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Teachers' Perceptions of Teaching Sustainable Artificial Intelligence: A Design Frame Perspective

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Abstract: Teaching artificial intelligence (AI) is an emerging challenge in global school education. There are considerable barriers to overcome, including the existing practices of technology education and teachers' knowledge of AI. Research evidence shows that studying teachers' experiences can be beneficial in informing how appropriate design in teaching sustainable AI should evolve. Design frames characterize teachers' design reasoning and can substantially influence their AI lesson design considerations. This study examined 18 experienced teachers' perceptions of teaching AI and identified effective designs to support AI instruction. Data collection methods involved semi-structured interviews, action study, classroom observation, and post-lesson discussions with the purpose of analyzing the teachers' perceptions of teaching AI. Grounded theory was employed to detail how teachers understand the pedagogical challenges of teaching AI and the emerging pedagogical solutions from their perspectives. Results reveal that effective AI instructional design should encompass five important components: (1) obstacles to and facilitators of participation in teaching AI, (2) interactive design thinking processes, (3) teachers' knowledge of teaching AI, (4) orienteering AI knowledge for social good, and (5) the holistic understanding of teaching AI. The implications for future teacher AI professional development activities are proposed.

Keywords: artificial intelligence; grounded theory; teachers' experience; teachers' professional development; K-12 education

Citation: Lin, X.-F.; Chen, L.; Chan, K.K.; Peng, S.; Chen, X.; Xie, S.; Liu, J.; Hu, Q. Teachers' Perceptions of Teaching Sustainable Artificial Intelligence: A Design Frame Perspective. *Sustainability* **2022**, *14*, 7811. https://doi.org/10.3390/su14137811

Academic Editors: Haoran Xie, Gary Cheng, Gwo-Jen Hwang and Morris JONG Siu-yung

Received: 7 June 2022
Accepted: 24 June 2022
Published: 27 June 2022

1. Introduction

A growing reliance on artificial intelligence (AI) as a pervasive computing technology expands the possible means for industrial and social sustainable development [1]. Given AI's importance, several AI curricula have been experimented with some emerging research on secondary and primary school students' perceptions of learning AI [2,3]. These studies indicate that students were generally motivated to learn about AI when instructed with a well-designed curriculum. Nonetheless, other issues associated with structural changes, such as redesigning the crowded ICT curriculum and teachers' professional development, need to be addressed [2]. There is currently a limited understanding of pedagogy for teaching AI in the K-12 sector [4]. In particular, there is an obvious need to explore how to teach AI well through the technological pedagogical content knowledge (TPACK) framework, which is likely to allow educators to distinguish teaching AI from teaching other technologies [5]. It is crucial to examine how teachers tackle the challenges they face when they are engaged in teaching AI to contribute to this effort.

Design frames are regarded as a resource that could help teachers explore effective methods to tackle the challenges they face in teaching AI courses. Existing research reveals teachers' efforts to explore appropriate pedagogies for teaching technology education through the TPACK framework [6]. TPACK is regarded as practical knowledge created through teachers' design reasoning, interpreted as design frames [7]. Teachers could use design frames to bridge their current and new practices for supporting instructional design. For instance, they may analyze their current practices to identify problems, design new teaching practices with technologies, refine their pedagogical content knowledge, and transform contextual limitations into opportunities [8]. With these design frames, teachers could continually compare decisions and outcomes in practice as they formulate new pedagogical solutions to achieve their teaching objectives [7]. Nevertheless, how teachers approach the design of AI lessons is relatively unexplored.

What is needed for teachers to teach AI effectively is still poorly understood. As an emerging subject, it is not yet known what the AI formal instructional planning approaches are [2]. As a result, teachers' emerging experience is regarded as one resource that could help researchers explore the effective instructional design approach in teaching the emerging subject of technology (e.g., AI). Fahrman et al. indicated that teachers' exploration of uncertainty plays a key role in shaping their subsequent teaching, consistent with Dixon et al., who examined how teachers' perceptions from emerging experience led to the formulation of effective strategies for supporting teaching [9,10]. Therefore, the approach of studying emerging experience may be helpful for addressing the poor understanding of what the effective strategies are to overcome teaching barriers in AI education. Given the current research and the gaps in understanding how teachers experience the teaching of AI, it is worth exploring the emerging experience based on design frames to inform how effective instructional design can be applied in teaching AI. Thus, this study aimed to characterize design frames related to teachers' perceptions from emerging experience to explore an effective design approach to teaching AI.

2. Literature Review

2.1. Teachers' Design Experience of Technology Education

Previous research revealed that teachers' design experience of technology education might be helpful for designing effective instruction to overcome teaching barriers [9–11]. The existing effective design experience of technology education includes problem-based learning, cooperative learning, and task-driven learning, which focus on students' ability to master basic information knowledge and skills [12,13]. Dagli and Tokmak explored computer science teachers' design experience (i.e., analytical discussion, posing alternatives, and cooperative learning) to help students promote successful computer programming by mastering the necessary computational thinking skills rather than only memorizing the programming syntax [12]. Lin et al. noted the importance of teachers' design experience (i.e., TESI framework) in flexibly adjusting the complexity level of learning tasks to achieve the curriculum goals related to technology-embedded organizing, managing, supporting, scheduling, implementation, and exploration [13].

As teaching AI is an emerging area of technology education, Haldorai et al. suggested that the experience of teaching AI can be considered a further expansion of the experience of teaching technology [5]. Thus, teachers may transfer their experience of teaching technology to teaching AI directly, which would lead to new and formidable challenges for technology teachers when they participate in AI curriculum design. On the one hand, design difficulties represent that the past or existing design of technology courses is insufficient to support the current AI curriculum design. On the other hand, Lindner and Romeike revealed that in-service AI teachers pay more attention to the value of sociocultural and technical knowledge, which may form existing routines in their AI teaching practice [14]. Koh et al.

suggested that in-service teachers' existing routines remain strong, resulting in surface-level pedagogical change [8]. The surface transformation may lead to difficulties in addressing the nonroutine and complex problems in the emerging field of AI teaching. Accordingly, it may still be necessary to explore how to meet the needs of AI education rather than merely transforming teachers' experiences of teaching technology into teaching AI. Furthermore, Chai et al. indicated that social good (e.g., using AI to offer meaningful solutions to social problems) and the usefulness of AI might predict students' intention to learn AI [15]. The above studies indicated that it is necessary for teachers to foster students' perceptions of the usefulness of AI before promoting their willingness to learn more about it. This finding may contradict Lin et al., who suggested that it is critical for teachers to equip students with technical knowledge before applying it [13]. As previous studies have shown contradictory findings regarding the most important points regarding how to teach AI well, there is an urgent need to explore how to help teachers improve their AI teaching practice [2].

2.2. Design Frames from Teachers' Perspectives

Design frames are defined as teachers' approaches to designing reasoning and designing decisions that help them formulate and evaluate new pedagogical solutions for instructional goals or design problems [7,8]. Previous researchers have pointed out several kinds of design frames from teachers' perspectives regarding innovative lesson design, such as pedagogical frames, knowledge-based design frames, process-based design frames, contextual design frames, idea development frames, perception frames, enactment frames, and institutional frames [7,8,16]. It has been investigated how to teach effectively with the support of design frames [7,13,17].

