International Society of the Learning Sciences

Supporting STEAM Design Collaboration via Knowledge Building Principles in an Online Teacher Professional Development Course

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Abstract: This study investigates the effectiveness of a professional development course that integrates Knowledge Building (KB) principles into Design Thinking (DT) activities to empower and engage teachers in collaborative STEAM lesson design activities. The course aimed to equip teachers with the knowledge and skills necessary to develop effective STEAM lessons for fostering student agency. Results indicate that the course significantly improved teachers' design thinking mindset, perceived understanding and perceived importance of KB principles, and their competency to develop effective lesson prototypes aligned with KB principles. The findings suggest that integrating KB principles into DT processes can be a useful approach for teacher professional development, leading to more collaborative, innovative and effective teaching practices.

Introduction

Providing professional development opportunities and social support for teacher collaboration is essential in teacher learning (Fishman et al., 2014). While contemporary education reform asking teachers to prioritize student-centered learning and knowledge construction (Hmelo-Silver & Barrows, 2008; Li et al., 2020), many Taiwanese teachers still tend to employ teacher-centered methods focused on textbook materials. These challenges often hinder the development of student agency and creativity. To address this issue, we aim to create an online professional development environment to engage teachers in collaborative lesson design within the context of transdisciplinary STEAM (i.e., science, technology, engineering, arts, and math) education.

Effective lesson design is a crucial component of teacher professional development (Gravett & van der Merwe, 2023). Teachers skilled at designing innovative and engaging lessons can significantly enhance student learning outcomes. Recent studies have shown that Knowledge Building (KB) principles and Design Thinking (DT) processes are promising frameworks for fostering teachers' innovative teaching practices (Bereiter & Scardamalia, 2014; Lin et al., 2020). Given the emphasis on creation and design inherent in both frameworks, we argue that KB emphasizes collaborative knowledge creation, while DT highlights a human-centered design process. By integrating these two approaches, we expect teachers to enhance their design mindset for creating more engaging learning environments and innovative pedagogical approaches in their lesson plans

Theoretical background

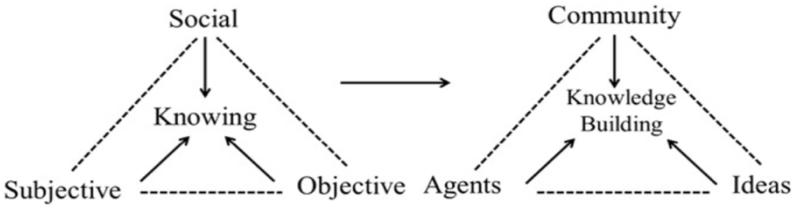
Knowledge building principles

Epistemically, there are three core entities for KB, including "agents", "ideas", and "community" (Lin et al., 2014). These entities correspond to the epistemic aspects: subjectivity (knowledge workers), objectivity (ideas), and sociality (community) (see Figure 1). Within this framework, knowledge workers are the active agents of inquiry, ideas serve as the building blocks of knowledge construction, and the community represents the social space where knowledge workers collaborate and ideas meet. These three dimensions function as an interconnected system where knowledge workers constantly refine ideas, driving collective knowledge work within the community.

To effectively mobilize the three epistemic entities for knowledge building, Scardamalia (2002) proposed 12 KB principles as pedagogical guidelines. These principles emphasize idea-centered activities and deep constructivism, replacing traditional knowledge acquisition methods. Research indicates that implementing these principles effectively leads to more adaptive and innovative teaching practices, fostering constructivist learning environments (Chen & Hong, 2016). However, adopting KB principles in practice takes time for teachers to reflect

on its nonlinear process with flexible uses in the classroom. This remains challenges for teacher educators to design proper professional development in a constructive approach. We therefore employ the design thinking process as a practical framework for more effective professional development (as elaborated below).

Figure 1
Relationship Between Three Essential Knowledge-Building Entities (Lin et al., 2014)



Design thinking

Design thinking emphasizes creativity and innovation with human-centered design processes. It employs brainstorming, experimentation, and iteration to designers' thinking processes, developing innovative solutions through collaboration, discussion, and sharing (Brown & Katz, 2011).

