This establishes connections between AI and the students' everyday experiences, i.e., establishes student relevance. In this way, students can gain a better understanding of the societal and personal impacts of AI by combining many high-quality local examples (e.g., KKbox [33], the local subway system's chatbots [34], which are applications of local relevance) that can be extended to understand examples in a global context (e.g., Spotify [35], which is an application found abroad). These examples engage students in a context within which they can develop.

D. Curriculum Activities Designed for Flexibility

Flexibility is very important for pretertiary education to cater for the diverse needs of the schools and their students, this curriculum modular and level-up design would offer maximum flexibility for school teachers in an adaptation based on their school environments and their students' interests and competencies [4], [24], [25]. A variety of examples/case studies were also created for the same task or discussion. For example, in the task "Explain why AI technologies may not always work"—three examples, including failure in facial recognition, failure in a chatbot, and failure in the prediction of World Cup results are used as illustrations. Moreover, various tools, such as Jupyter Notebooks, Blockly, WebAPPs, and technologies from industry (e.g., cognitive services and Google teachable machine) are included for hands-on activities. The team has also developed a hardware toolkit from scratch—the CUHKiCar (see Fig. 2) is a robotic car with six built-in AI functions, and offers interactive AI experiences to the students. Two AI experiments, namely, face-tracking and line following, have been designed and incorporated into the

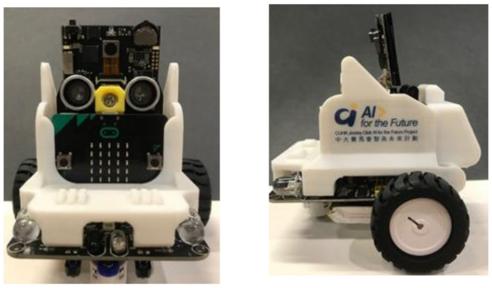

Fig. 2. CUHKiCar.

TABLE III
DESCRIPTIVE STATISTICS

Student (N=358)						
	Pre-questionnaire			Post-questionnaire		
Variables	Mean	SD	Cronbach alpha	Mean	SD	Cronbach alpha
AIKG	4.25	0.92	0.91	4.69	0.72	0.91
AIRD	4.37	0.84	0.89	4.54	0.76	0.90
AICF	4.17	0.91	0.91	4.40	0.83	0.91
AIRE	4.52	0.86	0.90	4.67	0.71	0.88
AIIM	4.37	0.96	0.92	4.51	0.78	0.89

CUHKiCar. They offer introductory experiences in interacting with AI to the students. Furthermore, the CUHKiCar is versatile and can be completely reprogrammed with totally new functions in other project work for the students. Overall, the learning activities offer a flexible curriculum with diverse options to match with the students' learning interests and the schools' teaching needs.

V. Curriculum Implementation

A. Student Enhancement

To answer RQ1, paired *t*-tests and analyses of covariance (ANCOVA) were used to assess the differences in the post-questionnaire scores after accounting for prequestionnaire scores [28], [36]. Table III presents the descriptive statistics. All the variables with Cronbach alpha coefficients, ranged from 0.88 to 0.92 (>0.70) were considered internally reliable [37]. Moreover, all the variables met the assumption of homogeneity of variance, with all p values >0.05 in Levene's tests.

The results of paired *t*-tests were statistically significant, and showed that the students attained higher improvements in all the variables—AIKG, AIRD, AICF, AIRE, and AIIM—with $t(335) = 8.01$ ($p < 0.001$), $t(335) = 3.45$ ($p < 0.001$), $t(335) = 4.43$ ($p < 0.001$), $t(335) = 2.30$ ($p = 0.003$), and $t(335) = 2.82$ ($p = 0.005$), respectively. Therefore, learning with the project's new AI curriculum has effectively enhanced students perceived AI knowledge, AI readiness, AI confidence, AI relevance, and intrinsic motivation to learn AI.

B. Evaluating the Benefits of the Co-Creation Process

Theme analysis was used to identify the two main themes: 1) teacher professional development and 2) teacher autonomy.