Design frames have increasingly become crucial in technology education to help teachers solve ill-defined and nonroutine teaching problems. For example, the idea development, pedagogical approach, knowledge-based design, and perception frames may subsequently improve teachers' pedagogical content knowledge and innovative lesson design of emerging materials and unacquainted circumstances. Lin et al. proposed the contextual, interactive, and visual framework to help tutors focus on the professional developmental trajectory of healthcare training when dealing with emerging technologies in COVID-19 context [16]. Saeli et al. extended the frame of pedagogical content knowledge to programming when redesigning material for teaching computer science [17]. In line with their study, Štuikys et al. employed the technology pedagogy and content knowledge framework in teaching programming with model-driven processes and tools for robot-based generative learning [18]. Their study suggested that design frameworks (e.g., technology pedagogy and content knowledge framework) can be applied as a reproducible teaching approach for teaching technology and the teaching AI process.

2.3. Sustainable AI Models from Appropriate Design in E-Education

As teaching AI is an important area of teaching technology, frameworks have the potential to be the kind of design frames that teachers could adopt in AI education. Previous studies have used design frames to create a generally recognized AI curriculum. For instance, Chiu and Chai extended the self-determination theory with four curriculum planning design frames for AI educational content, product, process, and praxis from AI teachers' perceptions of curriculum design [2]. They pointed out that experienced teachers could update AI instruction with the community to transform their emerging teaching experiences into effective ones. Furthermore, the previous study also emphasized the importance of analyzing the teaching experience regarding implementation methods, teaching activities, and practices to play a supporting role in a generally recognized AI curriculum [19]. For example, several previous studies have reported the potential of using AI models for helping teachers design AI educational activities [20], address obstacles in the teaching AI implementation [21], employ project-based teaching AI practice [22], and enhance teachers' knowledge of teaching AI [23]. To sum up, existing research evidence mainly focuses on the linkage of AI models in education from the perspective of AI material and curricula rather than identifying teachers with an effective AI model of teaching AI well. Thus, researchers have emphasized the need to enhance the linkage of AI models and a suitable framework that can be implemented as a reproducible teaching approach for teachers' professional development.

However, it is unclear what kind of design frames are the most beneficial for professional development in the AI teaching process. In other words, there is a lack of research on teachers' design knowledge of teaching AI to develop the linkage of AI models in education to provide effective teaching AI frameworks for improving their preparation and professional development [4]. Therefore, this study investigated an effective approach to teaching AI related to the perspective of design frames according to teachers' experiences with a helpful research methodology. The qualitative approach has been referred to as a useful research methodology to learn participants' experiences and to form theoretical frameworks [24]. A qualitative study was conducted on teaching computer science by Nakajima and Goode through analyzing computer science teachers' design experience with interviews to improve their pedagogical knowledge and classroom practices [25]. Grounded theory, a qualitative approach, could generate a theory regarding behavior patterns [26]. Due to the capacity of grounded theory to understand teachers' design experience in depth without tightly defining the scope of study in the initial research, it is wise to select grounded theory for gaining in-service AI teachers' design experience.

2.4. Research Question

One important challenge in teaching AI is the lack of effective design experience from teachers' perspectives to link AI models in professional development. Although there is an urgent need to research how to teach AI well from teachers' perspectives, more recent evidence has focused on K-12 AI material and curricula [20–23,27]. To the best of our knowledge, few studies have considered effective approaches to teaching AI from the perspective of design frames based on teachers' experiences. To fill this research gap and to provide some suggestions for teaching AI, this study used grounded theory to explore AI instructional design that encompasses effective design frames for guiding teachers' AI teaching. In this regard, the current research is one of the pioneering studies revealing the linkage of AI models in education from the perspective of teaching AI practitioner notes. Grounded theory was used with the aim to broaden the current understanding of how to teach AI well and to answer the following research question: How do teachers perceive teaching AI from their emerging experience?

3. Method

Grounded theory, which aims to generate theories from data, enables researchers to form and evolve a series of relationships into a theoretical framework [28]. Through the three types of coding (i.e., open, axial, and selective), the nonlinear and iterative processes of data collection, coding, and analysis were performed throughout the study [29].

3.1. Context and Participants of the Study

This study explored teachers' experiences of teaching AI. Eighteen experienced AI teachers were carefully selected from K-12 schools of southern China, where AI education is well developed. These teachers were all enrolled in a 2019 Ministry of Education program designed to facilitate the development of AI teachers. They have designed lessons in response to the initiative to teach AI in K-12 schools. All these teachers were trained in teaching technology for at least 12 years, ranging from 12 to 26 years, highlighting their good command of educational technology. Among them, 15 teachers (83.3%) had taught AI for 2 or more years. These selected participants were the core members of the AI teaching community in their region or schools, and they were identified as teachers with professional capital who were leading their AI teaching communities.

3.2. Data Collection

This study explored teachers' experiences of teaching AI using multiple methods including semi-structured interviews, action study, classroom observation, and post-lesson discussion. The data collection lasted almost 1 year (October 2020 to September 2021), comprising three main rounds, as illustrated in Figure 1.

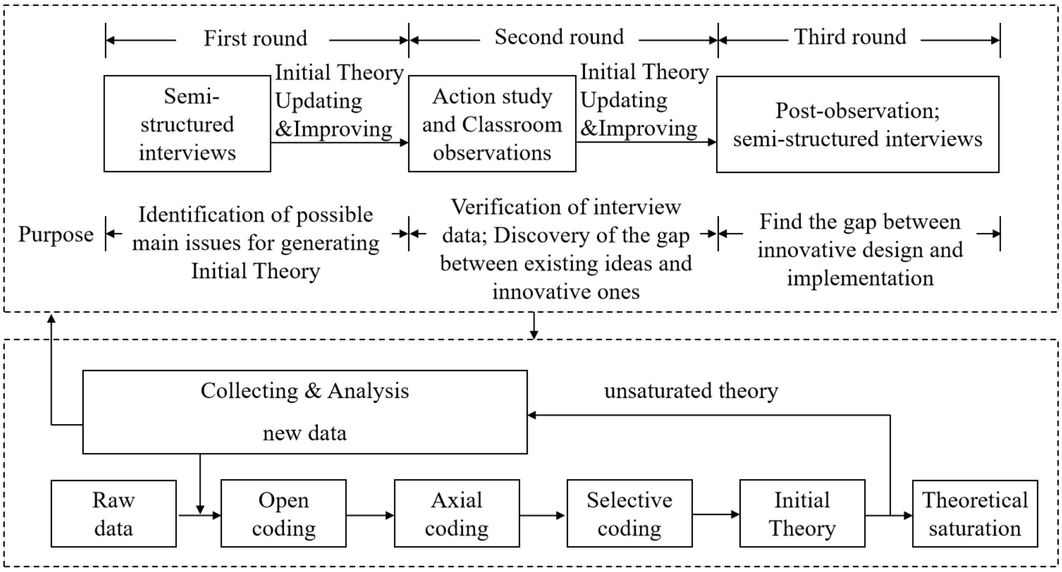

Figure 1. Details of the three-round data collection process.

The first round of semi-structured interviews collected teachers' perceptions of AI instructional design to generate the initial theory. The interviewers were trained to adjust the specific issues according to the actual situations for obtaining comprehensive and sufficient information. The interviews, conducted in the participants' native language (Chinese), were recorded and transcribed verbatim for subsequent analysis. The initial questions in the semi-structured interviews were organized by two experts who had extensive experience of teaching AI. In addition to demographic questions such as their professional background, initial interview questions included the following:

1. What comes to mind when you think about your AI teaching experiences? What are the most important processes in your AI instructional design? What are your teaching objectives when designing these methods? How are they formulated? How do you assess students' learning effects in the AI teaching process? How do you improve the teaching effect of your AI teaching experiences?
2. What knowledge do you need to prepare when designing AI lessons? How do you decide the objectives of teaching AI? What are the important contents for you when teaching AI?
3. What are your concerns about teaching AI? Are there any obstacles in the AI teaching process? How do you address them? What are your concerns about teaching AI?
4. What are the differences between teaching AI and other technology? What do you value when you are teaching AI? What is the important value orientation for you when teaching AI compared to teaching other technology disciplines? How do you teach AI when considering its value?

