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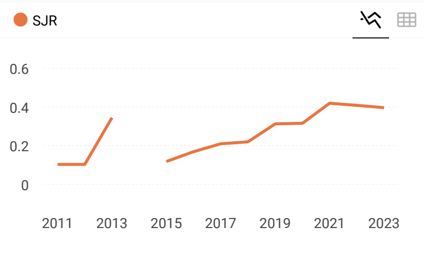

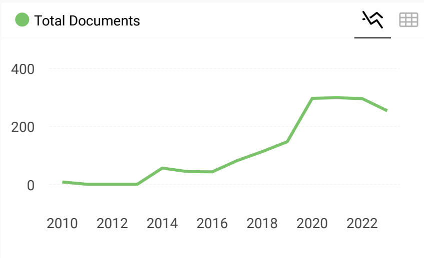

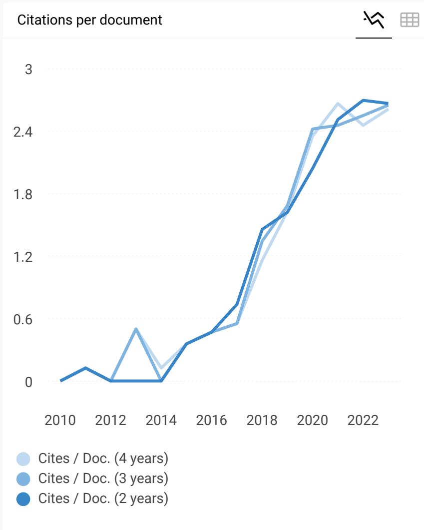

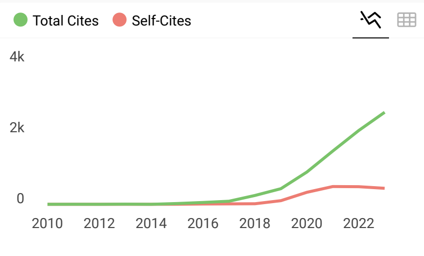

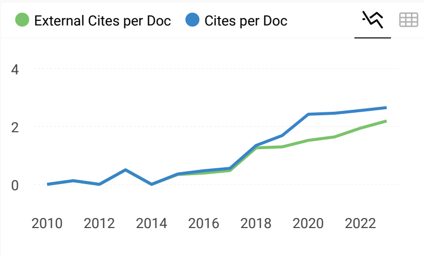

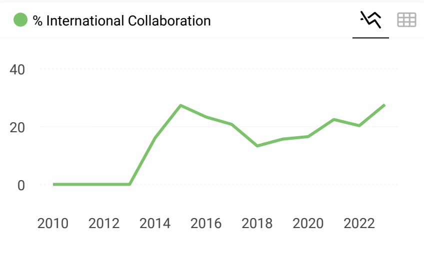

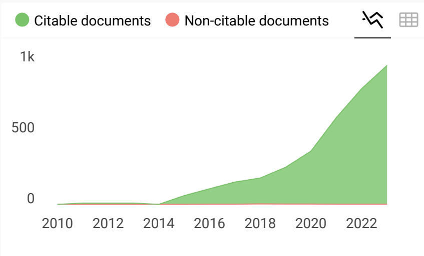

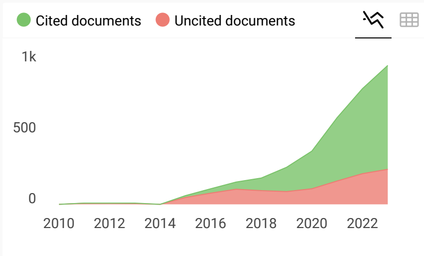

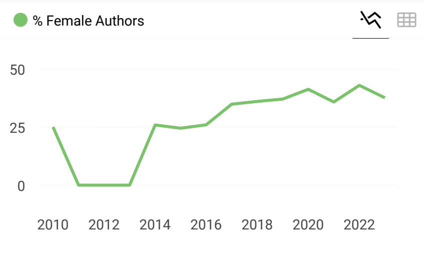

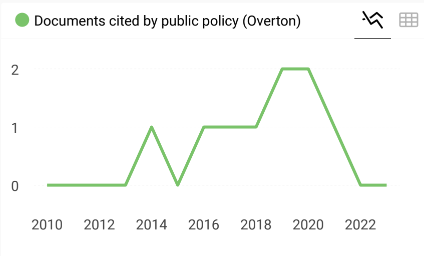

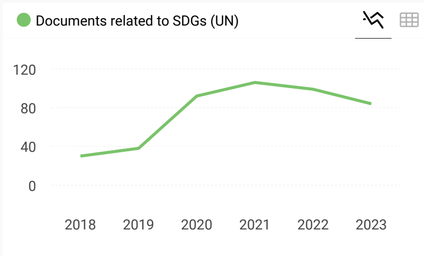

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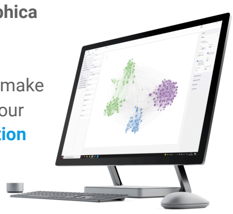

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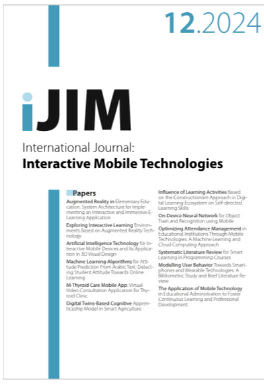

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PAPER

Digital Twins-Based Cognitive Apprenticeship Model in Smart Agriculture

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ABSTRACT

Applying digital technologies in education has been proven to have several positive impacts on teaching and learning. Digital twins have the potential to revolutionize education by offering immersive and interactive learning experiences. They can simulate virtual environments, enabling students to conduct experiments, practice techniques, and observe outcomes in a safe and cost-effective setting, particularly when access to physical laboratories is limited or expensive. This work proposes a learning management model that applies cognitive apprenticeship learning theory as a framework for learning digital twins to enhance the programming of a smart agriculture system and computational thinking skills. The model consists of three parts: input, learning process, and output with feedback. The input phase includes setting learning objectives, analyzing learners, determining learning content, planning learning activities, and