Curriculum Design of Artificial Intelligence and Sustainability in Secondary School

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***Abstract*—Artificial Intelligence (AI) is revolutionizing numerous sectors with its transformative power, while at the same time, there is an increasing sense of urgency to address sustainability challenges. Despite the significance of both areas, secondary school curriculums still lack comprehensive integration of AI and sustainability education. This paper presents a curriculum designed to bridge this gap. The curriculum integrates progressive objectives, computational thinking competencies and system thinking components across five modules—awareness, knowledge, interaction, empowerment and ethics—to cater to varying learner levels. System thinking components help students understand sustainability in a holistic manner. Computational thinking competencies aim to cultivate computational thinkers to guide the design of curriculum activities.**

Keywords—curriculum design, artificial intelligence education, education for sustainability, system thinking, computational thinking

I. Introduction

The advent of advanced artificial intelligence (AI) technologies like generative AI is reshaping our daily lives, education and professions remarkably. As these technologies become increasingly integrated into our everyday lives, it is crucial to inspire the next generation to understand and engage with AI. This calls for the early introduction of a relevant, engaging and future-oriented AI curriculum in schools. Incorporating AI education into school curricula is now recognized as a strategic global initiative, crucial for preparing students for the digital future [1]. However, the majority of AI education has traditionally been confined to teaching technical skills and knowledge. To maximize the impact of AI, it is essential that AI education adopts a more holistic approach.

Many curricula have proposed to integrate sustainability contexts into the Science, Technology, Engineering and Mathematics (STEM) discipline [2]. The integration of sustainability into STEM education can raise learners' awareness and knowledge to understand how the subject impacts sustainable development, which is crucial to cultivating students' holistic perspective and sense of engagement with the real world.

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As an extended module of the AI for the Future project in Hong Kong [3], this curriculum aims to nurture students to be computational thinkers who can solve sustainability issues with a holistic perspective leveraging the power of AI technology. By integrating progressive objectives order, computational thinking competencies and system thinking components, this curriculum introduces a comprehensive educational approach that goes beyond the traditional AI curriculum. The goal is to create a teaching resource for secondary school teachers to foster a generation of learners who grasp sustainability issues with a systematic lens, comprehend both the contributions and limitations of AI within a system, delve into the underlying principles of specific techniques in AI and acquire the capability to design and propose solutions to sustainability issues for this system.

II. Literature Review

A. Curriculum design in AI education for K-12

Numerous AI curricula have been developed for secondary students to learn, master and apply. In the United States, the AI4K12 initiative has proposed national curriculum standards, known as the '5 big ideas in AI' [4]. These standards provide guidelines for schools to construct curriculums, resources such as books, demos and curriculum materials for direct implementation and tools like AI platforms for experimental applications. The European Union has launched courses and online resources designed to foster AI literacy across the population. The AI+ initiative, part of the Erasmus+ project in Europe, was formulated to be adaptable to European High Schools, integrating knowledge and experience from AI researchers and high school teachers [5]. In Hong Kong, the AI for the Future (AI4Future) project launched at The Chinese University of Hong Kong developed the first secondary school formal AI curriculum in the region [3].

Previous curricula can be categorized into three groups based on their objectives: (1) AI tasks, (2) Technical knowledge of AI and (3) AI for real-world problem-solving.

AI Tasks: These curricula are built to solve specific tasks with AI, including computer vision, language processing, reasoning, etc. Students learn how AI technology perceives,

interprets and reasons. These tasks are taught separately, allowing students to focus on each [3], [5]–[7].

Technical Knowledge of AI: These curricula delve deeper into AI technical details, such as generative adversarial networks, convolutional neural networks, transformers, etc. Secondary students typically take these courses to learn how AI works to solve tasks.

AI for Real-World Problems: These curricula introduce how AI can be integrated with other fields to solve specific problems within those domains. For instance, a course on 'AI & Environment' might teach students how AI applications in camera traps can assist in wildlife population counts. 'AI & Dance' could demonstrate how AI recognizes skeletal movements for choreography [5], [8], [9].

B. Gaps in the Curriculum Design of AI and Sustainability

Previous literature shows a lack of a comprehensive curriculum on AI and sustainability education in secondary schools. As the curriculum design of AI education is still evolving, most courses tend to be fundamental. Specifically, when it comes to sustainability issues, there are courses with separate topics such as AI for environment and AI for health while lack of a comprehensive course encompassing AI and sustainability. These courses can not provide an overarching understanding of the role AI can play in driving sustainability across various sectors.