In the second stage of the research, nine AI teachers took part in the action study and classroom observation for professional development over 4 months.

The unsaturated initial theory garnered from the second round was then tested in the post-lesson discussion and semi-structured interviews with the remaining participants to analyze whether this abstract initial theory fit well with all the interviewees. In addition, on the basis of the feedback in this round, we could further clarify the relationships and functions of different teaching AI classifications for overall structural improvement, rather than a separation process. We continuously improved the theoretical unsaturation after finding the gap between innovative design and implementation. Accordingly, this three-round process was updated constantly until a temporary transition from theoretical unsaturation to theoretical saturation was achieved.

3.3. Data Analysis

On the basis of grounded theory, data analysis could be deductive. First, open coding was conducted. During the open coding process, the transcripts of all meaningful units were noted, such as teachers' perceptions, experience, attitudes, methods of teaching AI, class organization, adapting class materials, and teaching beliefs. We iteratively read the entire transcripts. Then, through constant comparison, the data were divided into incidents for initial categorization. Because of its inductive nature, grounded theory allows researchers to incorporate new data (e.g., follow-up interviews) as new ideas emerge. As long as new data were included, open-ended exploration continued. Second, axial coding was carried out to narrow the results of the open coding by identifying the relationships between concepts and categories [30]. Once the core categories were refined by searching for core values, the ideas in axial coding could be extended and consolidated to selective coding [28]. Consequently, we identified components from selective codes as effective design frames. Third, selective coding aimed to consolidate the ideas in the axial coding through their core values. These selective codes were viewed as the important component identified as effective design frames in this study.

3.4. Validity and Reliability

We devised a strategy of triangulation to enhance validity and reliability. The reliability and validity inspection processes were divided into three steps. First, three experts in education and AI were invited to evaluate our interview outline in the collection process for communicative validity checking, thus revising the hypothesized theories and completing three rounds of modifications during the analysis process. Following this, the interview data were coded independently. Furthermore, the percentage of the agreement was checked through cross-checking. After these processes, the percentages were increased from 81% to 86%. Third, to maintain distance for objective analysis, triangulation was conducted through different sources of evidence with semi-structured interviews, action study, classroom observation, post-lesson discussions, and other events or phenomena that reflected how teachers teach AI. Therefore, using different perceptions for data interpretation in triangulation, the validation could satisfy the requirement for further analysis and the next data collection method. On the basis of the feedback received from these three steps, validation could be performed to avoid subjective intervention and potential bias with the alternative data collection and analysis process.

4. Results and Discussion

In order to answer the research questions regarding how teachers perceive teaching AI, this study explored the perspectives of design frames from teachers' emerging experiences. Thus, the final version of 116 meaningful units was retained on the basis of a grounded theory process regarding teachers' emerging experiences.

It was categorized into 32 open codes concerning AI teachers' effective AI instructional design experience. Then, these 32 open codes were organized into 13 axial codes to explain experienced AI teachers' approaches to teaching AI. The result of the final five selective codes answered the research question, i.e., (a) obstacles to and facilitators of participation in teaching AI, (b) interactive design thinking processes, (c) teachers' knowledge of teaching AI, (d) orienteering AI knowledge for social good, and (e) the holistic understanding of teaching AI. As a result, the suitable design approach to teaching AI was developed according to these five selective codes to help us recognize productive insights into teachers' evolving understanding of teaching AI (see Figure 2).

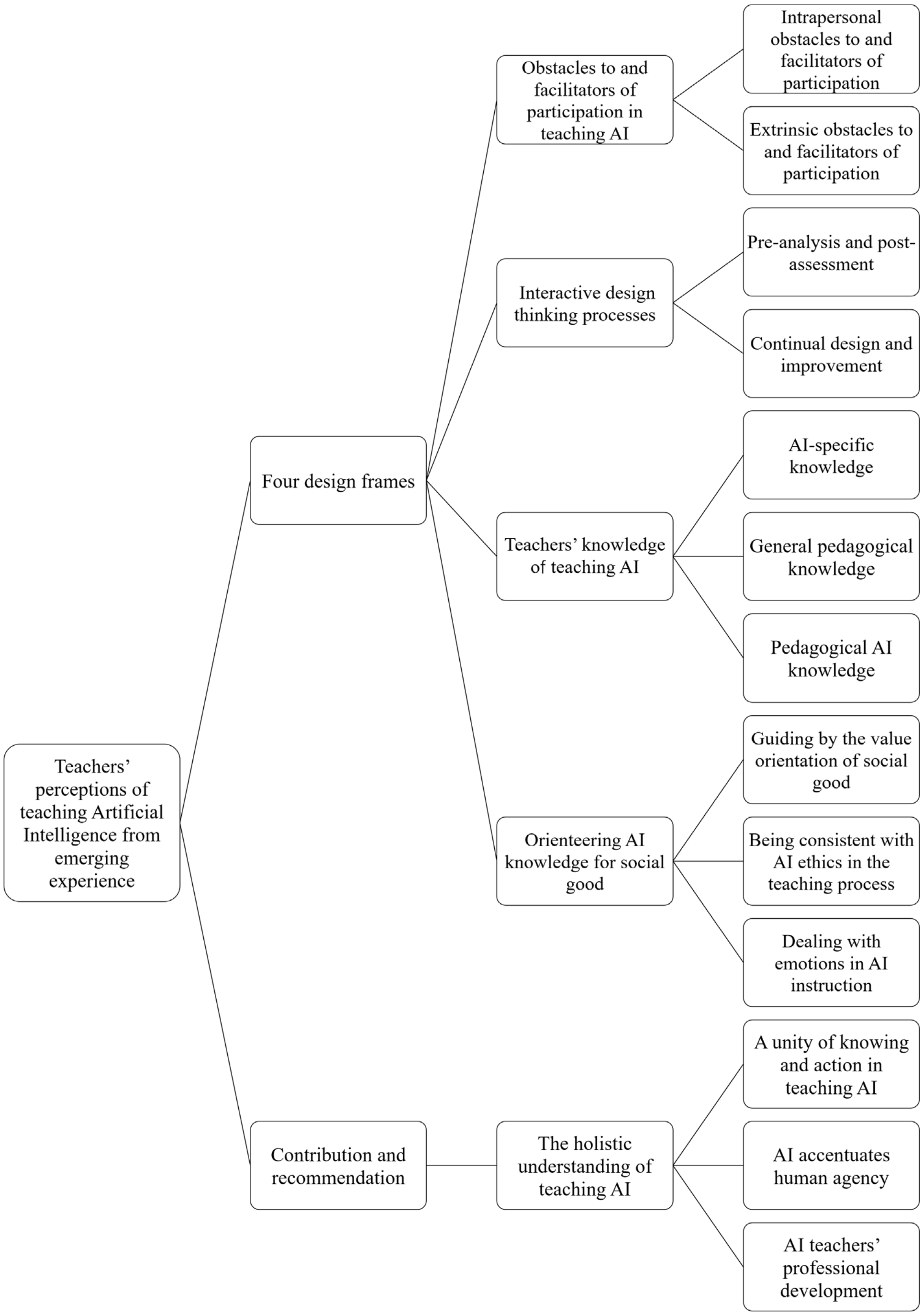

Figure 2. The teachers' perceptions of teaching artificial intelligence.