utilizing a digital twin virtual laboratory space for experimenting in the development of a smart agriculture system. The learning process involves engaging students in programming and problem-solving tasks by offering expert guidance and support in computationally solving problems. The achievement of learning outcomes and practices is included in the output and feedback sections. After evaluation, five experts in this subject agreed that the learning management model was at the most appropriate level.

KEYWORDS

digital twins, cognitive apprenticeship, computational thinking

1 INTRODUCTION

Adoption and expansion of digital transformation stem from the gradual increase in the digitalization of economies [1], [2]. Digital technology offers numerous benefits, such as competitive advantage, cost efficiency, increased productivity, and flexible business models. Among emerging technologies, digital twin technology shows great promise for digital transformation [3]. A digital twin is a virtual representation or replica of a physical object, system, or process created by capturing real-time data from sensors, devices, and other sources. This data is then used to develop a virtual

Thipphayasaeng, P., Piriyasurawong, P., Phanichsiti, S. (2024). Digital Twins-Based Cognitive Apprenticeship Model in Smart Agriculture. *International Journal of Interactive Mobile Technologies (iJIM)*, 18(12), pp. 72–84. https://doi.org/10.3991/ijim.v18i12.46847

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model that closely mirrors the physical counterpart [4], [5]. Digital twins are not only useful in economic industries, but they are also utilized in various fields, including education. Virtual twins can serve as a sandbox for students to learn and experience tasks that are otherwise challenging to access.