III. Curriculum Design Concept

A. Curriculum module

The AI4Future project put forward a curriculum with five levels of depth, including awareness, knowledge, interaction, empowerment and ethics [3]. Each chapter in the curriculum consists of these five modules for teachers to choose from for the beginner, intermediate and advanced levels. Furthermore, it specifies a development path for students to acquire AI techniques. This paper will design the hierarchical learning objectives based on these five modules.

B. Learning Unit Implementation based on System Thinking

System thinking has been proven to be an integrated approach in education for sustainability [10]. It helps students build a holistic perspective to understand sustainability instead of separating the Sustainable Development Goals (SDGs) into isolated targets. It has been widely used in the curriculum design of biology, geoscience and chemistry [11]–[13]. Based on previous studies, this paper takes four system thinking components in learning units for students to learn how AI contributes to sustainability. The four component includes (1) identifying the components of a system and data flow; (2) identifying dynamic relationships within the system; (3) organizing the system's components and processes within a framework of relationships; (4) Understanding the cyclic nature of systems.

C. Curriculum Activity Design Based on the Cultivation of Computational Thinking

The International Association for Educational Technology (ISTE) proposed five computational thinking competencies guide educators to teach students to be computational thinkers: (1) Computational thinking (learner), (2) Equity leader (leader), (3) Collaborating around computing (collaborator), (4) Creativity & Design (designer) and (5) Integrating computational thinking (facilitator). This paper takes cultivation of these competencies as a guide to design curriculum activity.

IV. Curriculum Course Design

A. Objectives Design

Based on the curriculum module proposed by AI4Future, this paper specifies the objectives of each module. The curriculum is designed into distinct sections to fit the varying learning needs and abilities of students at different academic levels. The 'Awareness', 'Knowledge', and 'Ethics' sections are designed as beginner units, suitable to lower secondary school students who are just embarking on their learning journey in this field. The 'Interaction' section is an intermediate unit, developed for students who possess a higher level of reflective thinking and learning capabilities. This unit is beneficial for those who are able to effectively interpret and gain insights from the materials presented. Lastly, the 'Empowerment' section is an advanced unit aimed at upper secondary school students. This section requires students to exhibit a higher degree of practical application skills. They will engage with computer systems through block-based visual programming, which fosters a more hands-on and immersive learning experience.

TABLE I. Curriculum objectives

Sections	Units	Objectives
Awareness	Beginner	Help students understand background, development and issues of sustainability, components and relationships within a system and AI applications to solve the issues.
Knowledge		Enrich students' knowledge of key concepts in specific AI technologies to solve sustainability issues.
Ethics		Instill an understanding of how AI technologies would inhibit sustainability issues.
Interaction	Intermediate	Provide interactive practices to experience essential techniques of the application.
Empowerment	Advanced	Train students to design, present AI technologies to solve real-world problems for sustainability.

B. Course Content and Activity Design

Based on the objectives design and the computational thinking competencies, this curriculum designs four sections, including awareness, knowledge, interaction and empowerment. The course content order is organized by the design of the objectives with a progressive depth of level. The teaching points and activity design is based on the computational thinking competencies to cultivate students into computational learner, leader, collaborator, designer and facilitator, as shown in Table 2.

TABLE II. COURSE CONTENT DESIGN

Sections	Teaching Points
Awareness	1) Sustainability and the relationship between environmental, social and economic aspects 2) Examples of AI technology in promoting sustainability in daily life
Knowledge	1) Four steps of system thinking 2) Analyze real-world AI-powered systems with four steps of system thinking 3) Design an AI-powered application for sustainability
Ethics	1) Environmental Impact of AI 2) Sustainable AI includes AI for sustainability and sustainability of AI
Interaction	1) Labeling land cover type from satellite images through online applications; 2) Exploring land cover change monitor 3) Computing carbon emission of model training through online application
Empowerment	1) Project solution on land cover change with AI, including dataset preparation, model definition, model training, model evaluation and prediction.

1) Awareness: In the awareness section, students will learn the wedding cake model of sustainability[14] to understand the interconnected sustainable development goals instead of learning them individually. It indicates that societies and economies are inherently based on the biosphere. It is about meeting human needs within ecological constraints. Besides, they will have a broad understanding of AI's applications in achieving these goals. Tasks are (1) recognizing AI applications from environmental, social and economic aspects in their daily life and (2) identifying what sustainability issues are solved by specific AI applications.

