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Design Thinking Mindsets Facilitating Students' Learning of Scientific Concepts in Design-Based Activities

Luecha Ladachart[1], Visit Radchanet[2], and Wilawan Phothong[3]

[1]*School of Education, University of Phayao, Thailand, ORCID ID: 0000-0001-5048-8276*
[2]*Thumpinwittayakom School, Thailand, ORCID ID: 0000-0003-4156-5385*
[3]*School of Education, University of Phayao, Thailand, ORCID ID: 0000-0002-1229-9375*

ABSTRACT
Design-based learning has been recognized by educational scholars as the key approach to science, technology, engineering, and mathematics (STEM) education at K-12 levels. However, it is unclear whether, and which dimensions of, design thinking mindsets support the conceptual learning of science. This quasi-experimental study aims to explore 37 eighth-grade students' conceptual learning and design-thinking mindsets in the context of design-based learning on pulleys. A conceptual test on pulleys and a Likert scale questionnaire, measuring design-thinking mindsets were administered to the students before and after the design-based learning treatment. In a comparison between two classes of students, using Mann-Whitney *U* tests in each measurement, some dimensions of design thinking mindsets that facilitate conceptual learning on pulleys were identified. These include: (a) orientation towards learning by making and testing; and (b) mindfulness of the process and impact on other people. Based on these results, recommendations were made for the effective enactment of design-based learning to develop students' scientific understanding.

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Introduction

Design thinking is a mode of thinking used by individuals when engaging in design-based tasks (Li et al., 2019). It involves several cognitive activities, such as analyzing the situation, defining the problem, modeling ideas, designing solutions, predicting results, questioning unexpected outcomes, and managing the designing process (Sung & Kelly, 2019). Design thinking is assumed to play a crucial role in students' learning when they are engaging in design-based activities (Cook & Bush, 2018). Design-based learning has now become a key pedagogical approach to science, technology, engineering, and mathematics (STEM) education at the K-12 levels (Kelly & Knowles, 2016). A substantial amount of research consistently indicates a positive influence on students' learning of scientific concepts (e.g., Apedoe et al., 2008; Chusinkunawut et al., 2021; Fortus et al., Kolodner et al., 2003). However, little is known as to how or which dimensions of design thinking play a significant role in facilitating students' development of scientific understanding.

This study aims to explore the roles of design thinking mindsets in students' development of scientific understanding in the context of design-based learning. Here, design thinking mindsets refer to "the set of opinions, beliefs, and behaviors that characterize an individual" (Paparo et al., 2017, p. 369) when he or she is engaging in a design-based activity. Design thinking can entail several mindsets, such as human-centeredness, bias toward action, collaboration, experimentation, optimism, and mindfulness of process (Blizzard et al., 2015). The connection between design thinking and science content learning has not previously been explored. This study attempts to identify the kinds of mindsets students bring into or develop during design-based learning that could facilitate their learning of the scientific concepts. By identifying such mindsets, this study can contribute to the literature on science education by emphasizing relevant characteristics so to support science teachers and educators in creating design-based activities to "teach the fundamental mindsets […] of design thinking [that] are entwined with content learning" (Carroll et al., 2010, p. 51).

Design-Based Learning

Design-based learning can be viewed as "a type of problem-based learning, in which students work together in teams to solve a problem" (Ellefson et al., 2008, p. 292), specifically where students collaborate "to create or design a new invention/prototype" (ibid, p. 292). Rather than solving one's own problems, design-based learning focuses on solving the problems of other people (e.g., users or customers) under given constraints and criteria (Dym et al., 2005). Similar labels can also be used to refer to design-based learning in science education, such as design-based science (Fortus et al., 2004) and learning by design (Kolodner et al., 2003). According to Lewis (2006, p. 269), design-based learning in science education can be classified into two main types: the design-through-science approach and the science-through-design approach. The former highlights "how science becomes the vehicle for prompting design", while the latter emphasizes "the design process […] as the vehicle for teaching science concepts" (p. 268). A key difference between these two approaches is the sequence of the engineering design process and scientific investigations.

While Lewis (2006) asserts that the effect of each design-based learning approach is the same in terms of highlighting the relationship between science and engineering, our tentative results of a quasi-experimental study suggest that the science-through-design approach is more effective than the design-through-science approach in facilitating students' scientific understanding. Perhaps, because the engineering design process is conducted before scientific investigation, students' prior knowledge and misconceptions are more likely to be activated, leading them to perform scientific investigation more meaningfully than students who complete scientific investigation before the engineering design process. Based on these results, the model of design-based learning (Apedoe et al. 2008), which can be classified as the science-through-design approach (Lewis, 2006), is used instead of the design-through-science approach, which is nationally recommended in Thailand (Institute for the Promotion of Teaching Science and Technology, 2015) where this study was conducted. Therefore, design-based learning includes seven stages: (1) creating designs, (2) evaluating outcomes, (3) generating reasons, (4) testing ideas, (5) analyzing results, (6) generalizing the results, and (7) connecting to big ideas.