The COVID-19 pandemic served as a catalyst for accelerating the urgency and adoption of digital transformation, forcing a change in educational approaches due to school closures and social distancing measures. Digital technology enables remote learning and ensures educational continuity during a pandemic. Despite the less strict measures against the pandemic nowadays, remote learning and computer-based learning tools are still preferred over traditional education methods. This preference ultimately enhances overall learning outcomes and student experiences [6], [7], [8]. In the era of fast-evolving digital technology, soft skills, including problem-solving skills and computational thinking skills, are necessary both now and in the future [9].

There are numerous studies on applying digital technology to enhance the educational process. One supportive example is to utilize digital twin technology to simulate real-world objects, allowing students to acquire practical experience. Such technology can provide a learning environment for students to visualize and understand complex concepts more engagingly and interactively, without the risk of actual operations. The studies also show that digital twin simulation benefits students and can help instructors predict the probability of successfully completing learning tasks [10] and optimize the learning process to ensure that the learning content is suitable for students [11].

Moreover, digital twins are a technology that provides an environment for an immersive learning experience. It is more appropriate to apply a learning approach, such as cognitive apprenticeship, to improve learning outcomes. Many researchers have shown that cognitive apprenticeship significantly improves learners' problem-solving processes [12], [13], [14]. Cognitive apprenticeship, as a teaching method, primarily focuses on instructing learners in the processes that experts use to manage complex tasks [15]. By applying cognitive apprenticeship theory to digital twin simulation, which is known for its interactive environment, it is likely to effectively achieve its learning objectives in terms of performance and the learning needs of various learners and a wide range of users [16]. Thus, we attempt to combine cognitive apprenticeship, a widely accepted teaching method, with digital twin technology to simulate real-world objectives and processes. This allows students to gain practical experience without any risk. This paper aims to design a learning management model using digital twin technology that applies a learning approach based on cognitive apprenticeship theory. To delineate the learning contents of the model, the selected topics for learning are programming for smart agriculture and computational thinking.

2 BACKGROUND

2.1 Digital twins technology

The concept of digital twins can be traced back to the early 2000s, although the term itself has only gained popularity in recent years. The origins of digital twins can be attributed to the aerospace industry. NASA pioneered the development of digital twin technology to monitor and analyze the performance of space missions as a virtual representation of physical assets in 2002 [17]. In 2010, General Electric played a significant role in popularizing the concept of digital twins through its Industrial Internet initiative. The company recognized the potential of connecting physical assets to digital counterparts and leveraging data analytics to optimize performance, reduce downtime, and improve maintenance processes. The rise of the Internet of Things (IoT) and advancements in sensor technologies have further fueled the development of digital twins. The increasing availability of sensors and connected devices has enabled organizations to capture real-time data from physical assets and utilize it to generate virtual representations. Digital twin technology has started gaining traction across various industries, including manufacturing, energy, healthcare, and transportation. Organizations have recognized the potential of digital twins to improve efficiency, enhance product development, enable predictive maintenance, and optimize overall operations.

In NASA technology roadmaps published in 2012, Glaessegen and Stargel provided a description of the digital twin as follows: "Digital twin means an integrated multiphysics, multiscale, probabilistic simulation of a complex product that functions to mirror the life of its corresponding twin" [18]. Digital twins typically consist of three key components that work together to create a comprehensive virtual representation of a physical object, system, or process. These components include the physical product, the virtual product, and the linkage between the physical and virtual products. The connection between the physical entity and its virtual counterpart is established by sensors and IoT devices, which are responsible for collecting real-time data from the physical object or system [19], [20]. These sensors can capture information, such as temperature, pressure, motion, vibration, and location, to synchronize real-world features with their virtual counterparts.

