Why and What to Teach: AI Curriculum for Elementary School

Seonghun Kim[1], Yeonju Jang[1], Woojin Kim[1], Seongyune Choi[1], Heeseok Jung[1], Soohwan Kim[2], Hyeoncheol. Kim[1]*

[1]Department of Computer Science and Engineering, Korea University, Republic of Korea
[2]Chongshin University, Republic of Korea
{ryankim0409, spring0425, woojinkim1021, poco2889 , csyun213, harrykim}@korea.ac.kr, skim@chongshin.ac.kr

Abstract

With the rapid technological change of society with Artificial Intelligence, elementary schools' goal should be to prepare the next generations according to competencies. We propose an AI curriculum to cultivate students' AI literacy to answer the question of 'why and what to teach' on AI. The proposed AI curriculum focuses on achieving AI literacy based on three competencies: AI Knowledge, AI Skill, and AI Attitude. We anticipate that the proposed curriculum will equip students with core competencies for the future with AI.

Introduction

As the integration of AI into society accelerates digital transformation, the ways of problem-solving shifts from the automation of human action to the automation of human cognition. AI technology is anticipated to develop into a general-purpose technology like electricity and networking technology in a shortcoming future. To reflect the future of AI integrated human labor systems, the objective of education should be reconfigured to portray the changing dynamics of our society (Parliament 2018). Accordingly, an elementary school curriculum should also be devised to prepare and inspire the next generation in a world flooded with AI.

The discussion of to whom AI should be taught reoriented from university students to elementary school students. Current AI education is mainly carried out at universities with a well-established curriculum. The aim of AI education in universities is to be academic and industry experts on the career development of students. However, AI education in elementary education should center on fostering the AI literacy of students. A blind application of higher education AI curriculum is inadequate to meet the educational purpose of elementary schools.

The AI curriculum of elementary school education should consider the competencies specific to elementary school students. The objective of elementary education is to provide students with an opportunity to strengthen core competencies to function as a member of a society successfully. The competency of elementary school should direct toward fostering students' ability to understand the AI integrated world.

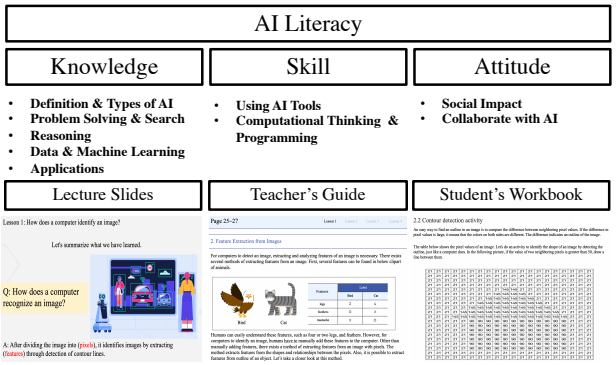

Figure 1: The complete outline of the proposed AI curriculum for elementary school.

As an answer to the question of 'why and what to teach' students on AI, we propose an AI curriculum tailored to elementary school students to develop AI literacy. The proposed AI curriculum is built upon the three competencies: AI Knowledge, AI Skill, and AI Attitude. The goal of the curriculum is to cultivate AI-literate elementary school students with mastery of the three competencies. Figure 1 illustrates the complete outline of the proposed curriculum. We further implemented a module of our curriculum to 60 elementary school students from five different schools and examined the content's adequacy, effectiveness, and value.

Existing Guidelines for K-12 AI Education

AI literacy is a set of competencies that enable an individual to function in AI integrated society proficiently. An individual with AI literacy would be able to critically evaluate AI, communicate and collaborate with AI and fluently use AI as a tool (Long and Magerko 2020). However, academic discussions on definitions and components of AI literacy is in continuation. We share a parallel perspective and the works that define AI literacy and its competencies for our curriculum. Among the competencies to achieve AI literacy in the work of Long and Magerko (2020), 'Recognizing AI', 'Ethics', and 'Programming Ability' are the core competencies that align with our curriculum development objective.