The obstacles and promotion factors encountered by teachers during the teaching process would encourage them to continuously optimize their AI teaching (i.e., the interactive design frame process). At the same time, the significance of teachers' cognitive social good orientation to AI teaching would also accelerate their integration of social good into all aspects of the design framework process (i.e., pre-analysis and post-assessment to achieve teaching objectives, as well as continuous design and improvement for renewal of AI instructional design). Teachers constantly learn new AI teaching techniques due to this process. In addition to AI-specific knowledge, general pedagogical knowledge, and pedagogical AI knowledge, teaching knowledge includes orienteering AI knowledge for social good. Hence, this study contributes to research on teaching AI by proposing five empirical implications, one theoretical contribution, and one practical recommendation.

4.1. Design Frame 1: Obstacles to and Facilitators of Participation in Teaching AI

Obstacles to and facilitators of participation in teaching AI were identified as the remarkable factors of teachers' further participation in teaching AI that they perceived when engaging in the teaching process. This study indicates how AI teachers are concerned about teaching AI. Some obstacles which affected their further participation in AI teaching were identified in the teaching process, including both intrapersonal (i.e., beliefs about teaching AI and AI technology) and extrinsic (i.e., the great need for AI resources and organization support) obstacles. To further engage in teaching AI practices, teachers have tried to address these obstacles with the facilitators they perceived. This selective code could be split into two axial codes on the basis of intrapersonal and extrinsic environmental factors of teaching AI.

Axial code 1: Intrapersonal obstacles to and facilitators of participation

In the literature, intrapersonal obstacles to and facilitators of participation usually refer to the various obstacles and facilitators perceived by AI teachers and how they influence their teaching. Participants indicated that two open codes influenced them: Intrapersonal facilitators of teaching AI well and intrapersonal obstacles which cause challenges in their AI instruction.

T13: "It is hoped that we could provide hope and development prospects to students in high school. Furthermore, students could have a good foundation for their future study in AI" (i.e., intrapersonal facilitators).

T7: "Teachers should change their roles. They are not the people with the most knowledge. Teachers should learn with students modestly, rather than feel superior to students" (i.e., intrapersonal obstacles).

Axial code 2: Extrinsic obstacles to and facilitators of participation

The extrinsic obstacles to and facilitators of participation are the teachers' perceived obstacles and facilitators in the teaching AI condition, such as the physical environment, software, and school resources. This axial code could be divided into two open codes: extrinsic facilitators of incorporating resources to participate in teaching AI, and extrinsic obstacles in the school environment to participation in teaching AI. As an emerging subject, AI is undergoing rapid technological development, which requires a wide range of knowledge, profound theory, and far-reaching applications. AI teachers are concerned about the extrinsic obstacles of the environment (e.g., equipment) when teaching AI. Moreover, they also attach importance to being equipped with the technological software and resources needed to facilitate AI teaching.

T4: "It will be easier for the teachers to conduct an AI curriculum after preparing the software and resources (e.g., a teaching tool that deconstructs principles of natural language recognition) well. For example, the teacher (T10) indicated that students who utilized an ordinary camera outperformed those who used an AI camera to improve their learning achievements in learning natural language recognition because they could encourage students to participate in thinking about how to use the ordinary camera to detect and analyze data" (i.e., extrinsic facilitators of incorporating resources).

T10: "There is a great need for equipment (master control devices for artificial intelligence) for teachers and students. If we cannot provide each student with this equipment, teaching AI in large-scale classes might be difficult. On the other hand, some experimental or public schools attach importance to preparing this equipment with a computer; therefore, the students could learn. However, preparing this equipment will be very costly" (i.e., extrinsic obstacles of the school environment).

4.2. Design Frame 2: Interactive Design Thinking Process

The interactive design thinking process can be described as the most important effective AI teaching experience process. Participants highlighted the importance of AI teaching processes, which connect the effects of implantation to teaching objectives. Research has tended to focus on the combination of AI-based functionalities and the design thinking process for providing a human-centered approach to promoting learners' problem solving, value creation, and creativity [31]. This combination is because design thinking plays a positive role in facilitating conceptual cognition of AI learning (e.g., relational conjunctions and AI concept classification) and learning AI attitudes (e.g., AI input and processing) [32]. From the above analysis point of view, two axial codes were identified: pre-analysis and post-assessment to achieve teaching objectives, as well as continual design and improvement for renewing AI instructional design. Teachers refined the preparational design process to a dynamic interactive design thinking process, including analysis, assessment, design, and improvement in AI teaching.

Axial code 1: Pre-analysis and post-assessment

This axial code, encompassing pre-analysis and post-assessment, delimits the problem space between students' learning performance and the teaching objectives. The AI teachers were concerned about incorporating analysis and assessment in the teaching process. For example, if teachers made analytical errors regarding teaching AI to achieve the curriculum standards teaching objectives, they would ignore giving positive assessment and interactive feedback to students. Therefore, they might focus on achieving the test objectives required by competition and course standards, which would be detrimental to students' sustainable development through interactive feedback. This analysis of teaching objectives as promoting students' achievement scores might lead to the obstacle that schools frequently administer an excessive number of tests or memorizing tasks, which concurred with the similar problem of pursuing examination scores in the context of traditional standard examinations. This analysis supports the consequence of AI teachers' concerns about neglecting to incorporate analysis and assessment in the teaching AI process and providing inaccurate goal analysis.

T12: "The main objective of teaching AI in large classes is to attain high scores in competitions, rather than to promote students' learning interest."

T3: "Teaching Python (i.e., a kind of AI algorithm) is to help students gain good scores on the exam."

T9: "One of the main issues in the teaching process is that teachers regard that they have achieved the objective of the teaching task as soon as they finish the 90 min lecture without assessment, meaning that they do not care whether the students understand the knowledge."

Moreover, the AI teachers expressed that pre-analysis and post-assessment constituted an integration pathway for effectively achieving teaching objectives to address the obstacle of incorporating analysis and assessment in the teaching process. This is in good agreement with the backward design approach, which suggests that teaching should begin with desired outcomes followed by the reflection of assessments [33]. In other words, once the teachers have analyzed the desired objective, they should assess whether it is possible to achieve the corresponding outcomes by matching teaching activities to objectives. With this backward design process in mind, the pre-analysis and post-assessment could be extended as a cycle in this study's interactive design thinking process. This cycle revealed three open codes: analyzing and assessing the teaching objectives and current performance, examining the effectiveness of AI instructional design, and assessing students' learning performance.

T13: "I analyze the teaching objectives by helping students learn the knowledge and appearance of specific knowledge regarding tracking faces. To achieve the teaching objectives, I use formative rubrics to assess the gap between students' existing knowledge and the teaching objective regarding knowledge and appearance . . . I can assess students' face tracking project performance to identify if their hands-on skills achieved the teaching objective of learning knowledge and appearance regarding tracking faces" (i.e., analyzing and assessing the teaching objectives and current performance).

T16: "You are supposed to find a good point that is interesting for students to enhance AI instruction effectiveness. The inquiry and discussion should start from a simple point, and then inspire the students and improve the complexity step by step until real artificial intelligence is achieved" (i.e., examining the effectiveness of AI instructional design).

T7: "We assess the project outcomes and students' performances by using formative rubrics" (i.e., assessing students' learning performance).