Digital twins can be effectively utilized for training purposes by offering a virtual environment for students to acquire practical experience and improve their skills. Digital twins can simulate real-world scenarios and provide a safe and controlled environment for training. Furthermore, digital twins enable remote training capabilities, which have become increasingly important, especially in situations where travel or physical presence are limited. Students can access the digital twin remotely using virtual reality (VR) or augmented reality (AR) technologies and receive interactive training, guided instructions, and real-time feedback [21]. The benefits of utilizing digital twins in the education industry are significant. They provide a scalable, immersive, and cost-effective training solution, allowing them to acquire practical experience, enhance their skills, and make informed decisions in a risk-free environment.

2.2 Computational thinking

Computational thinking refers to a problem-solving approach that involves breaking down complex problems into smaller, more manageable parts and devising systematic and logical strategies to solve them. This process draws on fundamental concepts from computer science [22]. Computational thinking encompasses a set of skills and concepts involving structured and algorithmic thinking to tackle problems [23], [24]. Computational thinking is a valuable skill set applicable in various domains. It promotes problem-solving, creativity, analytical thinking, and the ability to approach complex issues in a structured and systematic way [25], [26].

The core principles of computational thinking include 1) creating the solution to any problem in steps (algorithmic thinking), 2) associating the solution with similar problems (pattern recognition), 3) dividing complex problems into solvable sub-parts (decomposition), and 4) having the support of computers in solving problems (automation) [27], [28]. Computational thinking is increasingly recognized as an essential skill in the digital age because it helps individuals navigate and understand the data-driven and technology-rich world. It can be cultivated and developed through practice and exposure to computational concepts and problem-solving approaches.

2.3 Cognitive apprenticeship

The cognitive apprenticeship model was originally proposed by Collins, Brown, and Newman [15] and has since been applied in various educational and training contexts. It is based on the idea that learning is most effective when learners engage in meaningful activities within a social and collaborative environment. Cognitive apprenticeship is an instructional approach that draws on the traditional concept of apprenticeship and applies cognitive learning principles to facilitate skill acquisition and knowledge transfer. It emphasizes the active participation of learners in authentic, real-world tasks while receiving guidance and support from more knowledgeable individuals or experts in the field [29]. The core components of cognitive apprenticeship are as follows:

Modeling: In cognitive apprenticeship, experts or skilled practitioners serve as models, demonstrating the desired skills, strategies, and thinking processes to learners. Learners observe and imitate the expert's behaviors and thought processes to gain insight into effective problem-solving approaches.

Coaching: Coaches or mentors provide guidance and support to learners as they engage in authentic tasks. They offer feedback, ask probing questions, and help learners reflect on their experiences. Coaching aims to scaffold learners' understanding, foster metacognition, and promote the development of expertise.

Scaffolding: Scaffolding refers to the support provided by the mentor or coach to assist learners in completing complex tasks. This is known as articulation. It involves breaking down tasks into manageable steps, providing prompts, offering hints or cues, and gradually reducing support as learners become more proficient.

Articulation: Learners are encouraged to express their thinking processes and rationale while performing tasks. By verbalizing their thoughts, learners can clarify their understanding, reflect on their actions, and make their thinking explicit. This helps both the learner and the mentor identify areas of misconception or misunderstanding.

Reflection: Reflection is a critical component of cognitive apprenticeship. Learners are encouraged to reflect on their experiences, analyze their successes and failures, and identify strategies for improvement. Reflection promotes metacognitive awareness, self-regulation, and the transfer of learning to new situations.

Cognitive apprenticeship is often utilized in intricate domains where skills and expertise are acquired through practice and hands-on experience [12], such as medicine, engineering, and business. It focuses on developing not only procedural skills but also conceptual understanding, problem-solving abilities, and metacognitive skills. By engaging learners in authentic tasks and providing expert guidance and support, cognitive apprenticeship fosters the development of expertise, promotes deep understanding, and prepares learners to apply their knowledge and skills in real-world contexts. In [25], the researchers examined the implementation of cognitive apprenticeship to enhance the acquisition of productive learning skills among young adults aged 18–25. Their study concluded that scaffolding is important for an apprentice to acquire abilities and skills. Trainees require constant assistance, hints, feedback, cues, and directives to enhance productivity.