More specifically, after seeing a video clip of an elderly person having difficulty lifting a basket of water from a well in a rural area without electricity, groups of four or five students were challenged to collaboratively design a pulley set-up to help the elderly person use less force. Each group's designs were then tested and compared to identify which factors affect the amount of force required to lift the given object. In a whole-class discussion aimed towards exploring the issues of a pulley set-up (e.g., fixed or moveable), each group was encouraged to do a scientific investigation in a structured manner to explore the force required by each pulley setup, leading to the conclusion that a moveable pulley requires less force than a fixed pulley. In light of this conclusion, relevant scientific concepts such as distance, work, and mechanical advantages were introduced before students were challenged once again to collaboratively design and test a pulley set-up to help the elderly person. Through these design-based activities, it was expected that the students would not only develop a more scientific understanding of pulleys but would also use design thinking mindsets to facilitate their conceptual learning.

Design Thinking Mindsets

The engineering design process can be defined as "a systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients' objectives or users' needs while satisfying a specified set of constraints" (Dym et al., 2005, p. 104). This process requires individuals to have and use design thinking mindsets to engage in it meaningfully and effectively. For example, since design-based tasks involve designing a solution to clients' or users' problems under specific situations, design thinkers must empathize with those people's problems, needs, and situations. Moreover, as achieving an appropriate solution to the problem in a way that satisfies the clients or users is not an easy task, design thinkers are required to be tolerant of uncertainty and ambiguity arising during the process. While some of these characteristics can be referred to as "traits" (Blizzard et al., 2015), "attributes" (Schweitzer et al., 2016), or "mindsets" (Dosi et al., 2018), the term "mindsets" is used in this paper, as it covers the opinions, beliefs, and behaviors of those who are design thinkers (Paparo et al., 2017).

Regardless of the term used, it appears that design thinking mindsets are a multi-dimensional concept. Design thinking mindsets can entail as many as 19 aspects: (1) tolerance for ambiguity, (2) embracing risks, (3) human-centeredness, (4) empathy, (5) mindfulness of process, (6) holistic view, (7) problem framing, (8) team working, (9), multi-disciplinary collaboration, (10) being open to different perspectives, (11) orientation to learning, (12) experimentation, (13) bias toward action, (14) critical questioning, (15) abductive thinking, (16) envisioning new things, (17) creative confidence, (18) desire to make a difference, and (19) optimism to have an impact (Dosi et al., 2018). However, as some of these aspects are interrelated, they can be merged. Schweitzer et al. (2016), for example, highlight that design thinkers are: (1) empathetic toward people's needs and contexts, (2) collaboratively geared and embracing diversity, (3) inquisitive and open to new perspectives and learning, (4) mindful of the process and thinking modes, (5) experientially intelligent, (6) taking action deliberately and overtly, (7) consciously creative, (8) accepting of uncertainty and open to risk, (9) modeling behaviors, (10) having a desire and determination to make a difference, and (11) critically questioning.

Given a vast list of design thinking mindsets, it is neither reasonable nor practical to expect students to develop all mindsets simultaneously. By applying exploratory factor analyses and regression models, Blizzard et al. (2015) achieved an ample number of design thinking mindsets of students: (1) collaboration, (2) experimentation, (3) optimism, (4) feedback-seeking, and (5) integrative thinking. Moreover, at elementary levels, Cook and Bush (2018) highlighted five aspects of design thinking: (1) human-centeredness, (2) bias toward action, (3) radical collaboration, (4) culture of prototyping, and (5) mindfulness of process. In summary, design thinking mindsets generally entail empathy with people's problems, a desire to take action, and learning during the process of problem-solving in order to have an impact on people's lives and societies. While "designing", design thinkers aim: to communicate ideas and collaborate with others, be open to diverse perspectives, be mindful of the process of problem-solving, be aware of their own thinking modes, be comfortable with ambiguity and uncertainty, be confident in creativity, embrace risks when trying different approaches or testing new ideas, and be resilient not to back down from challenging problems.

Methods

As illustrated in Table 1, this study was conducted as a post hoc analysis of a quasi-experimental research study with a pretest-posttest design (Chiang et al., 2015) aiming to examine the influences of two approaches of design-based learning on three classes of eighth-grade students' scientific understanding, in a lesson on pulleys. Based on Apedoe and Schunn's (2013) results that students' learning during design-based activities depends on experiences and strategies they have and use in the process of designing, students' design thinking mindsets were collected as supplementary data to better understand whether, and what dimensions of, such mindsets could contribute to their learning. It was these two sets of data that constituted this study. Given the quasi-experimental design of this study, while a causal inference between design thinking mindsets and conceptual learning on pulleys cannot be achieved, useful insights into the roles that design thinking mindsets play in students' development of scientific understanding can be gained. In the following sections, the details of the context, the participants, the instruments, the data collection, and the data analysis are described.