The AI for K-12 working group established guidelines

AI Competencies	Competency Subcategories
AI Knowledge	• K1: Definition and Types of AI • K2: Problem-Solving and Search • K3: Reasoning • K4: Data and Machine Learning • K5: Applications
AI Skill	• S1: Using AI Tools • S2: Computational Thinking and Programming
AI Attitude	• A1: Social Impact • A2: Collaborate with AI

Table 1: Three AI competencies and its subcategories.

that future AI curricula should fulfill (Touretzky et al. 2019). The guideline analyzes five AI's Big Ideas and defines what students should know about AI. Our curriculum mainly focuses on the Big Idea #1, #2, #3, and #5 of the guideline, each associated with topics in our separate module. Our curriculum's extent of knowledge coincides with the guideline's K3-5 grade band. The K3-5 grade band's specified topics are sensors, representation, vision, NLP, and self-driving cars, with emphasis on developing the programming ability of students using children's programming framework. All modules of our curriculum cover every mentioned topic and include programming activities using block-programming language. Further, all modules incorporate discussion activities on social impacts of AI, following the Big Idea #5 of the guideline.

Satisfying the guideline, our curriculum provides tailored learning activities, instructional materials, and evaluation rubrics. Our curriculum's content structure comprises unplugged activities on diverse AI technologies and associated ethical issues. The learning activities are constructed to maximize the students' learning on AI topics presented in the guidelines with computational thinking skills. This aspect of our curriculum differs from the existing K-12 AI curriculum where it addresses only certain AI areas, or the construction of the learning topics is disjointed (Wong et al. 2020). We start the modules by experiencing AI technologies that students can encounter in their daily lives. By experiencing familiar AI technologies, students may divest preconceived misconceptions about AI.

AI Literacy and Competencies of the Curriculum

The goal of the proposed AI curriculum is to equip elementary school students with AI literacy. Our primary considerations of the curriculum development are threefold: First, elementary students should identify AI technologies in their daily lives. Second, students should be equipped with programming skills to use the technology in real-world situations. Third, students should be able to consider potential ethical issues of using AI technologies.

We define the three competencies to achieve AI literacy: AI Knowledge, AI Skill, and AI Attitude. We do not establish priority among the three competencies since even developing all three competencies is necessary to attain AI literacy. Table 1 presents our definition and its subcategories of the three competencies. For simplicity, we use number order to indicate each of the subcategories.

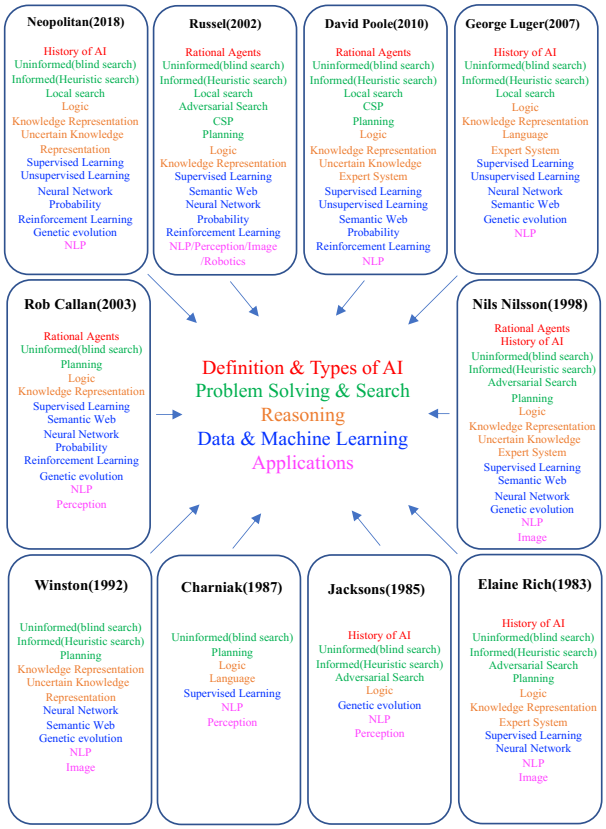

Figure 2: Analysis of the common concepts in AI textbooks. Best viewed in color.