Design thinking has been widely used in course innovation in school to cultivate learners' critical skills such as creativity and problem-solving. For example, many studies show that fostering design thinking and design thinking mindsets effectively promotes students' creativity, collaboration, and communication skills (Sándorová et al., 2020), and enhances students' knowledge creation and complex problem-solving abilities (Lin et al., 2020; Ejsing-Duun et al., 2019). Furthermore, Wang (2024) pointed out that design thinking facilitates teaching innovation and interdisciplinary curriculum design among university teachers.

Framework and questions

The present study applies KB pedagogy principles and design thinking process to support teachers' professional development and to guide them in their STEAM (science, technology, engineering, art, mathematics) lesson design during the Knowledge Building Teacher Professional Development (KB-TPD) course. This study aims to enhance teachers' understanding and application of KB principles, foster their design thinking mindset and capacity, and ultimately transform them into knowledge workers in the field of education.

This study investigates the following research questions: (1) Do the prototype lessons created by teachers in this course better align with KB principles compared to model lesson plans designed based on Taiwan's national curriculum standards? (2) What are the effects of the KB-TPD course on teachers' design thinking mindset and their perceived understanding, importance, and feasibility of KB principles? (3) During the lesson design process, how do teachers engage collaboratively in the online knowledge building environment?

Method

Background

This jointly organized KB teacher professional development course (KB-TPD) was conducted online by several universities from Taiwan and the United States during October 2023 to December 2023. The 10-week course aimed to cultivate teachers' design-thinking mindset and deepen their understanding of KB principles for effective lesson design. A total of seventy-five teachers' participated. The present study only focused on analyzing forty-eight K-12 teachers who completed this KB-TPD training.

Teacher professional development (KB-TPD) course design

Figure 2 illustrates the conceptual structure of the KB Teacher Professional Development (KB-TPD) course. It outlines a multi-tiered approach to teacher professional development:

- *Theoretical Foundation*: This layer represents the three epistemic entities that undergird the course, including ideas, agents (knowledge workers), and community. Building on this foundation, we further suggest 7 design components to emphasize the importance of creating a context for students to play active roles as knowledge workers, setting a shared mission or goal for the class, and providing shared resources to support collective knowledge growth. Table 1 outlines all 7 design components, including

the role of students, learning outcomes, authentic context, community's top-level goal, shared resources, and tasks.

- *Principle-Based Guidance*: This layer provides a guiding framework for teachers to engage in effective lessons. It is guided by the 12 KB principles (see Scardamalia, 2002, for more detailed description of each principle), which offer practical guidelines for designing a KB lesson and for effective implementation of KB in the classroom.
- *Lesson Design Process*: This layer outlines the design thinking (DT) steps involved in lesson design. By starting with a lesson template, there were five cycles to allow teachers to empathize with learners' needs, define themes and topics, ideate and refine the design, prototype a final lesson design, and test the prototype (see Figure 3). The iterative process between lesson design template and lesson design prototype, guided by DT process, ensures that the final design is well-thought-out and aligns with the principles of KB.
- *Knowledge Forum Environment*: This layer highlights the role of KF technology as an online collaborative environment in supporting the KB-TPD course. The KF is a digital platform (see Figure 4) that can be used to facilitate collaborative knowledge building among participants. Figure 3 shows a screenshot of teacher discussion during KB-TPD. In each design cycle, participants were required to share and discuss the following prompts: (1) their understanding of KB principles; (2) their main lesson design ideas; (3) the current challenges they encounter in their lesson design.

Overall, the KB-TPD course integrates theoretical foundation, KB principles as guidelines, five DT processes, and KF environment, to equip teachers with the knowledge and skills necessary to design effective KB lessons.