1) Teacher Professional Development: To answer RQ2, analyses reveal that all the participating teachers did not receive formal AI training, and they were able to learn the necessary AI knowledge for curriculum design from the co-creation process. They felt more qualified and confident to teach AI. The followings are supporting excerpts from their feedback:

1) 'I learned more AI knowledge in the co-design process, which helped me design my AI teaching' (Teacher A)
2) 'In the co-design process, I had chances to try different tools, and discussed with others to learn more AI knowledge. It was fun.' (Teacher M)

2) Teacher Autonomy: Analyses show that all the teachers agreed that participation in the co-creation process facilitates their understanding of the curriculum design, content, and activities. Such improved understanding allowed them to effectively adapt the contents to their own school-based teaching through selecting appropriate examples, case studies, tools, and modules. This promoted the teachers' sense of autonomy. The following are supporting excerpts from their feedback:

1) 'The process helped me understand different cases in the content. ... I chose Chapter 1 – awareness, knowledge, and ethic and Chapter 7.' (Teacher E)
2) 'The discussions (in the co-creation process) fostered my understanding of the Chapter. ... Therefore, I combined the modules from Chapter 1 and 11 to teach my students.' (Teacher C)
3) 'I am involved in commenting (selecting) the tools for the curriculum ... I chose some tools to let students experience what AI is.' (Teacher T)'

VI. Discussion

The main goal of this study was to create and evaluate an AI curriculum for junior secondary school level using the co-creation process. This study presented two empirical findings and discussed its two major practical contributions to pretertiary AI education.

A. Two Empirical Findings

The first finding is the proposed curriculum has significantly enhanced perceived competence in (AIKG, AIRD), attitude (AICF, AIRE), and intrinsic motivation toward AI (AIIM)—please refer to RQ1. This result supports those of related studies that suggest how the K–12 engineering curriculum should be designed, such as those by Delaine *et al.* [38], Moore *et al.* [19], and Locke [39]. This finding further confirmed that the developed content and activities were appropriate for school students, and covered what students should master for AI technologies. It should also be noted that the collaborating schools in this study were situated in a diversity of districts across Hong Kong with different socioeconomic backgrounds, which also led to a wide learning diversity. The involvement of school teachers was critical in this context, where the curriculum can facilitate the teachers in support of the student' interests and needs in order to optimize learning [40]. In other words, the

AIKKE curriculum framework is more likely to offer a holistic, comprehensive, and flexible view of AI, which fosters the perceived knowledge, readiness, confidence, relevance of AI, and motivation to learn AI for a student sample that is from diverse backgrounds. Moreover, this finding showed that the co-creation process effectively created synergy among the AI and education experts and secondary school teachers to create the curriculum, which includes the components of overview, framework, content, and activities. This process aligns with the development approach of the recent studies done in Australia, mainland China, Korea, India, the United States, and Turkey [8]–[10], [15], [16]. Accordingly, design-based research is an appropriate methodology to bridge the gap between researchers and practitioners in developing AI education [28], [29]. Therefore, the co-creation process has a positive impact on the development of the AI resources for classroom practices [29]. Finally, since this study was implemented during the COVID-19 pandemic, the developed curriculum was found to be able to support classroom, blended, as well as remote learning, i.e., the resources in the curriculum are more likely to satisfy school students' innate needs for better engagement [41], [42].

The second finding is that the co-creation process has been shown to be an empowering and enabling process for teachers in supporting their efforts to bring AI into their classrooms. This is accomplished by enhancing the teachers' AI competencies, which in turn, brought out teacher autonomy in shaping the co-created curriculum for their classrooms. The co-creation process not only served as a co-authoring but also offered a contemporary teacher professional development program [43], [44]. However, contemporary teacher professional development programs should be of sustained duration [40]. This process was labor-intensive, requiring much effort from researchers and practitioners. Using the co-creation process as teacher professional development programs may need substantial support from the ministry, schools, and universities for it to be sustainable in the long run.