2) Knowledge: The knowledge part cultivates students' system thinking with a deconstruction guideline on real-world applications. In the first part of knowledge section, students engage with an AI-driven application and finish 4 tasks: (1) identifying the components of technology, humans and environment and tracking the data flow between the components, (2) finding relationships, including feedback loops, (3) drawing the system map that includes their finding, and (4) proposing one of the supra systems or connected systems to find how this one affects other components outside their system. The second and advanced part of the knowledge section is a simplified project-based learning activity. Students will form a group and design a new AI-driven application to solve sustainability issues they found. They can follow questions on a worksheet to design their system. Then present their project to their classmates.

3) Ethics: In the ethics part, students will learn about sustainable AI. It does not only include AI for sustainability but also the sustainability of AI. The sustainability of AI is an emerging ethical issue. Students will learn the environmental impact of developing and using AI models. How much carbon dioxide it emits? Tasks are (1) answering questions about what is green AI and how to foster green AI through instructive video and (2) drawing a flow chart to consider how to develop a sustainable AI application in the process of model training.

4) Interaction: Students experience machine learning techniques that they learn from the Knowledge part. Tasks are as follows: (1) To understand how to build a training dataset, they would participate in a crowd-sourced project of recognizing forest areas with human impact with satellite images contributing to labeling tasks for AI model training to detect human intrusion (2) exploring land cover change monitor and (3) computing carbon emission of model training through online application.

5) Empowerment: Students learn about how to use satellite data to monitor land cover change over ten years to monitor how different land cover types change. For a simplified version, the material includes data collection, model training, testing and model application. For an advanced version, the material covers data collection, data preprocessing, model building, model training, testing, performance improvement and model application for prediction. When they get their trained model they can use it to predict, get quantity of different land cover areas and identify changes in their interested areas like their neighborhoods.

C. Implementation of System Thinking Components

1) System Component and data flow: Students will learn to identify components in the system, including technology (how to collect, train or analyze data), human (who develops, uses or benefits), and environment (what is monitored, affected or protected). Besides, in any AI-driven system, data is an essential component that flows between technology, human and environment. Students will specify the data component with the following questions: What data are collected and utilized in the system? Which data does the AI component need to use? What data or information does the AI component produce?

2) Relationships within the system: Students will finish tasks to find relationships between components in the system. Moreover, students will learn about feedback loops existing between the components. There are two types of feedback loops that explain how changes happen in a system and why. Balancing feedback loop unveils how the change of a component is dampened by another component. Balancing feedback loop leads to stability within the system. Reinforcing feedback loop shows how the change is amplified. So the change will continue in the same direction, reinforcing the change effect. Reinforcing feedback loop makes the system less stable.

3) System map: Students will draw a system map to illustrate the components and relationships they learned before. Through these knowledge integration activities, they can understand how AI directly contributes to and indirectly influences the system.

4) Supra system and connected system: Students will learn to identify supra system and connected system of the previous system map to find how this one affects other components outside the system. Besides, students will be encouraged to consider the remotely connected system to detect hidden costs and untapped benefits in this telecoupled world.[14]

V. DISCUSSION

This curriculum is not just about teaching AI but about empowering students to become thoughtful, creative and responsible problem-solvers who can leverage AI as a tool for

sustainable development. By integrating progressive objectives order, computational thinking competencies and system thinking components, this curriculum introduces a comprehensive educational approach. The five depths of level, awareness, knowledge, ethics, interaction and empowerment provide a layered approach to learning. This structure allows educators to tailor content to students' abilities while ensuring a coherent progression in their learning journey. The activities designed based on computational thinking ensure students learn both comprehensive views and specific technology details. Implementation of system thinking components in learning units enables students to perceive the role of AI within the system and interconnection in the AI-driven system.

VI. LIMITATIONS AND FUTURE STUDIES

Limitations in this article are noted here. One key constraint is the time available for instruction. As an extended module in the AI4Future project, this curriculum design starts from a time-constraint setting. The design tries to fulfill the goal of being a holistic course at this stage, which has more direct teaching and demonstration in pedagogy. Further improvement could be more active and project-based learning strategies, which have been shown to significantly promote student engagement and learning. Moreover, this curriculum is developed based on theory guidelines and references from previous curricula, assessment of the curriculum's effectiveness through empirical research could provide valuable insights for its continuous refinement. This could include studies on student engagement, learning outcomes and the applicability of skills learned in real-world contexts.

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