AI Knowledge The AI Knowledge aims for the ability to comprehend the core concepts of AI. We define the subcategories of AI Knowledge competency as 'Definitions and Types of AI', 'Problem-Solving and Search', 'Reasoning', 'Data and Machine Learning', and 'Applications'.

'Definition and Types of AI' refers to the knowledge to identify what properties separate AI-based systems and algorithm-based systems. 'Problem-Solving and Search' indicates the knowledge of search algorithms. 'Reasoning' is knowledge on simulation of human logical reasoning process with a computing model. 'Data and Machine Learning' is understanding machine learning algorithms that finds patterns from data. 'Applications' refers to knowledge in various AI applications domains, such as computer vision, speech recognition, and machine translation.

The contents of 'Applications' subcategory are substantially associated with the curriculum's goal of developing AI literacy. The activities of 'Applications' aim to experience and learn everyday AI technologies such as voice recognition and optical text recognition. Experiencing AI applications in real-world situations allow students to utilize AI ap-

CS2013 topics	Subcategories of AI Knowledge
Fundamental Issues	Definition and Types of AI
Basic Search Strategies	Problem-Solving and Search
Basic Knowledge Representation and Reasoning	Reasoning
Basic Machine Learning	Data and Machine Learning
Perception and Computer, Vision, Natural Language Processing	Applications

Table 2: Associations between CS2013 Intelligent System topics and subcategories of the AI Knowledge competency.

plications based on their understanding of technology.

We construct the curriculum's content by surveying prominent AI textbooks, and Computer Science Curricula 2013 (CS2013) (Sahami et al. 2013). CS2013 reflected contributions from many researchers, educators, and practitioners in computer science and regarded as a primary guideline in designing computing curricula (Sahami 2015). Therefore, the proposed curriculum's content aligns with what is currently taught in college with adjusted difficulty suitable for elementary school students. Adopting a backward curriculum design approach, we first identified the desired learning outcomes and then designed learning activities with instructional strategies (Wiggins and McTighe 1998). Table 2 shows associations between CS2013 topics and subcategories of AI Knowledge competency.

We further verified the relevance of our five subcategories of AI Knowledge competency on ten AI textbooks' contents. Figure 2 illustrates a summary of the analysis of the mutual concepts of AI textbooks (Neapolitan and Jiang 2018; Russell and Norvig 2002; Poole and Mackworth 2010; Luger 2007; Callan 2003; Nilsson 1998; Winston 1992; Charniak and McDermott 1987; Jackson 1985; Rich and Knight 1983).

- All textbooks include the 'Definitions and Types of AI' as their introductory topic. Five out of ten textbooks cover AI's history with the definition of AI, and four out of ten textbooks include topics on rational agents.
- All textbooks include the 'Problem-Solving and Search'. The topics covered in this concept are uninformed (blind search), informed (heuristic search), local search, adversarial search, constraint satisfaction problem (CSP), and planning.
- All textbooks include logic, knowledge representation, uncertain knowledge, and expert systems, which all relate to 'Reasoning'. Nine out of ten textbooks cover logic, and eight out of ten textbooks cover knowledge representations.
- All textbooks cover topics on 'Data and Machine learning'. Included concepts are Supervised Learning, Unsupervised Learning, Neural Networks, Reinforcement Learning, Genetic Evolution, and Semantic Web. Especially, recently published textbooks put more emphasis on these topics.
- All textbooks contain topics on the 'Applications' of AI. The included domains are Natural Language Processing(NLP), Image, Perception, and Robotics. Specifically, NLP is consistently addressed in all textbooks.