3 RESEARCH METHODOLOGY

In this study, there are two phases, including:

Phase 1: Development of a digital twins-based cognitive apprenticeship model in smart agriculture to enhance computational thinking skills. The development processes include:

a) Engaging in the study and review of existing research on cognitive apprenticeship, digital twins, smart agriculture, and computational thinking
b) Synthesizing digital twin technology
c) Synthesizing computational thinking
d) Design a digital twins-based cognitive apprenticeship model for smart agriculture to enhance computational thinking through the analysis of outcomes.

Phase 2: Evaluating the appropriateness of the digital twins-based cognitive apprenticeship model in smart agriculture to enhance computational thinking

a) Designing a questionnaire using a 5-point Likert scale (1–5) to evaluate the appropriateness of the developed model synthesizing digital twin technology.
b) Conducting an evaluation of the appropriateness of the digital twins-based cognitive apprenticeship model.

The population in this study consists of five experts selected through purposive sampling. The experts are tasked with performing an assessment of the proposed learning management model. Two selected experts have a minimum of five years of experience in teaching at a university, while the other three experts specialize in information technology and also have at least five years of teaching experience at a university.

4 RESULTS

4.1 Results of phase 1: Development of the digital twins-based cognitive apprenticeship model

Synthesizing results. By reviewing, we identified and selected six publications related to the use of digital twins for training target audiences to enhance specific skills. After studying these works, we synthesized digital twin technology in comparison to this work, as shown in Table 1, and provided a description of the five components in terms of their digital twins in Table 2.

Table 1. Synthesizing results towards digital twin technology

Component	[21]	[30]	[31]	[32]	[17]	[33]	This Work
Physical artifact	✓	✓	✓	✓	✓	✓	✓
Digital/Virtual artifact	✓	✓	✓	✓	✓	✓	✓
Virtual-physical connection	✓	✓	✓	✓	✓	✓	✓
Data		✓		✓		✓	✓
Service				✓		✓	✓

Table 2. Definition of the five components of digital twins

Components	Definition
Physical artifact	An artefact in the real-world: In our work, the physical artifacts related to smart agriculture include farm environmental factors, and sensor devices.
Digital/Virtual artifact	A computer-generated representation of the physical artefacts.
Virtual-physical connection	Connection model between Physical and-Virtual artifacts consisting of all the links connecting each component of the digital twin [32].
Data	The data model of a digital twin includes data from the physical space, virtual space, service model, and the integration of all these data [32].
Service	Smart services in smart agriculture developed by the students within a virtual space such as automatic water pump controller and light controller for greenhouse [33].

In terms of computational thinking, we selected five publications related to training computational thinking. We synthesized their components by comparing them to the design of our work, as shown in Table 3.

Table 3. Principles of computational thinking used in existing studies

Component	[28]	[34]	[35]	[36]	[37]	This Work
Decomposition	✓	✓	✓	✓	✓	✓
Abstraction	✓	✓	✓	✓	✓	✓
Pattern Recognition	✓	✓	✓		✓	✓
Algorithm	✓	✓	✓	✓	✓	✓
Automation		✓				
Generalization				✓		
Evaluation				✓		

In Table 3, we present a list of current studies and the principles of computational thinking they involve. Some principles are selected differently based on the objectives of the studies. Thus, we selected four principles and provided their definitions for this work as follows:

a) Problem decomposition is a method for dissecting problems and breaking them down into smaller and more understandable components. This method is also known as "Divide and Conquer."
b) Abstraction is the process of making an artifact more understandable by reducing unnecessary details and variables; therefore, it should lead to simpler solutions.
c) Pattern recognition involves identifying similarities or patterns in problems in order to solve complex issues more effectively.
d) Algorithmic thinking is the process of constructing a systematic scheme of steps that can be followed to offer solutions to all the individual problems required to solve the original problem.