B. Two Major Practical Contributions

The first finding of this study contributes to AI school education by presenting an effective curriculum and its evaluation approach. The curriculum is able to successfully transform the subject matter of AI, which is traditionally taught at the tertiary level, into pretertiary, junior secondary classrooms. To the best of our knowledge, this study could be one of the first research that evaluates the effectiveness of AI school formal curriculum in a territory scale. Moreover, this study could add to the AI education community by introducing a new curriculum framework, alternative evaluation approach—student perceptions of AI learning, and the new measure—Perceived AI knowledge (AIKG).

Moreover, the second finding highlighted the importance of the co-creation process for AI curriculum development. The second contribution is thus AI4future co-creation process design (see Fig. 3). The process can: 1) actualize the developing AI curriculum framework by redesigning and pedagogizing content into various classroom learning resources and 2) enhance the teachers' knowledge of AI by offering a sustained professional development process. The various co-created resources also empower the teachers and foster teacher autonomy [24], [25]. The design can be applied in any school curriculum development of any engineering subjects and emerging knowledge.

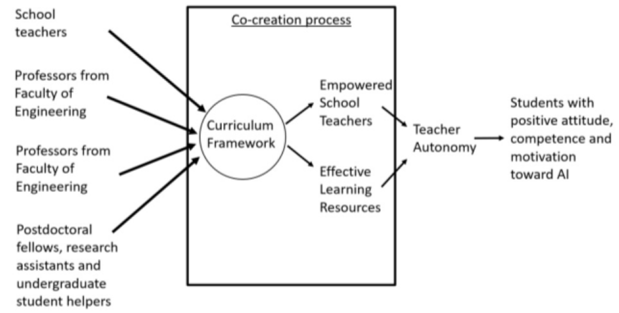

Fig. 3. Team formation and workflow organization of the co-creation process that brings the AI4Future project's new curriculum into junior secondary classrooms.

VII. Limitations and Future Studies

Four limitations in this article are noted here. First, although the results appear to suggest that the curriculum can improve students' perceived competence, attitude, and intrinsic motivation, the implementation was conducted during the pandemic. The public health crisis may have affected students' perceptions (self-reported data) and the findings might not apply to classrooms in normal times [45]. Therefore, additional studies using objective measures, such as AI knowledge and the number of students attempts in doing the tasks should be conducted in normal times to validate the findings. Second, this article did not examine the effectiveness of all the chapters or individual modules. It will be of great interest to see how the curriculum can be optimally adapted to each mode of teaching. The results could be extended by additional studies on using individual modules or chapters. Third, this article did not consider how teachers select learning resources in the curriculum, and longitudinal research design is suggested to track teaching and learning activities will capture valuable data to support learning analytics and inform future pedagogical development. Finally, diversity and inclusion are important to ensure the success of AI Education [46], [47], further studies should investigate how the curriculum addresses the needs of varied academic abilities and gender differences.

This article presents the first step of AI4future in the creation of a pretertiary AI curriculum for Hong Kong. The co-creation process enhanced the teachers' knowledge in AI, as well as fostered teachers' autonomy in bringing the subject matter into their classrooms. It could guide teachers to inspire students to strive to become future-ready, through facilitating student perceived competence, attitude, and motivation toward AI. This project is also poised for the next phase and expands to over thirty participating schools.

Appendix

Pre- and Post-Questionnaire Survey for Students

AIIKG1: I have general knowledge about how AI is used today.

AIIKG2: I have general knowledge about AI capabilities.

AIIKG3: I have general knowledge about AI.

AIIKG4: I have general knowledge of how AI is created.

AIRD1: AI technologies give people more control over their own lives.

AIRD2: Products and services that use the latest AI technologies are much more convenient to use.

AIRD3: I prefer to use the most advanced AI technologies.

AIRD4: I like AI technologies that allow me to tailor applications to fit my needs.

AIRD5: I find new AI technologies to be mentally stimulating.

AIRD6: I am confident that AI technologies will follow my instructions.

AIRE1: I am aware that AI technology will change the world AIRE2: The things that I am learning in this AI class will be useful for me.

AIRE3: I should learn the basic knowledge of AI.

AIRE4: It is clear to me how the content of this AI class is related to my future.

AIRE5: The content of this AI class is relevant to my interests.

AIRE6: I could relate the content this AI class to things that I have seen, done or thought in my own life.