Axial code 2: Continual design and improvement

This axial code was identified as a continual innovative process, including designing, implementing, and modifying teaching AI. After teachers create their instructional plans, they may pursue better instructional design by comparing the gap between the implementation results and the plan. In practice, they are aware of a strong need for an interactive design and improvement to achieve their teaching objectives. As an emerging discipline, there is still a need for AI teachers to adjust their AI instructional design and improvement to achieve better teaching effectiveness by engaging in a cycle of design–improvement–design. The effective design–improvement process related to AI instruction focuses on planning the AI teaching intervention with motivational objectives, as well as improving the original AI instructional design by identifying students' AI learning problems in practice to address the gap between AI teachers' teaching objectives and students' learning performance. Accordingly, in the improvement–design process, AI teachers could improve the practiced AI instruction with the help of the teaching community and experts to generate a reproducible teaching AI approach. AI teachers could redesign their AI instruction in this cycle to achieve better teaching effects. These findings are consistent with those of Koh et al., whose study found that it is crucial to conduct design framing involving creation (i.e., design), development (i.e., improvement), and recreation (i.e., redesign) in the reflection-in-action process [8]. The continual design and improvement could be divided into three AI open codes: continual design and improvement for renewal of AI instructional design, designing the teaching AI strategy to achieve the teaching objective, and improving the teaching effect.

T5: "I design group cooperation inquiry activities to provide the students with a preliminary conceptual understanding of face recognition. Moreover, I improve the teaching effect with an excellent case review session to deepen the students' understanding of face recognition" (i.e., continual design and improvement for renewal of AI instructional design).

T15: "Teachers have designed the application context with easy-to-use training activities (e.g., using the tool (i.e., Uknow) for taking photos and training models) to help students perceive the entire AI learning process. Therefore, students can experience the magic of AI and be willing to pay more attention to learning AI" (i.e., designing the teaching AI strategy to achieve the teaching objective).

Our results further highlight the interactive design thinking process for teaching AI. This process ensures that teachers can have the capacity to teach better through continuous design and improvement. The finding concurs with Hsieh and Tsai, who also found that teachers implemented their instructional design thinking plans to teach effectively for mobile learning [34]. Williams et al. designed an AI platform called PopBots to assess learners interactively. However, their calculation only referred to the specific area of young children [35]. In contrast to Williams et al., this study found a way to evaluate and reflect the performance of an AI project and to conduct classes efficiently from teachers' perspectives [35]. In contrast to Geng et al.'s finding that teachers employ design thinking in teaching to address the barrier of resource shortages, beliefs, and redesign of curricula, our results suggest training teachers on AI contextual problem design to help them deal with teaching problems such as solving conflicts peacefully [17].

4.3. Design Frame 3: Teachers' Knowledge of Teaching AI

Teachers' knowledge of teaching AI demonstrates an understanding of the knowledge required to conduct effective AI instruction. To design effective AI instruction, AI teachers expressed that they need to have a knowledge framework for teaching AI in three axial codes: AI-specific knowledge, general pedagogical knowledge, and pedagogical AI knowledge.

Axial code 1: AI-specific knowledge

This axial code is described as the specific knowledge of AI subject matter. As a technological subject, the teachers expressed that the AI curriculum (e.g., content) and existing technology might not be separable [2]. They described the distinctions between AI-specific and general technological knowledge and also highlighted the crucial role of teaching AI-specific knowledge in AI education compared with general technological knowledge. There were three open codes in AI-specific knowledge: programming transactions (e.g., scratch, programming, algorithms, and robots), intelligent perception, and intelligent decision making.

T3: "I use an intelligence system for rice breeding that helps students understand how to use AI for decision making because it can give a certain breeding plan after inputting the data and question" (i.e., intelligent decision making).

T8: "One of my students who won a national AI competition started learning visual programming in the second grade" (i.e., programming transactions).

Axial code 2: General pedagogical knowledge

General pedagogical knowledge is defined as teachers' knowledge of student learning issues and methods for teaching AI and other subjects. This axial code was subdivided into two open codes: knowledge of the project-based learning method and knowledge of the group learning method. With the purpose of helping students achieve AI teaching objectives, teachers need to master the knowledge of the project-based learning method for teaching AI. It is a vital issue for the teacher to teach AI appropriately by obtaining knowledge of the group learning method, which includes four perspectives of knowledge: (a) the knowledge of how to group students from different knowledge backgrounds and interests, (b) the knowledge of guiding the group-based students to accept or reject team members' advice with reason in the AI works' design, implementation, and modification process until tangible works have been produced, (c) the knowledge of leading students to intuitively experience the pleasure of group success, and (d) the knowledge of improving students' confidence in solving complex problems regarding AI robots, among other topics.

T1: "There are some general teaching methods in the AI teaching process. For example, group discussions and autonomous cooperative activities teach general knowledge in AI courses. The group discussion-based autonomous cooperative activity can be used to teach any subject because it does not have its unique model" (i.e., knowledge of the group learning method).

T8: "We can conduct project-based learning to popularize AI courses, such as establishing a smart home system, investigating the application of intelligent systems, or exploring unmanned driving in AI manufacturers" (i.e., knowledge of the project-based learning method).

Axial code 3: Pedagogical AI knowledge

Pedagogical AI knowledge is described as transformative knowledge that AI teachers use to teach AI content. This axial code was gradually formed when teachers drew upon their pedagogical knowledge and AI-specific knowledge to develop AI-specific teaching strategies in the teaching process. This kind of pedagogical content knowledge has the potential to help teachers represent the subject to meet students' different learning requirements [18]. This finding offers powerful evidence that AI teachers need to obtain pedagogical AI knowledge to support effective knowledge for AI teaching objectives. The experience of the teachers interviewed could be summarized in three different open codes of pedagogical AI knowledge: adopting an "experience–experiment–application" approach to gradually teach computational thinking, incorporating social dilemmas into the discussion related to AI, and examining the similarities and differences between humans and AI. AI teachers should have enough relevant knowledge about incorporating the experience–experiment–application approach to teach computational thinking gradually. The pedagogical AI knowledge of incorporating social dilemmas into the discussion related to AI means that AI teachers should engage in AI instructional design to help students learn AI for social good. AI teachers should use pedagogical AI knowledge to draw upon the existing AI-related knowledge of pedagogy and content for classifying the similarities and differences between humans and AI. It is helpful for teachers to teach two AI examining aspects: similarities and differences. AI teachers identified that AI might take humans' jobs because of the similarities, while also expressing the differences between humans and AI (e.g., emotion, outpouring, and creating).

T1: "It is not suitable to adopt a task-driven AI pedagogy. Teachers need to help students understand, practice, and apply AI in an experiment. Therefore, students should know where this technology is used in other areas. Then, the teacher can ask students to think about in what areas they could apply AI in the future. The teaching mentioned above involves experience, experiment, and application" (i.e., based on "experience–experiment–application" approach to gradually teach computational thinking).

T10: "I will give time and space for students to express, rather than evaluating whether their opinions are correct in the discussion regarding the dilemma of AI autonomous driving" (i.e., incorporating social dilemmas into the discussion related to AI).

T6: "The Xiaobing app (i.e., an AI app that can write poetry) can help students understand the words and procedure of writing poetry. However, it cannot write poetry using emotion, outpouring, or creating. We believe that, rather than using AI, it might be more useful to guide students to know how to write poetry with AI to touch the human soul and emotion using AI" (i.e., examining the similarities and differences between humans and AI).