Table 1

Research Design

Samples	Pretest of the dependent variable	Interventions of the independent variable	Posttest of the dependent variable
One class of control group	A conceptual test on the understanding of pulleys and a questionnaire measuring design thinking mindsets	Design-based learning on pulleys according to the Institute for the Promotion of Teaching Science and Technology's model (2015), can be classified as the design-through-science approach (Lewis, 2006)	A conceptual test on the understanding of pulleys and a questionnaire measuring design thinking mindsets
Two classes of the experimental group		Design-based learning on pulleys according to Apedoe et al.'s model (2008), can be classified as the science-through-design approach (Lewis, 2006)	

Note. The control group was excluded in this study because of no significant gain in their scientific understanding of pulleys.

Context

This study took place in a secondary school in a rural area with a total of 401 students from seventh to twelfth grades, in the second semester of the 2020 academic year (about January-February 2021). The school is surrounded by rice fields, even though it is only about 30 kilometers from the city. Given this distance, which takes about 40 minutes driving by car, parents with sufficient incomes (e.g., businessmen and government officials) prefer to send their children to the more privileged school located in the city, so that most students in the school, including those participating in this study, are from local families with less income (e.g., agricultural families and laboring families). The students' families' average income is about 411 USD per month. 42 teachers are working at the school. Of these teachers, there are five science teachers, including the second author, who has a background in physics. He has 24 years of teaching experience in total, and 12 years of teaching experience at lower secondary levels. With his interest in STEM education and design-based learning, he voluntarily participated in the study. When this study was conducted, he was responsible for teaching science to one seventh-grade class and three eighth-grade classes, as well as for teaching physics to one tenth-grade class and one twelfth-grade class.

Participants

Two of the three eighth-grade classes (about 14 years old), which engaged in Apedoe et al.'s (2008) model of design-based learning, participated in this study. One class (hereafter called the first class) included 14 males and 14 females, and the other class (hereafter called the second class) included nine males and 11 females; thus, there were 48 students in total. The difference in the number of students in the two classes resulted from the fact that this study was conducted during the

COVID-19 pandemic, just after the new-year holidays. Since some students or their family members, mostly from the second class, had visited other places during those holidays, they had to self-quarantine at home for 14 days due to the pandemic and were not able to physically participate in any activities at the school. Moreover, given this limited number of students, some students did not complete the process of data collection either before or after the design-based learning. As a consequence, there were only 20 students (nine males and 11 females) from the first class and 17 students (eight males and nine females) from the second class, a total of 37 students, who provided data for this study. This number is lower than the expected value of the sample size at a 0.05 confidence level (i.e., 42 of 48), according to Yamane (1970); thus, it was not completely representative of all eighth-grade students in the school. Given the similar ratios of males to females in each class, there was no or little gender bias. Based on the school's records, none of the participating students were diagnosed as having difficulties in reading and writing the Thai language.

Instruments

Two instruments were used for data collection in this study. The first instrument was a conceptual test on pulleys. This conceptual test comprised of 12 multiple-choice questions taken from the literature (Chini, 2006; Sullivan et al., 2017). These questions were translated into Thai and were sent to three unbiased Physics educators to check their validity and reliability. After several rounds of revision according to the Physics educators' comments and feedback, the questions were tested out on 65 seventh-grade students in the same school. These questions were specifically developed to detect students' misconceptions on pulleys, with statements such as "the more pulleys there are in a setup, the easier it is to pull to lift a load", "the longer the string is in a pulley setup, the easier it is to pull to lift a load", and "having more pulleys in a pulley setup reduces the amount of work" (Myneni & Narayanan, 2012, p. 75). The result of this trial study indicated that many students might have misconceptions about pulleys, since the mean score was 3.38 out of 12 maximum, with a standard variation of 1.49. Overall, the conceptual test seemed to be difficult for students, as its item difficulties ranged from 0.14 to 0.37, with a mean of 0.28.

The second instrument was a five-point, Likert-scale survey on design thinking mindsets, which is normally used in the literature (Blizzard et al., 2015; Dosi et al., 2018; Schweitzer et al., 2016). This kind of design requires to be contextually sensitive when used in a particular context. In order to develop and validate the instrument for this study, the most extensive list of design thinking characteristics (Dosi et al., 2018) was used as the starting point. After translating about 70 items regarding 19 design thinking mindsets, exploratory and confirmatory factor analyses were successively conducted with 297 and 593 secondary students, respectively. This resulted in 30 items representing six design thinking mindsets, namely: (1) "collaboratively working with diversity" with five items, (2) "being confident and optimistic to use creativity" with eight items, (3) "orientation to learning by making and testing" with four items, (4) "mindfulness to process and impacts on others" with three items, (5) "being comfortable with uncertainty and risks" with six items, and (6) "human-centeredness" with four items, with loading factors of 0.852, 0.822, 0.879, 0.974, 0.784, and 0.979, respectively. A copy of the second instrument is presented in the Appendix.