AICF1: I feel confident that I will have a good grade in this AI class.

AICF2: I am certain that I can succeed if I work hard enough in this AI class.

AICF3: I am certain that I can understand the most difficult material presented in this AI class.

AICF4: I am certain that I can learn the basic concepts taught in this AI class.

AICF5: I am certain that I can understand the most complex material presented by a teacher in this AI class.

AIIM1: In this AI class, I prefer AI topics that arouse my curiosity, even if they are difficult to learn.

AIIM2: In this AI class, I prefer the materials that really challenge me so that I can learn new things.

AIIM3: The most satisfying thing for me in this AI class is trying to understand the content as thoroughly as possible.

AIIM4: I like studying in this AI class.

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References

[1] R. André and R. Hilbig, "Prerequisites for artificial intelligence in further education: Identification of drivers, barriers, and business models of educational technology companies," *Int. J. Educ. Technol. Higher Educ.*, vol. 18, p. 11, Feb. 2021, doi: 10.1186/s41239-021-00245-2.

[2] D. Touretzky, C. Gardner-McCune, F. Martin, and D. Seehorn, "Envisioning AI for K-12: What should every child know about AI?" in *Proc. AAAI Conf. Artif. Intell.*, Honolulu, HI, USA, 2019, pp. 9795–9799.

[3] C. Gardner-McCune, D. Touretzky, F. Martin, and D. Seehorn, "AI for K-12: Making room for AI in K-12 CS curricula," in *Proc. 50th ACM Techn. Symp. Comput. Sci. Educ.*, 2019, p. 1244.

[4] T. K. F. Chiu and C.-S. Chai, "Sustainable curriculum planning for artificial intelligence education: A self-determination theory perspective," *Sustainability*, vol. 12, no. 14, p. 5568, 2020, doi: 10.3390/su12145568.

[5] O. Zawacki-Richter, I. M. Victoria, B. M. Bond, and G. Franziska, "Systematic review of research on artificial intelligence applications in higher education—Where are the educators?" *Int. J. Educ. Technol. High. Educ.*, vol. 16, no. 1, pp. 1–27, 2019.

[6] S. Papert and C. Solomon, "Twenty things to do with a computer," in *Artificial Intelligence Memo 248*. Cambridge, MA, USA: MIT, 1971.

[7] E. Y. Lee, "A comparative analysis of contents related to artificial intelligence in national and international K-12 curriculum," *J. Korean Assoc. Comput. Educ.*, vol. 23, no. 1, pp. 37–44, 2020.

[8] D. Touretzky, F. Martin, D. Seehorn, C. Breazeal, and T. Posner, "Special session: AI for K-12 guidelines initiative," in *Proc. 50th ACM Techn. Symp. Comput. Sci. Educ.*, 2019, pp. 492–493.

[9] D. Touretzky, C. Gardner-McCune, C. Breazeal, F. Martin, and D. Seehorn, "A year in K-12 AI education," *AI Mag.*, vol. 40, no. 4, pp. 88–90, 2019.

[10] "Introduction of artificial intelligence, early childhood care education and yoga as new subjects in school curriculum from the academic session 2019–2020," Central Board Secondary Educ., New Delhi, India, Rep. 14/2019, 2019. [Online]. Available: http://cbseacademic.nic.in/web_material/Circulars/2019/14_Circular_2019.pdf

[11] A. Vazhayil, R. Shetty, R. R. Bhavani, and N. Akshay, "Focusing on teacher education to introduce AI in schools: Perspectives and illustrative findings," in *Proc. IEEE 10th Int. Conf. Technol. Educ. (T4E)*, Goa, India, 2019, pp. 71–77.

[12] mq.edu.au. (2020). *Artificial Intelligence (AI) Education for Teachers*. Accessed: Mar. 10, 2020. [Online]. Available: https://www.mq.edu.au/faculty-of-arts/departments-and-schools/macquarie-school-of-education/academy-of-continuing-professional-development-in-education/our-courses/artificial-intelligence-ai-education-for-teachers

[13] Sensetime, *Fundamentals of Artificial Intelligence*, East China Normal Univ., Shanghai, China, 2018.