Design of the digital twins-based cognitive apprenticeship model in smart agriculture to improve computational thinking. In this section, we outline the design of a learning management model for cognitive apprenticeship using digital twin technology for smart agriculture. The aim is to cultivate computational thinking skills through the analysis of previous research. The overview is shown in Figure 1.

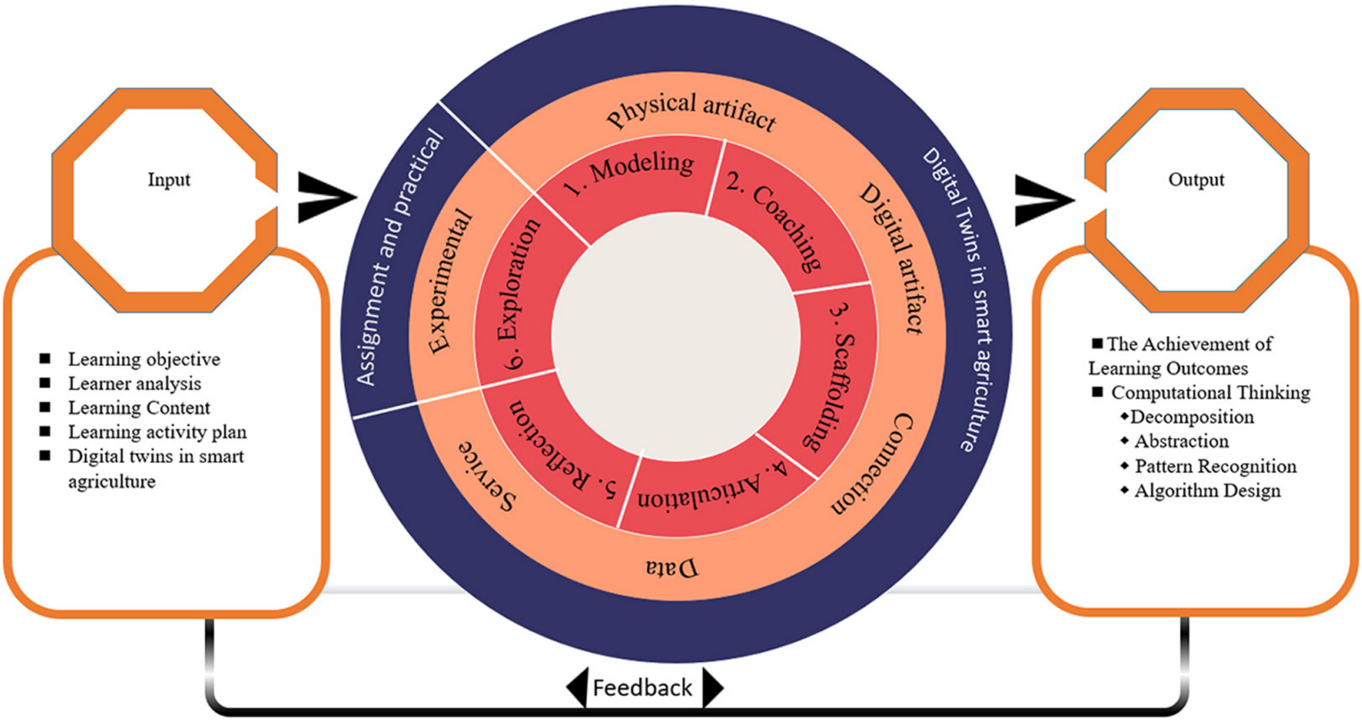

Fig. 1. An overview of the digital twins-based cognitive apprenticeship model in smart agriculture to enhance computational thinking

There are three parts to the learning management model: 1) input, 2) learning process, and 3) output and feedback.