The emerging understanding from experienced teachers demonstrated how important pedagogical AI knowledge is in teaching AI. In teaching practice, such teachers' knowledge requires a deep understanding of pedagogical content knowledge. Teachers may create this new knowledge when applying existing pedagogical knowledge and content knowledge in specific teaching methods [8]. Therefore, if AI teachers lack this kind of framework of pedagogical content knowledge for teaching AI, they may feel confused when transforming their previous knowledge of teaching other subjects into new knowledge for teaching AI. This framework of teachers' knowledge for teaching AI can potentially interpret the main knowledge for teachers' teaching achievements in similar teaching technology contexts from emerging experience. Our results share similarities with Saeli et al.'s [18] findings. They highlighted the vital attribution of developing the framework of teachers' pedagogical content knowledge for teaching technology subjects (e.g., programming) to help teachers conduct instruction effectively.

Despite the current efforts in AI education, there is still a need to address the difficulties of hiring qualified and experienced teachers to teach AI. Computer science teachers (e.g., AI teachers) are sometimes trained from other subject areas or the computer science industry. Therefore, they may have sufficient pedagogical knowledge (PK) from their teaching experience or professional content knowledge (CK) from their working experience. However, using pedagogical knowledge or content knowledge separately could lead to barriers to becoming a teacher. Combining pedagogical knowledge and content knowledge is still lacking [11]. There has been some prior work on PK and CK of AI topics (e.g., programming). A previous study focused on the PCK of programming to evaluate teachers' knowledge [11]. The evidence of the current study may clarify what teachers need to know for teaching AI from the perspective of PCK. AI teachers need to be trained to enhance their PCK for meeting their professional development. These values of teachers' knowledge (e.g., PCK) correlate favorably with Koh and Chai, and they further support the idea that improving teachers' knowledge needs training of teachers' design practices and resolving the conflicting lesson design ideas [7]. Therefore, it is critical to note that there is still a need to support teachers in facilitating design ideas with knowledge building practices [8]. This is in good agreement with our findings regarding design frames in the process of selecting, reorganizing, and integrating experience. For instance, experienced teachers may form new AI-specific knowledge and pedagogical AI knowledge from their knowledge of AI in the design frame.

4.4. Design Frame 3: Orienteering AI Knowledge for Social Good

Orienteering AI knowledge for social good is described as something (e.g., a "good" or a belief) that benefits the largest number of people in the largest possible way when teaching AI. Teachers need to teach students to use AI for social good. AI teachers expressed their design experience regarding orienteering AI knowledge for social good in three axial codes: guiding by the value orientation of social good, being consistent with AI ethics in the teaching process, and dealing with emotions in AI instruction. AI teachers also highlighted the importance of social good in teaching AI, tending to engage students in the discussion of the pros and cons of AI in social issues.

Axial code 1: Guiding by the value orientation of social good

This axial code refers to the value objectives of teaching AI. The AI teachers perceived that they should cultivate the students' innovation ability according to the needs of society. This axial code was subdivided into two open codes of perceiving the social good of AI and the choice between the pros and cons of AI for social good. This axial code also indicates that making choices between the pros and cons of AI is increasingly becoming a vital factor in teaching AI.

T10: "In my opinion, the cultivation of students' innovation ability is in line with the needs of society" (i.e., perceiving the social good of AI).

T9: "I designed a dilemma, hoping that students could understand through discussion that, when we use AI, it is an integration of pros and cons" (i.e., the choice between the pros and cons of AI for social good).

T12: "We chose the dilemma caused by AI because human beings tend to seek self-benefits. There is a lack of social good for humans compared with animals (e.g., prisoner's dilemma)" (i.e., the choice between the pros and cons of AI for social good).

Axial code 2: Being consistent with AI ethics in the teaching process

In general terms, this axial code can be defined as addressing some things that AI cannot solve, such as AI ethical issues that need people to work with AI. This supports previous findings of Chiu and Chai, who indicated that inappropriate use of AI techniques and ethical issues might lead to educational difficulties [2]. In order to overcome such difficulties, teachers have the idea of avoiding social and moral problems in the teaching process, thus enabling a new perspective of AI ethics in the teaching process, organized as two open codes: recognizing ethical problems and following AI ethics.

T4: "I reckon the instruction of AI ethics plays an important role in the process of students using artificial intelligence in the future. AI ethics is the principle that we should follow when using artificial intelligence" (i.e., following AI ethics).

T7: "A surprising number of robots for education, nursing, and service may enter the industry of rehabilitating the elderly, patients, and children. We need to consider whether these interactions raise many ethical problems between humans and AI robots" (i.e., recognizing ethical problems).

Axial code 3: Dealing with emotions in AI instruction

This axial code indicates how teachers deal with emotion in the teaching process. From the AI teachers' viewpoint, dealing with emotions in AI instruction could be seen in terms of two open codes: psychological problems (e.g., powerlessness) and emotion control problems.

T14: "When I encourage students to innovate, I feel that I am always a little powerless" (i.e., psychological problems).

T18: "The problem of dealing with emotions in AI instruction has strongly challenged teachers because there is little teacher training focused on dealing with emotional issues generated by students and teachers in class" (i.e., emotion control problems).

The results are, to some extent, in line with those of Aoun, whose study demonstrated that teachers need to promote social justice and social needs that AI agents cannot implement by equipping students with human literacy [36]. Chai et al. emphasized the role of the specific AI belief that helps teachers show students how to use AI for social good to promote their intention to learn AI [15]. There is increasing evidence that adapting a social good orientation in teaching will ensure that AI will be utilized in a socially responsible way [37].

Although the above perspectives could offer the promising potential to address the common problems in AI education, there is still a need to understand the strong ethical concern regarding using AI for social good to equip students with an AI-powered future [38]. To understand this concern, this study pays attention to teaching AI through the emerging experience of teachers for social good. At the same time, we argue that orienteering AI knowledge for social good is vital for teaching AI from the teachers' perspectives. Moreover, this study proposes that teachers need to stimulate students' intention to learn AI by providing some authentic topics of using AI for social good. Teachers need to engage students in thinking and making decisions to balance the profit and concern of AI.

4.5. The Holistic Understanding of Teaching AI

Axial code 1: A unity of knowing and action in teaching AI

This axial code reveals that the experienced AI teachers exhibited a holistic understanding of teaching AI as a unity of knowing and action in practice. There were two open codes: the image of designers and knowledge mapping. The image of designers indicated that this kind of teachers' holistic understanding of teaching AI was fully manifested when they described the image used to describe teaching AI (e.g., I am a designer). The teachers are passionate about teaching AI as they may spend almost all of their spare time improving their teaching. In their spare time, they read a wide range of classical technological AI literature, design various AI teaching aids spontaneously, organize extracurricular activities for their students, and maintain relationships with AI practitioners. The image of knowledge mapping showed that the teachers borrowed the concept from traditional Chinese medicine (i.e., acupuncture) and presented an AI knowledge acupuncture point map in the AI lesson.

T17: "Whether teaching AI or learning about the frontiers of AI, I like it. It has become a way of life for me to think about the design of AI lessons. I have also designed various AI teaching aids spontaneously" (i.e., the image of designers).

T3: "When a student encounters an obstacle in learning AI or asks a question, I can immediately know the difficulty, just like finding a block in the nervous system. As I acupuncture the block (e.g., offering feedback), the student's intellectual nervous system is immediately activated, which results in a 'one-stop-shopping' effect" (i.e., the image of acupuncture).

Axial code 2: AI accentuates human agency

This axial code presents a holistic understanding of teaching AI to accentuate human agency with AI. The axial code shows that it is vital for AI teachers to consider the human–AI interaction for AI-accentuated human agency. They regarded the human–AI interaction as three open codes: collaborating with AI, AI as the expansion of human ability, and learning assisted by AI.