AI Skill AI Skill competency equips students with computational thinking upon programming skills. The subcategories of AI Skill competency are 'Using AI Tools' and 'Computational Thinking and Programming'. 'Using AI Tools' indicates an ability to use appropriate AI utilities for problem-solving. 'Computational Thinking and Programming' refers to an ability to program simple AI applications, ultimately developing Computational Thinking of students.

For the AI Skill competency, we share our view with the AI competency framework by ReadyAI. ReadyAI considers 'Computational Thinking and Programming' as one of its core components of AI competency[1].

Computational Thinking is considered one of the fundamental skills for elementary school students and reading, writing, and arithmetic. Computational Thinking refers to "a student's ability to solve problems, design systems, and understand human behavior based on computer science" (Wing 2006). Computational Thinking emphasizes thinking on multiple abstraction levels for achieving the essential analytical ability of a student in a computer-ubiquitous world. Since computer science encompasses AI, we regard Computational Thinking as an imperative competency of a student in acquiring AI literacy.

AI Attitude With rich examples of AI applications, AI Attitude competency advances students' ability to consider all aspects of AI in society collectively. The subcategories of AI Attitude are 'Social Impact' and 'Collaborate with AI'. The AI Attitude competency seeks students' ability to acknowledge both the positive and negative effects of AI on society and a critical perspective on using AI technology.

An AI literate citizen should possess the ability to use AI for the benefit of humanity. The assimilation of AI into the human decision-making process introduces concerns toward ethics on its usage. Addressed issues include a commercial gender-biased face classifier (Buolamwini and Gebru 2018) and word embedding with encoded racial stereotypes (Manzini et al. 2019). It is necessary to provide a balanced view of the conflicting ethical issues of AI for students to reflect on themselves and acknowledge different opinions. In this regard, competencies for AI literacy should ensure that students perceive AI without any misconception (Wong et al. 2020).

[1] edu.readyai.org/wp-content/uploads/2020/05/summer_camp_lesson_plans_demo.pdf

Module	Lesson	Activities	AI Competencies		
1. Introduction to AI	1	• Play with Smart Speaker • Explore Applications of AI • Distinguish between AI and Algorithm	K1	S1	-
	2, 3	• Programming Activity: Smart Speaker	-	S2	-
	4	• Daily Applications of AI • Social Impact of AI	-	-	A1
2. Traditional Approaches of AI - Search and Reasoning	1	• Understand Search Algorithms • Solve Crossing the River Problem • Play Tic-Tac-Toe Game • Applications of Search Algorithms	K2	-	-
	2	• Understand Reasoning • Applications of Reasoning • Classify Animals with Reasoning Algorithms • Play Bulls and Cows Game	K2	-	-
	3	• Programming Activity: Animal Classifier	-	S2	-
	4	• AI Applications in Medicine • Positive Impacts of AI • Draw AI helping humanity	-	-	A2
3. Face Detection	1	• Play with Face Filter Apps • Understand Pixel in Image Processing • Feature Extraction and Edge Detection	K5	S1	-
	2,3	• Programming Activity: Face Filter App	-	S2	-
	4	• Distinguish between Face Detection and Face Recognition • The Impact of Face Recognition on Society	K5	-	A1
4. Speech Recognition	1	• How does the Computer Understand Audio?	K5	S1	-
	2,3	• Programming Activity: My Smart Home System	-	S2	-
	4	• The Impact of Speech Recognition on Society	-	-	A1
5. Machine Translation	1	• Play with Speech Translator • Tokenization and Encoding • Play with Speech Synthesis Application	K5	S1	-
	2,3	• Programming Activity: Speech Translator	-	S2	-
	4	• Draw Applications of Speech Translator • Applications of Speech Synthesis	K5	-	A1
6. Image Classification	1	• Play with Smart Lens • Distinguish between Supervised and Unsupervised Learning	K4	S1	-
	2,3	• Programming Activity: Image Classifier	-	S2	-
	4	• Applications of Image Classification • Draw an Ad of a Commercial Image Classifier	-	-	A1
7. Text Classification	1	• Play with Toxic Comment Blocker • Distinguish between Classification and Regression • Predict a Height from a Shoe Size • Classification with Decision Trees	K4	S1	-
	2,3	• Programming Activity: Toxic Comment Blocker	-	S2	-
	4	• Importance of Training Data • Jeopardy: Classification vs Regression	K4	-	A1
8. Self-Driving Cars	1	• Understand AI in Self-Driving Cars • Propose New AI Functions for Self-Driving Cars	K5	-	-
	2,3	• Programming Activity: Self-Driving Robot	-	S2	-
	4	• The Impact of Self-Driving Cars on Society	-	-	A1