[14] R. Williams, H. W. Park, and C. Breazeal, "A is for artificial intelligence: The impact of artificial intelligence activities on young children's perceptions of robots," in *Proc. Conf. Hum. Factors Comput. Syst. (SIGCHI)*, Glasgow, Scotland, 2019, pp. 1–11.

[15] mq.edu.au. (2020). *Partnership Profile: IBM and School of Education Team Up to Teach AI*. Accessed: Mar. 10, 2020. [Online]. Available: https://www.mq.edu.au/thisweek/2020/04/27/partnership-profile-ibm-and-school-of-education-team-up-to-teach-ai/#.YEhJtmgzZPY

[16] A. Sabuncuoglu, "Designing one year curriculum to teach artificial intelligence for middle school," in *Proc. ACM Conf. Innovat. Technol. Comput. Sci. Educ.*, 2020, pp. 96–102.

[17] I. Roll and R. Wylie, "Evolution and revolution in artificial intelligence in education," *Int. J. Artif. Intell. Educ.*, vol. 26, no. 2, pp. 582–599, 2016.

[18] A. Bozkurt, K. Abdulkadir, D. Baneres, A. E. Guerrero-Roldán, and M. E. Rodríguez, "Artificial intelligence and reflections from educational landscape: A review of AI studies in half a century," *Sustainability*, vol. 13, no. 2, p. 800, 2021.

[19] T. J. Moore, A. W. Glancy, K. M. Tank, J. A. Kersten, K. A. Smith, and M. S. Stohlmann, "A framework for quality K-12 engineering education: Research and development," *J. Pre-Coll. Eng. Educ. Res.*, vol. 4, no. 1, p. 2, 2014.

[20] J. L. Riskowski, C. D. Todd, B. Wee, M. Dark, and J. Harbor, "Exploring the effectiveness of an interdisciplinary water resources engineering module in an eighth grade science course," *Int. J. Eng. Educ.*, vol. 25, no. 1, pp. 181–195, 2009.

[21] G. H. Roehrig, T. J. Moore, H.-H. Wang, and M. S. Park, "Is adding the E enough? Investigating the impact of K-12 engineering standards on the implementation of STEM integration," *School Sci. Math.*, vol. 112, no. 1, pp. 31–44, 2012.

[22] R. L. Carr, L. D. Bennett IV, and J. Strobel, "Engineering in the K-12 STEM standards of the 50 U.S. states: An analysis of presence and extent," *J. Eng. Educ.*, vol. 101, no. 3, pp. 539–564, 2012.

[23] A. V. Kelly, *The Curriculum: Theory and Practice*, 6th ed. London, U.K.: Sage, 2009.

[24] A. L. L. da Silva and C. E. Mølstad, "Teacher autonomy and teacher agency: A comparative study in Brazilian and Norwegian lower secondary education," *Curriculum J.*, vol. 31, no. 1, pp. 115–131, 2020.

[25] W. Wermke, S. O. Rick, and M. Salokangas, "Decision-making and control: Perceived autonomy of teachers in Germany and Sweden," *J. Curriculum Stud.*, vol. 51, no. 3, pp. 306–325, 2019.

[26] T. K. F. Chiu, "Introducing electronic textbooks as daily-use technology in schools: A top-down adoption process," *Brit. J. Educ. Technol.*, vol. 48, pp. 524–537, Mar. 2017.

[27] A. Cribb and S. Gewirtz, "Unpacking autonomy and control in education: Some conceptual and normative groundwork for a comparative analysis," *Eur. Educ. Res. J.*, vol. 6, no. 3, pp. 203–213, 2007.

[28] S. Ryu, "The role of mixed methods in conducting design-based research," *Educ. Psychol.*, vol. 55, no. 4, pp. 232–243, 2020.

[29] T. K. F. Chiu, and D. Churchill, "Exploring the characteristics of an optimal design of digital materials for concept learning in mathematics: Multimedia learning and variation theory," *Comput. Educ.*, vol. 82, pp. 280–291, Mar. 2015.