T3: "Teachers should design AI lessons to promote the thought that there is the possibility of cooperation between humans and AI in the realm of aesthetics" (i.e., collaborating with AI).

T12: "Manual data collection should be presented before computing to study the temperature of volcanoes, right? However, within AI, we tried to observe the camera and conduct automatic data processing. The two results turned out to be very similar" (i.e., AI as the expansion of human ability).

T6: "At the same time, we believe that the Xiaobing app guides students to write poetry. We guide students to write their first poetry assisted by AI" (i.e., learning assisted by AI).

Axial code 3: AI teachers' professional development

This axial code refers to a holistic understanding of the professional development activities recommended by experienced AI teachers, such as collaboration with colleagues when teaching AI. In this axial code, AI teachers applied their pedagogical design framework affected by the interpersonal contextual factors, which could be broken down into three open codes: sharing resources in the AI collaborative community (e.g., providing AI material packages in the teachers' training activities), discussing teaching experience (e.g., the discussion of design plans and teaching methods), and interdisciplinary cooperation (e.g., cooperating with teachers from other subjects such as big data, environment, finance, fine arts, film and television, and life science and technology).

T4: "The optimization of the teaching AI material packages would be an important part in the second half of teachers' training activities. These material packages could be brought back by the teacher to be used directly" (i.e., sharing resources).

T10: "I have discussed the teaching design plan of a demonstration class together with the experts many times" (i.e., discussing teaching experiences).

T8: "To help teachers optimize the design of teaching AI, our teaching community has had experts and professors from many disciplines, such as big data, environment, finance, fine arts, film and television, and life science and technology" (i.e., interdisciplinary cooperation).

The holistic understanding of teaching AI shows that the perception of teaching AI should be treated as a whole rather than as discrete pieces. It cannot be prevented simply by proposition or logic, separated from context, action, and direct experience as theoretical knowledge, or delivered by expression. On the one hand, it represents the teacher's ownership of the knowledge for teaching AI, which comes from the teacher's personal experience. Teachers should be present in the problems of teaching AI and participate in the problem-solving process of teaching to experience the ways and effects of their actions to gain new experience and gradually enrich their repertoire. It differs from theoretical knowledge, which needs little personal experience and can be obtained indirectly from reading, lectures, or training projects. On the other hand, individual teachers as subjects have different characteristics, life histories, experiences, and beliefs. Different teachers may express the same practical knowledge in different ways. Teachers usually exhibit their unique judgment, execution, and instructional intelligence when they address specific problems. These ideas lay the foundation for the holistic understanding of AI teachers' professional development in China. The holistic understanding of teaching AI in this study furthers the finding of Lindner et al. [14], who focused on revealing the general knowledge, educational goals, and challenges in the field of AI using a questionnaire survey. This study extends the existing teaching AI research a step further with grounded theory by pinpointing the genuine AI instructional design, which encompasses four effective design frames that guide teachers' actions of teaching AI.

5. Conclusions

In conclusion, this study supports the extension regarding the theoretical framework of three design frames (e.g., process-based, knowledge-based, and contextual design frames) of Koh et al. [8]. This study further promotes the above three design frames, which explain and update the norms of teachers' scientific teaching of AI. The norms include five important components: obstacles to and facilitators of participating in teaching AI, interactive design thinking processes, teachers' knowledge of teaching AI, guiding AI knowledge for social good, and the holistic understanding of teaching AI. As social good is generally understood to be a strong ethical concern regarding the use of AI to equip students with an AI-powered future, orienteering AI knowledge for social good is an indispensable part of AI education [38]. Therefore, the finding of this study suggests integrating AI knowledge for social good into the above three general design frames. For example, teachers may incorporate social dilemmas into the general discussion related to AI to help students understand the advantages and disadvantages of AI autonomous driving. More importantly, these design frames focus on the importance of teachers' mastery of teaching AI and emphasize that it is important to use AI to promote social good in the whole interactive design frame process. This can help improve the holistic understanding of the effective design norms of teaching AI, which has not been systematically highlighted in previous studies. This study may contribute to the development of AI educational direction by guiding the teaching AI insight from basic information knowledge and skills to the competency of solving practical problems by AI, including moral values of properly using AI (i.e., social good).

In addition, this study provides practical recommendations by proposing five stages for effective instructional design approaches to teaching AI from teachers' perspectives (see Figure 3). These five stages can help educators improve AI teacher preparation and professional development.

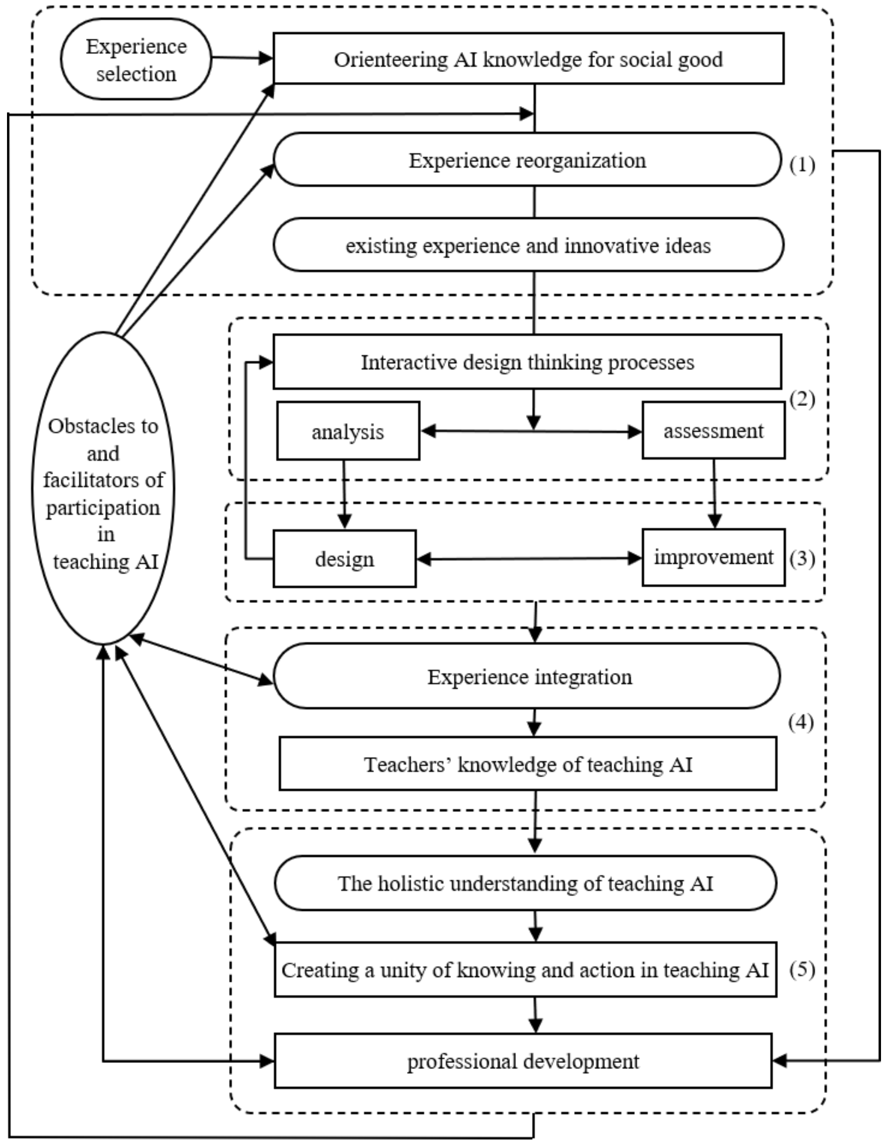

Figure 3. Design approaches based on teachers' perceptions of teaching AI from emerging experience.