First, an input stage is required before the learning process begins. This includes:

a) Learning objective: It refers to a clear and concise statement that describes what learners are expected to know, understand, or be able to do at the end of a learning experience. The learning objective in this work is aligned with our learning outcomes, which are 1) understanding of how to develop smart agriculture and 2) increasing computational thinking skills.

b) Learner analysis: This refers to the gathering of information about the characteristics, needs, and preferences of the learners who will be participating in a learning experience. It involves understanding the target audience's demographics, prior knowledge and skills, and any other relevant factors. In this work, the students are analyzed for digital literacy, which is higher than standard due to their past experience with online education during the COVID-19 pandemic.

c) Learning content: The content for learning aligns with the learning objective. The content in this work includes 1) a principle of visual programming that involves 'sequence', 'selection', 'loop', 'connecting to GPIO (general-purpose input/output pin)', and 'connecting to IoT devices', 2) the design of electronic circuits and controllers for sensors relating to smart agriculture, and 3) knowledge and skill management for computational thinking.

d) Learning activity plan: This document utilizes cognitive apprenticeship to outline primary activities and sub-activities aimed at accomplishing learning objectives.

e) Digital twins for smart agriculture: This study utilizes digital twin technology to simulate an agricultural process, enabling students to gain hands-on experience in developing an IoT system and optimizing it for smart agriculture. Students can monitor the effects of changes in their actions and make adjustments in the virtual space.

Second, the learning process in this work is based on the theory of cognitive apprenticeship, as follows:

a) Modeling: Instructors demonstrate computational thinking in their explanation of setting up an environment for an agricultural digital twin. The demonstration of computational thinking is as follows:
   1. Decomposition: Instructors explain how the components of the digital twin for smart agriculture are structured and interconnected.
   2. Abstraction: Instructors analyze existing agricultural problems and categorize them into groups to highlight the underlying root issues in their explanations.
   3. Pattern recognition: Instructors highlight the similarities and shared components of patterns found in electronic circuits and sensors.
   4. Algorithmic thinking: Instructors exemplify how to solve the previously mentioned problem step-by-step with a logical explanation.

b) Coaching: Instructors are assigned to coach students while they are working on programming smart agriculture. The coach's tasks are to give feedback, advice, and ask probing questions to help students reflect on their experiences.

c) Scaffolding: Instructors are expected to provide support by introducing information resources related to students' current problems and offering clues or hints by comparing the problem to similar content that students are familiar with. Moreover, instructors can remind students of the computational thinking process to help them break down complex problems effectively.

d) Articulation: Students are motivated to verbalize and summarize their learning experiences. Preferably, the feedback should align with the principles of computational thinking.

e) Reflection: Students are tasked with reflecting on their experiences, analyzing their own and classmates' successes and failures, and identifying strategies for improvement based on the concept of computational thinking.

f) Exploration: After completing the assigned simple task, instructors provide guidance and motivate students to expand their task to tackle more complex problems or apply it to a related topic in a different context. Moreover, a presentation is assigned to summarize the problem-solving method following the concept of computational thinking. The presentation aims to analyze the mistakes that occurred in the initial planning and actual practice.

Last, the output and feedback part is where instructors evaluate the finished task and summarize the report of the student to assess students' knowledge and skills in terms of smart agriculture programming and computational thinking skills. The evaluation of smart agriculture programming is based on the final outcome of the system developed by the student. The aspects to be evaluated include the appropriate programming logic used in the system, the chosen problem-solving method, and the results of the smart agriculture system. For the computational thinking evaluation, the feedback reports are examined to determine if the content is based on computational thinking theory.

4.2 Evaluation of the digital twins-based cognitive apprenticeship model by experts

To evaluate the proposed digital twins-based cognitive apprenticeship model in smart agriculture for enhancing computational thinking, we invited five experts to assess the suitability of the learning management model. The results were collected using a 5-point Likert scale, where 1 indicates strong disagreement and 5 indicates strong agreement. The expert-based evaluation results are presented in Table 4.