[30] C. S. Chai, P. Y. Lin, M. S. Y. Jong, Y. Dai, T. K. F. Chiu, and J. Qin, "Perceptions of and behavioral intentions towards learning artificial intelligence in primary school students," *Educ. Technol. Soc.*, to be published.

[31] Y. Dai, C.-S. Chai, P.-Y. Lin, M. S.-Y. Jong, Y. Guo, and J. Qin, "Promoting students' well-being by developing their readiness for the artificial intelligence age," *Sustainability*, vol. 12, no. 16, p. 6597, 2020.

[32] T. G. Duncan and W. J. McKeachie, "The making of the motivated strategies for learning questionnaire," *Educ. Psychol.*, vol. 40, no. 2, pp. 117–128, 2005.

[33] kkbox.com. (2020). *MTR "KKbox" Front Page*. Accessed: Nov. 16, 2020. [Online]. Available: https://www.kkbox.com/hk/en/

[34] mtr.com.hk. (2020). *MTR "Chatbot" Function*. Accessed: Nov. 16, 2020. [Online]. Available: https://www.mtr.com.hk/chatbot/land_page.html?lang=en&params=chatbot

[35] sportfy.com. (2020). *Sportify Front Page*. Accessed: Nov. 16, 2020. [Online]. Available: https://www.spotify.com/hk-en/

[36] P. L. Bonate, *Analysis of Pretest-Posttest Designs*. Boca Raton, FL, USA: CRC Press, 2000.

[37] L. J. Cronbach, "Coefficient alpha and the internal structure of tests," *Psychometrika*, vol. 16, no. 3, pp. 297–334, 1951.

[38] D. A. Delaine, R. Tull, R. Sigamoney, and D. N. Williams, "Global diversity and inclusion in engineering education: Developing platforms toward global alignment," *Int. J. Eng. Pedagogy*, vol. 6, no. 1, pp. 56–71, 2016.

[39] E. Locke, "Proposed model for a streamlined, cohesive, and optimized K-12 STEM curriculum with a focus on engineering," *J. Technol. Stud.*, vol. 35, no. 2, pp. 23–35, 2009.

[40] A. Assor, K. Haya, and R. Guy, "Choice is good, but relevance is excellent: Autonomy-enhancing and suppressing teacher behaviours predicting students' engagement in schoolwork," *Brit. J. Educ. Psychol.*, vol. 72, no. 2, pp. 261–278, 2002.

[41] T. K. F. Chiu, "Applying the self-determination theory (SDT) to explain student engagement in online learning during the COVID-19 pandemic," *J. Res. Technol. Educ.*, to be published, doi: 10.1080/15391523.2021.1891998.

[42] T. K. F. Chiu, "Student engagement in K-12 online learning amid COVID-19: A qualitative approach from a self-determination theory perspective," *Interact. Learn. Environ.*, to be published, doi: 10.1080/10494820.2021.1926289.

[43] L. Darling-Hammond, "Teacher education around the world: What can we learn from international practice?" *Eur. J. Teach. Educ.*, vol. 40, no. 3, pp. 291–309, 2017.

[44] T. K. F. Chiu and D. Churchill, "Adoption of mobile devices in teaching: Changes in teacher beliefs, attitudes and anxiety," *Interact. Learn. Environ.*, vol. 24, no. 23, pp. 317–327, 2016.

[45] S. L. Orstad, M. H. Meghan, S. S. McDonough, A. Ceren, and P. J. Troped, "A systematic review of agreement between perceived and objective neighborhood environment measures and associations with physical activity outcomes," *Environ. Behav.*, vol. 49, no. 8, pp. 904–932, 2017.

[46] N. A. Ibe, R. Howsmon, L. Penney, N. Granor, L. A. DeLyser, and K. Wang, "Reflections of a diversity, equity, and inclusion working group based on data from a national CS education program," in *Proc. 49th ACM Techn. Symp. Comput. Sci. Educ. (SIGCSE)*, Baltimore, MD, USA, 2018, pp. 711–716.

[47] C. B. Rogers, W. Kristen, and F. Jacob, "A review of the NAE report, engineering in K-12 education," *J. Eng. Educ.*, vol. 99, no. 2, pp. 179–181, 2010.

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