(1) Experience selection and reorganization: This stage identifies and selects effective experiences and methods to address the present problems in the teaching problem context according to teachers' rich existing prototype (or descriptive) experiences. Guided by orienteering AI knowledge for social good, AI teachers tend to apply experience selection, which means that they should test and innovate on the characteristics of social benefit, authenticity, and usefulness when performing the next step of experience reorganization [39]. Additionally, experience reorganization is highlighted to help teachers identify the differences between existing experiences and innovative ideas. If AI teachers' experiences achieve the optimal level of teaching AI solutions, they may form a relatively balanced and stable new structure of teachers' AI teaching knowledge. However, with the constantly changing conditions and deeper understanding, AI teachers face emerging teaching difficulties. Teachers may be concerned about emerging difficulties when external conditions of teaching AI experience change reach a certain threshold. In that case, the equilibrium of teachers' knowledge of teaching AI could be destroyed. Therefore, AI teachers tend to produce a new balance of knowledge for teaching AI with experience absorption and function recombination. In other words, function recombination could be inherited with experience selection and reorganization to promote AI teaching.

(2) Pre-analysis and post-assessment: This stage focuses on transforming the teaching experience from its existing status through reflection on the experience. The reflection focuses on identifying the differences between innovative design outcomes and assessment of the desired teaching objectives. Analysis refers to examining clear objectives to enhance the students' learning effect according to the deep analysis of AI knowledge structure and students' learning readiness. Assessment refers to collecting evidence of students' learning effect on the AI curriculum for assessing students' learning results. Therefore, AI teachers could conduct project assessments of AI curriculum performance by providing positive feedback. Pre-analysis and post-assessment can be combined to delimit the gap between students' AI learning performance and the teaching objective.

(3) Continual design and improvement: The stage is designed to help AI teachers reflect on experience with the aim of identifying the gap between innovative designs and the improved implementation of the designs. Design means formulating the teaching AI strategy to achieve the teaching objective and learning progression (e.g., identifying difficulties and critical content). Improvement means improving instructional behaviors by reflection to adjust student-learning contexts for improving AI teaching effects by adjusting classroom behaviors. However, continual design and improvement cannot result in effective teaching if teachers apply these processes separately from pre-analysis and post-assessment. Thus, the interactive design thinking process is a critical part of the four components of design frames, including analysis, assessment, design, and improvement. The interactive design thinking process is becoming an increasingly vital factor in these four design frames because new emerging experience and practice can be created by focusing on analysis to clarify and judge the new practice of AI teaching.

(4) Experience integration and knowledge creation: In this stage, teachers' knowledge of teaching AI is a required design frame for knowledge creation in teaching AI. In order to promote teachers' knowledge creation of teaching AI, it is crucial to use a criterion where the interactive design thinking process can be applied successfully with sufficient pedagogical AI knowledge for the teachers to assess. This design frame also focuses on orienteering AI knowledge for social good to stimulate students' motivation to learn AI [38]. Orienteering AI knowledge for social good (e.g., following AI ethics) is more likely to be adopted in the interactive design thinking process for formulating the teaching AI strategy to achieve the teaching objective or to motivate students. Obstacles to and facilitators of participation in teaching AI are presented to clarify the significant differences between teaching AI and other technology disciplines. Incorporating obstacles to and facilitators of teaching AI into the interactive design thinking process can enable AI teachers to encounter the challenges of teaching AI rather than automating their existing design frame of teaching other technology disciplines to teach AI. This is a fundamental design frame for successfully implementing the AI instructional plan. The obstacles to and facilitators of participation in teaching AI are external influences beyond the interactive design thinking process. Teachers should manage the environmental variables in the AI instructional design process of enacting pedagogical AI knowledge and AI-specific knowledge. If the AI teachers could clarify the relationship between obstacles and facilitators to participation in teaching AI and other design frames, they might cultivate students' knowledge and ability. Another aspect is that these obstacles to and facilitators of participation in teaching AI help teachers realize that they need to orienteer AI knowledge for social good.

(5) The holistic understanding of teaching AI: In the design of professional development for AI teachers, they should be encouraged to form a holistic understanding of teaching AI as a unity of knowing and action in practice. Furthermore, teachers could achieve unity of knowing and action through the four-component interactive design thinking process. The relationships among these four components are illustrated below. The design should be built on analysis, and assessment should provide evidence for reflective improvement [40]. Additionally, the mutually beneficial relationship between design and reflective improvement should be highlighted. Meanwhile, analysis and assessment should be used to inform each other. According to the framework, analysis is the first step of AI lesson planning. On the basis of the analysis, teachers can design AI learning tasks to help students implement the instructional tasks and achieve the value of orientation for social good. During a class or after a class, teachers can obtain evidence of student learning and compare teaching effects and learning goals to assess the effect of AI instructional design and implementation. This formative assessment could provide evidence for identifying the differences between the design and implementation of AI instruction, and for improving teachers' instructional behaviors in class. Continual design and improvement also interact within a professional development cycle. Mentoring for the professional development of AI teachers involves many cyclic actions which can allow teachers to improve their designs and implementations of the next AI instruction.

6. Limitations and Future Directions

This study had limitations due to its small number of participants, limited scope, and exploratory nature. Firstly, one explicit limitation arises from the small number of participants involved in the case study, which is a common limitation of grounded theory research [26]. Secondly, although there are symbols of theoretical saturation, the study setting was in southern China and, thus, lacks teaching experience from other cultural backgrounds. We suggest that future research be conducted in other cultural settings. While this study proposed the development theory of teaching AI, more work is needed to investigate this problem, and to validate, enrich, and refine this approach. It can be extended by additional studies on other emerging subjects and curriculum innovations. Future research may clarify more nuanced understandings of teachers' experiences with AI, thus producing a more developed theory.

Author Contributions: Conceptualization, X.-F.L., S.P., Q.H., and J.L.; methodology, J.L., X.-F.L., X.C., S.X., and S.P.; software, J.L. and S.X.; validation, J.L.; resources, J.L. and S.X.; data curation, J.L. and X.-F.L.; writing—original draft preparation, J.L. and Q.H.; writing—review and editing, K.K.C., Q.H., S.P., L.C., and X.-F.L.; project administration, X.-F.L. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by The National Natural Science Foundation of China, grant number 62007010; the Major Project of National Social Science Fund of China, grant number 18ZDA334; The Science and Technology Projects in Guangzhou, grant number 202102021217; the 2021 Annual Education Planning Project of Guangdong Province, grant number 2021JKZQ022; the Philosophy and Social Science Project of Guangdong Province, grant number GD20CJY39; the South China Normal University "Challenge Cup" Golden Seed Cultivation Project, grant number 21JXKA08; the Special Funds of the Climbing Program regarding the Cultivation of Guangdong College Students' Scientific and Technological Innovation, grant number pdjh2022 b0145; and the Education Science Planning Project of Guangdong Province (Special Project for Higher Education) "Training of teachers for artificial intelligence education in K-12 stage in the era of artificial intelligence", grant number 2021GXJK625.

Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Academic ethics review committee of South China Normal University (protocol code IRB-SCNU-EIT-2021-016).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Not applicable.

Acknowledgments: We would like to thank Chai, Ching Sing, Wenyi Li, Zhong-Mei Liang, and Tsai Yu-Ling for their insightful contribution that helped shape this paper. The authors express their gratitude to the anonymous reviewers and editors for their helpful comments about this paper.

Conflicts of Interest: The authors declare no conflict of interest.

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