Figure 2

The Conceptual Structure of the KB Teacher Professional Development (KB-TPD)

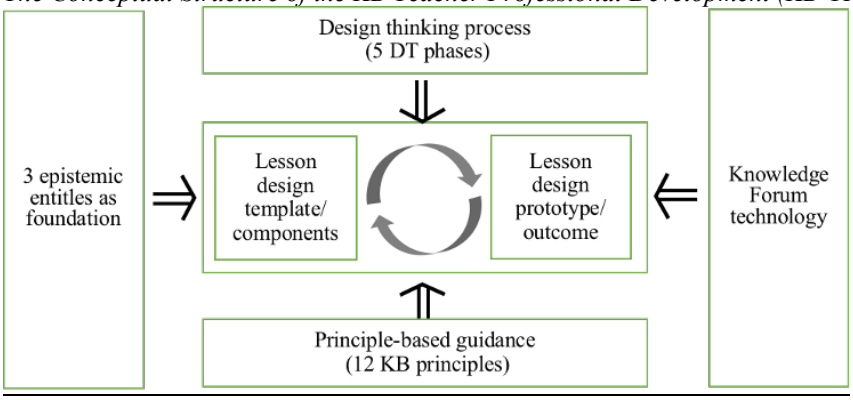


Table 1

Lesson Design Components Corresponding to the Epistemic Entities

Epistemic Framework	Design Components	Contextualization	Integrated
Subjectivity (Agents)	Knowledge worker role; expected outcomes	Describe the student's role, the types of knowledge workers involved, and the desired learning outcomes.	Design specific activities and tasks that contribute to the main objectives, ensuring sub-tasks align with the overall mission and the rise-above activity supports achieving the top-level goal.
Objectivity (Ideas)	Authentic context; mission to complete	Design a real-world context related to the SDGs, involving a collective mission for students.	
Sociality (Community)	Top-level goal; resources	Set a shared goal for the class and provide relevant resources to achieve it collectively.	

Figure 3
Five Cycles of Lesson Design Process in KB-TPD Course

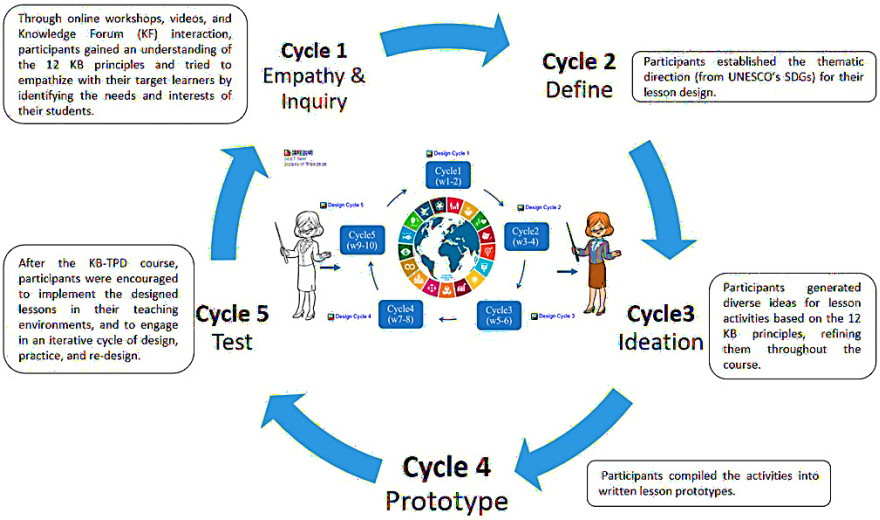
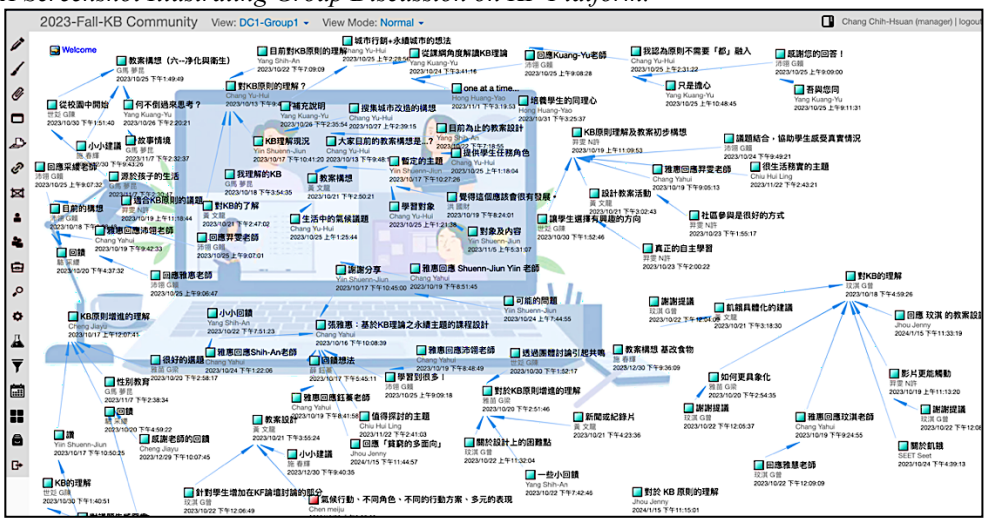