Table 3: The content structure of the proposed AI Curriculum. Each capital letters of AI competencies indicate the competency subcategories of Table 1. For example, 'K1' denotes 'Definition and Types of AI'.

AI Curriculum for Elementary School Students

A full content structure of the proposed AI curriculum is demonstrated in Table 3. The curriculum is most suitable for the K5-6 grade band. The only required prerequisite for the curriculum is programming skills on constructing a sequence of commands using block-coding programming languages.

Module Design Considerations We design all modules of the AI curriculum on following considerations. Each module is constructed for even development of the three competencies to foster AI literacy of elementary school students. The content for enhancing AI Knowledge competency is built to uniformly address the core concepts of AI without emphasizing one particular knowledge. The activities to develop AI Skill competency are constructed to experience using AI technologies in students' day-to-day activities. Further, the curriculum includes programming activities to strengthen the student's computational thinking and creativity. The curriculum content for developing AI Attitude competency presents various ethical issues and dilemmas caused by AI integration into society.

The Structure of the Curriculum Each module of the curriculum consists of four consecutive lessons, where each of the lessons in the module is designed to incorporate at least one more AI competencies. Activities to develop AI Skill competency are included in all modules. Although each module covers different topics of AI, the flow of the lessons are similar. In the first lesson, students experience AI technologies present in their everyday lives. The second and third lessons include programming activities using the Entry (Han, Kim, and Wohn 2015). Entry is a platform for the block-based programming language that supports various coding blocks with high-level AI functionalities, such as video detection, machine translation, and speech recognition. The last lesson includes a review of previous topics and discussions on the social impact of AI with peers.

Module 1: Introduction to AI The first module introduces the core concepts of AI to students. The module's activities are programming a simple speech recognition algorithm and discussing the social impacts of AI with peers. Through the lessons in the module, students understand the definitions and characteristics of AI and distinguish between AI and algorithms. The learning objective of the module is to resolve students' potential misunderstanding of AI. The first module grows AI Knowledge competency of 'Definitions and Types of AI' and AI Attitude competency of 'Social Impact'.

Module 2: Traditional Approaches to AI The second module explores problem-solving with search algorithms. Activities of the module are programming an animal classifier with reasoning algorithms. The learning outcome of the module is understanding a traditional AI approach through search and reasoning algorithms. The second module fosters the AI Knowledge competency of 'Problem-Solving and Search', 'Reasoning', and AI Attitude competency of 'Collaborate with AI'.

Module 3: Face Detection The third module introduces how computers process images. Activities of the module are programming a face filter application. Then, students watch multimedia resources on the positive and negative impacts of computer vision technologies on society and proceed to in-depth discussion. The module's learning objective is to understand the difference between how humans and computers perceive visual information and how computers gain an advanced level of understanding through images or videos. Competencies included in the module are AI Knowledge of 'Applications' and AI Attitude of 'Social Impact'.

Module 4: Speech Recognition The fourth module covers speech recognition. Students learn about how computers process audio signals and deepen their understanding through programming a home automation system. Students also engage in a group discussion on how speech recognition influences their daily lives. The learning objective of the module is to know the speech recognition process. The module advances competencies of 'Applications' in AI Knowledge and 'Social Impact' in AI Attitude.