Table 4. Evaluation Results from experts regarding appropriateness

Evaluation List	Mean	S.D.	Appropriateness Level
Input Process			
1. Learning Objective	5.00	0.00	Strongly agree
2. Learner analysis	4.60	0.49	Strongly agree
3. Learning Content	5.00	0.00	Strongly agree
4. Learning activity plan	4.80	0.40	Strongly agree
5. Digital twins in smart agriculture	4.80	0.40	Strongly agree
Total of Input Process	**4.84**	**0.37**	Strongly agree
Learning Process			
1. Modeling	5.00	0.00	Strongly agree
2. Coaching	5.00	0.00	Strongly agree
3. Scaffolding	4.80	0.40	Strongly agree
4. Articulation	4.60	0.49	Strongly agree
5. Reflection	5.00	0.00	Strongly agree
6. Exploration	4.80	0.40	Strongly agree
Total of Learning Process	**4.87**	**0.34**	Strongly agree
Output and Feedback Process			
1. The Achievement of Learning Outcomes	4.80	0.40	Strongly agree
2. Computational Thinking	4.60	0.49	Strongly agree
Total of Output and Feedback Process	**4.70**	**0.46**	Strongly agree
Total	**4.81**	**0.40**	Strongly agree

As shown in Table 4, the overall mean score for the entire framework was 4.81, with a standard deviation of 0.40, indicating a robust level of appropriateness as perceived by the expert evaluators. The experts strongly agreed with the design of the input processes, particularly the components of learning objectives and learning content, which both received the highest evaluation. This indicates that the selected components were valuable and essential to the model. For the learning process, they all strongly agreed. The evaluation implied that the experts found the proposed components necessary for the learning process. From the output results and feedback, it can be inferred that experts agreed that both computational thinking and the achievement of learning outcomes were suitable for the model. The expert evaluation results affirm the suitability of the learning management model for smart agriculture education. The high level of agreement among experts instills confidence in the framework's suitability for enhancing effective learning experiences in the realm of smart agriculture.

5 DISCUSSION

Our proposed method is related to Busi's work [29], which utilized cognitive apprenticeship as a factor in fostering productive learning among out-of-school emerging adults. The study showed that cognitive apprenticeship fosters trust between learners and instructors, motivating learning and enhancing learning proficiency [38]. Moreover, a cognitive apprenticeship approach can be incorporated into a course if the course contents allow for it. According to a study by [21], digital twins are utilized for educational purposes and in the field of engineering science. The numerous advantages of the virtual sandbox establish it as a crucial tool in the technological and academic realms of the twenty-first century.

Our findings, along with those in the literature, suggest that managing learning with an emphasis on cognitive apprenticeship and digital twin technology can enhance the learning process and lead to improved learning outcomes. This work focuses on developing knowledge in smart agriculture and computational thinking skills as our primary objectives. We aim to demonstrate how to adapt a specific topic in the model. In the future, we plan to introduce additional subjects and topics to broaden the scope of knowledge and support learning both within and beyond academic education. Namely, the designed model can be extended to other popular topics and training for daily life skills, such as AI development and English learning. Moreover, the model is not limited to being used in an academic setting but is also applicable as an online application for those interested in learning the available topics.

6 CONCLUSION AND REMARKS

This work applies digital twin technology to teach students about smart agriculture programming and enhance their computational thinking skills. Digital twins play a crucial role in the educational environment by enabling students to learn about programming smart agricultural systems in a cost-effective and secure manner. In the proposed learning management model, we apply the cognitive apprenticeship theory to emphasize computational thinking skills in programming lessons and problem-solving. Thus, students who participate in the proposed learning management model will receive an immersive experience learning designated content in a comfortable and risk-free manner, as their mistakes only occur in a virtual sandbox. Students can also experiment with creativity and have the opportunity to hone their computational thinking skills. Five experts on this subject concur that the learning management model developed was at the most appropriate level.

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