Figure 4
A Screenshot Illustrating Group Discussion on KF Platform.



Data collection and analysis

Lesson design prototype analysis

The 12 KB principles were employed as rubrics to evaluate lesson design outcomes/prototypes created by participants. Each principle was rated on a 5-point scale, with 5 indicating the closest alignment and 1 indicating the least alignment. For comparison, a total of fifty lesson plan examples published by Taiwan's Ministry of Education were used as a reference models and evaluated using the same criteria. Independent samples t-tests compared the KB lesson plans to the lesson plan models.

DT mindset scale

The DT mindset scale (Vignoli et al., 2023) (consisting of 40 items with 10 latent variables with Cronbach α between 0.718-0.871) was administered before and after the KB-TPD course. Paired sample t-tests assessed changes in teachers' scores across the 10 variables and overall score.

KB perceptions survey

A pre-post KB Perceptions Survey, using a 7-point Likert scale (1=strongly disagree; 7=strongly agree), was employed to measures teachers' knowledge building perceptions which include their perceived understanding, perceived importance, and perceived feasibility of KB principles. This survey was adapted from Hong et al. (2011). Paired sample t-test were performed to understand whether there was any significant change. Furthermore, a correlation between the DT mindset and the KB perceptions derived from the post-test score was also conducted.

KF collaborative online discussion

To address RQ3, a descriptive analysis was performed on the recorded dataset in KF to provide an overview of the online KB activities. Then, a qualitative coding analysis was conducted to analyze the online discussion content, focusing on the challenges that teachers mentioned during lesson plan design. Each note was used as a unit of analysis and was analyzed in alignment with the DT process and its design cycles: empathize/explore, define, ideate, prototype and test (which is actually a re-design phase in this study). The coding scheme is shown in Table 2. This study conveniently selected half of the participants' collaborative discussion on the KF platform for preliminary analysis to illustrate how they demonstrated their DT mindset for knowledge creation.

Table 2

Lesson Design Components Corresponding to the Epistemic Entities

Coding scheme	Definition
Empathy and Exploration	Teachers focus primarily on exploring the needs of learners/students/children and their understanding of the application of Knowledge Building (KB) principles.
Course Theme Definition	Teachers define the theme of the lesson plan, aligning it with Sustainable Development Goals (SDGs), and set clear learning objectives.
Ideation for Lesson Activities	Teachers explore innovative teaching designs, strategies, or resources to enrich their instructional approach.
Lesson Plan Prototyping and Reflection	Teachers complete the lesson plan design, implement it in practice, and then reflect on and refine it based on feedback or analysis.

Results

Comparison of Lesson design prototypes

Regarding RQ1, the KB lesson design prototypes significantly outperformed the reference lesson plan models in overall performance ($t=6.51$, $p<.01$). This indicates that KB teachers' designed lessons are aligned more closely with the 12 KB principles. However, two principles, Pervasive Knowledge Building and Embedded ($t=1.56$, $p>.05$), Concurrent and Transformative Assessment ($t=1.04$, $p>.05$), did not show significant differences, suggesting similar performance between KB and lesson plan models.