Module 5: Machine Translation The fifth module explores machine translation. The module's activities are about how computers to convert audio signals to written text and programming a simple machine translation application. The module's learning objective is an introduction to basic natural language processing concepts and distinguishing between speech recognition and language processing. The competencies fostered in the fifth module are the AI Knowledge competency of 'Applications' and AI Attitude competency of 'Social Impact'.

Module 6: Image Classification The sixth module covers the concepts of supervised and unsupervised machine learning. Students program a color classification model. Then, students discuss and present how image classification impacts society. The module's learning objectives are understanding fundamental concepts of machine learning and differentiating supervised and unsupervised learning. Competencies integrated into the module are AI Knowledge of 'Data and Machine Learning' and AI Attitude of 'Social Impact'.

Module 7: Text Classification The seventh module explores text classification, centered explicitly on toxic online comments. The programming activity for the module is to build a toxic comment blocker. Students are further presented with the topic of biased data and discuss the consequences of data bias. Students are also introduced to the concept of classification and regression. Through the course of activities, students learn the importance of using quality data by experiencing imbalanced and biased training data and how it affects machine learning models' decision-making. With the module, students develop AI Knowledge competency of 'Data and Machine Learning' and AI Attitude of 'Social Impact'.

Module 8: Self-Driving Cars The final module is on self-driving cars. Based on previous modules, students classify technologies in self-driving cars according to AI concepts that they have learned. The programming activity for the module is to build a self-driving robot with computer vision technology. The module's learning objective is to understand the importance and necessity of AI and how AI transforms daily lives, society, and future careers. Competencies for the module are AI Knowledge of 'Applications' and AI Attitude of 'Social Impact'.

Programming Activities Students acquire essential programming skills and basics of computer science through the programming activities of the curriculum. The programming activities are designed to incorporate basic object-oriented programming concepts and knowledge of data structures such as variables, data types, and lists. The programming activities also cover topics on functions and control flow commands.

Teaching Strategies We suggest the following teaching strategies for the effective implementation of the curriculum.

- The overall learning experience should be focused on achieving AI literacy through project-based learning and problem-solving rather than emphasizing a particular AI concept or tool.
- The activities should be aimed at developing a student's ability to use AI-based tools in their daily lives through unplugged learning rather than lectures on AI concepts.
- The teaching method should be constructed with an appropriate selection of machine learning tools and platforms considering the student's understanding and the classroom environment.
- The teaching method should employ appropriate topics to draw students' attention and motivation but present them to consider varying levels of topic importance.

Assessment Suggestions We suggest the following for student assessment when implementing our curriculum.

- Assessment should be centered on a rational and objective evaluation of students during all stages of peer interaction, presentation, and discussion. A checklist on the detailed assessment standard may assist the evaluation. The created assessment standard may be utilized for self-assessment or peer-assessment.
- Small group-based discussion is suitable for evaluating the process of discussion of a student. Teachers should instruct students to present in an orderly manner for even evaluation of all students.
- Teachers should create a learning environment enriched with a sense of accomplishment by providing various assessment criteria selected with careful consideration of student ability and understanding.
- When evaluating programming activities and the student's ability to use AI-based tools, teachers should evaluate the overall process of problem-solving altogether with the activities' outcome.

Instructional Material Development

The proposed AI curriculum further includes an instructional material package that includes lecture slides, student workbooks, and instructor's guides. The instructional materials are designed together with the curriculum to facilitate immediate and direct curriculum implementation. Figure 3 presents a sample of the instructional material. The instructional materials are publicly available online[2].

[2]https://www.playsw.or.kr/artificial/textbook

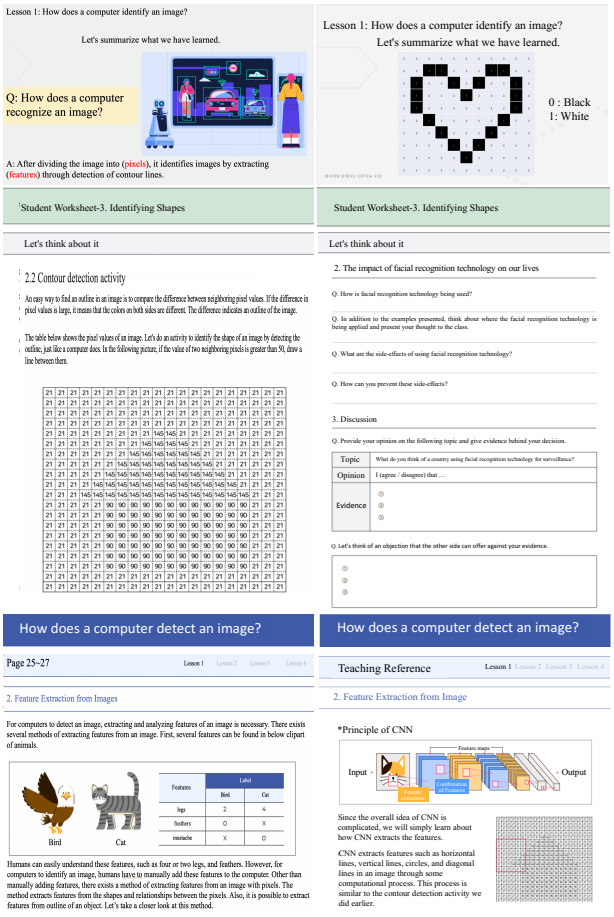

Figure 3: A sample of lecture slides (top), student workbooks (middle) and instructor's guide (bottom).

The lecture slides are designed per module and consist of lesson objectives, multimedia components on the topic, the lesson's core content, and an evaluation rubric.

The student workbook per module is divided into four sections, each covering a lesson of a module. The first worksheet supports student's unplugged learning activities in understanding essential topic concepts. The second and third worksheet provides step-by-step explanations and instructions for students to follow in their programming activities. The last worksheet aims to develop AI Attitude competency.

The instructor's guide further reduces the burden of teachers who might not be familiar with the concepts of AI (Sabuncuoglu 2020). The instructor's guide provides supplementary material containing a detailed explanation of AI topics, emphasizing the core concepts for teaching.

Curriculum Implementation

We implemented the first module of our curriculum as a pilot test, 'Introduction to AI', and analyzed students' learning outcomes. We evaluate the validity of our curriculum with a focus on enhancing the AI literacy of students. The first module is selected with the consideration that students have

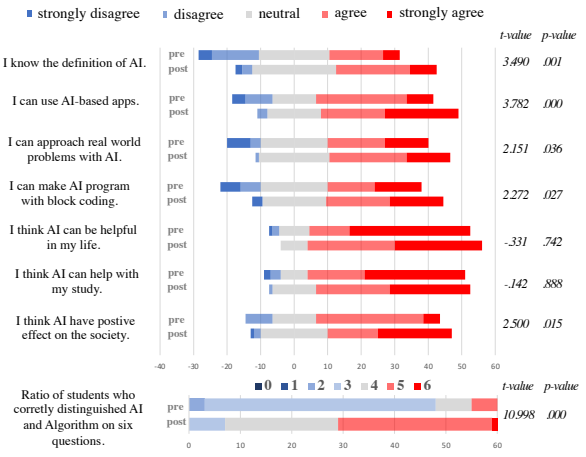

Figure 4: The t-test analysis of the student survey on the 'Introduction to AI' module.

no prior learning experience on AI.

The learning objective of the first module's lesson is understanding the definition of AI. Activities of the module include interacting with smart speakers and solving exercises to differentiate AI and algorithms. The second and third lesson's activity is programming a smart speaker with a block-based programming language. Students build a baseline model in the second lesson and develop the model in the third lesson. The fourth lesson's activity is understanding how AI changes people's everyday lives and discussing the social impacts of AI.