Design thinking mindset and KB perceptions

Regarding RQ2, Table 3 shows significant differences in pre- and post-test scores on the DT mindset scale, both overall ($t=-11.20$, $p<.01$) and across the 10 variables ($t=-10.83, -7.45, -10.80, -8.28, -8.37, -10.13, -8.05, -8.41, -10.28, -9.03$, $p<.01$). This indicates that the KB-TPD course enhanced teachers' design thinking mindset in various aspects.

Table 3 also shows that there were significant differences in terms of teachers' perceived understanding and perceived importance of KB principles between pre-test and post-test ($t=-11.03$, $p<.01$; $t=-4.98$, $p<.01$). However, there was no significant difference in perceived feasibility of KB principle. Furthermore, there was a significant correlation between DT mindset and KB perceptions ($r = .60^{**}$, $p< .01$) after the KB-TPD course.

Table 3

T-Test of Teachers' DT Mindset and KB Perceptions.

Dimension	Pre-test		Post-test		t
	M	SD	M	SD	
Design thinking Total	4.96	0.84	6.05	0.58	-11.20**

1. Uncertainty & Risk	4.38	1.29	5.85	0.91	-10.83 **
2. Empathy	4.84	0.96	5.75	0.84	-7.45 **
3. Holistic Think	4.67	1.04	5.90	0.69	-10.80 **
4. Collaboration & Diversity	5.18	1.09	6.24	0.70	-8.28 **
5. Learning Orientation	5.45	0.97	6.43	0.54	-8.37 **
6. Experimentation	4.99	0.98	6.07	0.73	-10.13 **
7. Critical Questioning	5.40	0.95	6.32	0.80	-8.05 **
8. Abduction	4.60	0.99	5.69	0.94	-8.41 **
9. Creative Confidence	4.94	0.92	6.09	0.81	-10.28 **
10. Impact	5.15	0.95	6.14	0.74	-9.03 **
KB Perceptions					
Perceived understanding	3.94	1.42	5.82	0.75	-11.03**
Perceived importance	5.77	0.79	6.30	0.57	-4.98**
Perceived feasibility	3.15	0.93	3.34	1.06	-1.08

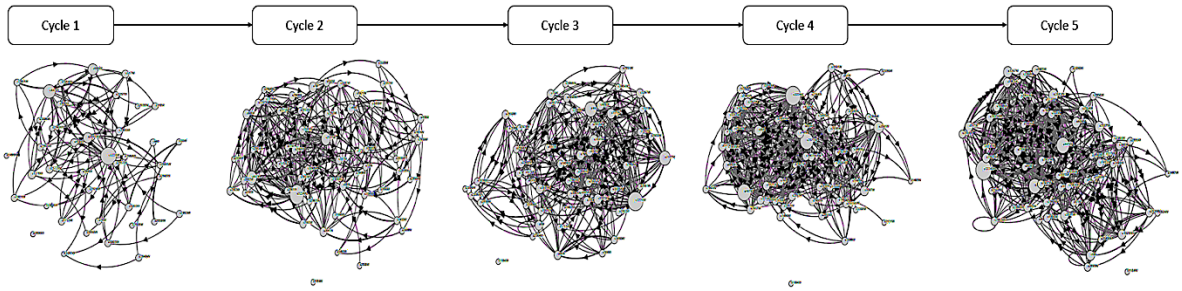
**p<.01

KF-collaborative lesson design process

Regarding RQ3, a descriptive analysis was performed on the online activities of notes-read, -created, and modified by teachers over the 10-week course. It was found that each participant on average read 176 notes (M= 175.73; SD=91.05), contributed 20 notes (M= 20.06; SD=10.37), and modified their notes 47 times (M= 46.69; SD=28.04). This indicates that the participants were actively engaged in interactive knowledge building in KF. Figure 5 shows the cumulative social activities in KF for each of the five cycles, indicating sustained interactions among community members.