Survey Respondents We taught four fifth grade and four sixth grade classes of five elementary schools in South Korea over a weekly one-hour lesson for four weeks. We received consent to participate in research and an agreement to collect and use personal information. There were 60 participants, consisting of 25 fifth grade students and 35 sixth grade students.

Survey Method We surveyed students before and after implementing the module on AI Knowledge, AI Skill, and AI Attitude. We measure students' level of competencies with a five-point Likert scale, with five being 'Strongly Agree'. We also surveyed students on their knowledge to differentiate between AI and algorithms. We then compared the student's pre- and post- responses and analyzed the results using the t-test analysis with a 0.05 level of significance.

Results

Figure 4 demonstrates the analysis of the survey respondent's pre- and post-survey on AI literacy. The analysis demonstrates an increased average of the responses and statistically significant differences. The analysis shows that our curriculum successfully enhanced AI literacy in students.

AI Knowledge We confirm that the implementation of the module enhances student's AI Knowledge competency. On the survey question of 'I know the definition of AI', students were not confident about AI's definition (Mean: 3.07, SD: 1.056). After the module implementation, the students were more confident in their knowledge of the definition of AI (Mean: 3.52, SD: 0.911). The t-test analysis showed a significant difference (Mean: 4.42, SD: 0.720).

On the student's ability to differentiate between AI and algorithm, the module implementation has demonstrated to develop the AI Knowledge competency of students. We analyze how students have succeeded in distinguishing between AI and algorithms before and after the module implementation. The bottom composite bar graph of Figure 4 presents the result. The pre-survey results indicate that the students are not familiar with differentiating between AI and algorithms (Mean: 3.23, SD: 0.673). After the implementation, students successfully distinguished AI and algorithm (Mean: 4.42, SD: 0.720). The t-test analysis showed a significant difference of ($t=10.998$, $p < 0.01$).

AI Skill For the survey items on AI Skill competency, the module implementation increased students' competency on 'Using AI Tools' and 'Computational Thinking and Programming'. The analysis on the pre- and post-survey reveals that the curriculum implementation has developed students' AI Skill competency with statistical significance of ($t=3.782$, $p<0.01$), ($t=2.151$, $p<0.05$) and ($t=2.272$, $p<0.05$) on the survey questions of 'I can use AI-based apps', 'I can approach real-world problems with AI' and 'I can make AI program with block coding'.

AI Attitude The pre- and post-survey show that the module implementation strengthens student's AI Attitude competency. Response to the question of 'I think AI has a positive effect on society' demonstrates the statistical significance ($t=2.500$, $p<0.05$). However, on the questions of 'I think AI can be helpful in my life' and 'I think AI can help with my study', the means of both questions were already high with (Mean: 4.33, SD: 0.968) and (Mean: 4.17, SD: 1.060), respectively. We speculate that a high percentage of students had already formulated a positive attitude toward AI even before the module was implemented.

Conclusion

We propose to establish AI literacy as the main objective of elementary school AI curriculum and define the components of AI literacy with three competencies: AI Knowledge, AI Skill, and AI Attitude.

Based on three core competencies, we build a curriculum accompanying teaching and learning resources for elementary school students on AI education to equip students with AI literacy. Our implemented AI curriculum enhances AI literacy for elementary school students with statistically significant differences. We expect that our curriculum successfully satisfies the goal of empowering students to prosper in the world of AI.

For future work, we aim to evaluate all modules' validity. We also hope to develop an AI education curriculum for the entire K-12, expanding from this AI elementary school curriculum.

Acknowledgements

This research was supported by the MSIT(Ministry of Science and ICT), Korea, under the ITRC(Information Technology Research Center) support program(IITP-2018-0-01405) supervised by the IITP(Institute for Information & communications Technology Promotion).

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