Figure 5

The Social Network on KF (from week 1 to week 10)



Next, half of the participants were selected for preliminary analysis to examine how they engaged in collaboration throughout the five cycles. Table 4 shows the results of the qualitative coding analysis of online discussion content in five cycles. In the design Cycle 1, teachers focused on empathy and exploration to address learning needs and how they approach to KB principles. For example, one participant considered "students have varied levels of computer skills thus supporting with different tech tools is a must" (teacher F). Another participant further mentioned that "some of the KB principles are abstract so more effort is needed to understand and apply them effectively" (teacher M).

From the design Cycle 2 to Cycle 4, the focus shifted to ideation for learning activities and improving with better design ideas. They engaged in this online PD community and focused on student-centered strategies, such as "considering how to guide students' conversations and encourage group interaction" (teacher A), or considering using different technologies "as a visual interface for displaying students' ideas" (teacher H). They also asked questions to each other for design suggestions more explicitly with teaching examples to seek for improvement.

In the design Cycle 5, the discussion focused on testing and revising the lesson plan, with some teachers also reflecting on the feasibility of implementing KB-based lesson plans. They indicated their interests and curious the

implementation of lesson design (teacher K). Some teachers conducted in the classroom and found that "the lesson plan design still can be revised to make the process smoother" (teacher C).

Table 4
Frequencies of Participants' Collaborative Discussion in Each Cycle about Design Challenges on the KF Platform

	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Total
Empathy and Exploration	15 (68%)	3 (17%)	2 (17%)	2 (14%)	2 (9%)	24
Theme Definition	2 (9%)	3 (17%)	2 (17%)	0 (0%)	1 (5%)	8
Ideation for Lesson	1 (5%)	11 (61%)	4 (33%)	7 (50%)	6 (27%)	29
Prototyping	4 (18%)	1 (6%)	4 (33%)	5 (36%)	13 (59%)	27
Total	22	18	12	14	22	

Conclusion

This study developed an online KB teacher professional development (KB-TPD) course in Knowledge Forum, which integrates knowledge building principles and design thinking process as an innovative pedagogical framework to enhance teachers' design thinking mindset and capacity.

The results highlight the effectiveness of teacher collaboration, supported by layers of social support and design cycle. The findings reveal that the KB-TPD course enabled teachers to create lesson plan prototypes that align more closely align with KB principles. Furthermore, teachers demonstrated significant improvements in tier perceived understanding and perceived importance of KB principles after KB-TPD course; and their design thinking mindset was also effectively enhanced. Additionally, teachers' peer discussions demonstrated collective efforts to address and resolve each other's' challenges in understanding KB principles throughout the design cycles.

KF serves as the collaborative learning environment for the teacher community in this course. This study analyzed the lesson design challenges raised by participants during each design cycle on KF. The results revealed that their discussion corresponded to the DT process. Additionally, analysis of half of participants' collaborative discussions indicated that challenges related to understanding and applying KB principles were primarily mentioned during Cycle 1. In subsequent cycles, participants shifted toward peer collaborative discussions to address and resolve these challenges effectively.

In addition, the study found that teachers' perceived feasibility of KB principles is relatively lower compared to their perceived understanding and importance. Previous research suggests that prior conventional classroom experience (Hong et al., 2011) could greatly hinder the effective implementation of KB principles in teaching practices. In this study, low feasibility of KB might be attributed to the need for more teaching guidance and reflection in the PD training. Researches on professional development also indicate that incorporating classroom practice, ongoing reflection, and constructive feedback can positively affect teachers' teaching practices (Cheng & Li, 2020; de Putter-Smits et al., 2022; Smith & Browne, 2024). Based on these findings, this study suggests that future KB training courses for teachers should highlight connecting KB principles with classroom practices to enhance teachers' perceived feasibility of KB implementation.

The findings of this study can inform the improvement of online professional development by integrating DT processes to guide the application of KB principles in lesson design. By providing tailored resources and support, KB-TPD courses can enhance teachers' understanding and application of KB principles, foster their DT mindsets, and promote the effective implementation of Knowledge Building theory in educational practice.

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