Given that "empathy [is the] most important piece of the design thinking process" (Cook & Bush, 2018, p. 99), it is important to note that the items originally belonging to the factor of "empathy" in Dosi et al.'s (2018) list of design thinking mindsets did not appear to constitute a single factor in the exploratory and confirmatory analyses conducted for developing the instrument of this study. Rather, some of the items were merged with other factors (i.e., human-centeredness and mindfulness to process). This is understandable given that human-centeredness can refer to "developing empathy for the people for whom you are designing" (Cook & Bush, 2018, p. 95). On the other hand, this might mean that empathy does not operate only in the first stage of the design thinking process, as graphically illustrated by the Institute of Design at Stanford (2019), but also in the whole process of design-based activities. This hypothesis supports a claim that "empathy […] functions from the beginning to the end of a design project" (Hess and Fila 2016, p. 108). Thus, the empathic aspect of design thinking mindsets was measured in several items belonging to "human-centeredness" and "mindfulness to the process and impacts on others" in this study.

Data Collection

As summarized in Table 2, both instruments were simultaneously administered to each class as a pre-measurement in December 2020. Students had one period of 50 minutes to complete both instruments. After the holidays and a school break lasting for a week, the design-based activities were implemented during the four following weeks. There were two sessions per week: one session lasting two class periods (100 minutes) on Monday mornings for the first class and Tuesday afternoons for the second class, while the other session lasted one period (50 minutes) on Thursday mornings for both classes. During the implementation of the design-based activities, the teacher's classroom practices were observed by a non-participating two researchers and recorded using a VDO camera placed at the back of the classroom. After about three weeks or eight periods of the design-based activities, both classes were asked to complete the same instruments as the post-measurement, again on the same day. Given this timeframe, a month-long interval between the two measurements could limit the influence of re-testing as a validity threat of this study (Yu, 2021).

Table 2

Research Procedure

Procedure	Research Activities
1	Pre-measurement: Both classes of students completed a conceptual test on pulleys and a questionnaire measuring design thinking mindsets.
2	Design-based learning: Both classes of students separately engaged in the same design-based learning on pulleys. Examples of pulley setups designed by a group of students before and after the scientific investigation are presented in Figure 1.
3	Post-measurement: Both classes of students once again were administered the same instruments (i.e., the conceptual test on pulleys and the questionnaire measuring design thinking mindsets)
4	Analysis of conceptual learning on pulleys: Students' scores on the conceptual test were analyzed, indicating significant improvement in conceptual learning on pulleys, with each class demonstrating different effect sizes (about 1.5 vs. 1.0).
5	Post-hoc analysis: Both classes of students' design thinking mindsets, as measured by the questionnaire, were compared considering the improvement in their conceptual learning on pulleys, to identify what dimensions of such mindsets caused the differences between them.

Data Analysis

Data from the pre- and post-measurements were analyzed using descriptive and inferential statistics (Morgan et al., 2013). Regarding the conceptual learning on pulleys, the mean scores with a standard deviation of students were calculated for each class before and after the design-based learning application. The normality of each set of data was checked using Shapiro-Wilk tests since the number of students in each class was fewer than 50. The results of the Shapiro-Wilk tests indicated that the first class's scores on the pretest and the posttest were not normally distributed: $W(20) = 0.877$, $p = 0.015$ and $W(20) = 0.887$, $p = 0.023$, respectively, while the second class's scores on pretest and posttest were normally distributed: $W(17) = 0.959$, $p = 0.610$ and $W(17) = 0.916$, $p = 0.126$, respectively. As a consequence, the non-parametric Wilcoxon signed-rank test was used to compare the mean scores on pretest and posttest for the first class, while the paired-sample t-test was used to compare the mean scores on pretest and posttest for the second class. For comparison between the two classes' mean scores in each measurement, non-parametric Mann-Whitney *U* tests were used, due to the non-normal distribution of one class's scores.

Figure 1

Examples of Pulley Setups Designed By a Group of Students

(a) Before scientific investigation; students designed a pulley setup without a mobile pulley.

(b) After scientific investigation; students designed a pulley setup with mobile pulleys.

Regarding the data about students' design thinking mindsets, students' mean scores on each aspect in both measurements were calculated with standard deviation. Since these data were ordinal, the non-parametric Wilcoxon signed-rank test was used to compare the mean scores on each aspect between both measurements for each class. In comparing the mean scores on each aspect of each measurement between the two classes, non-parametric Mann-Whitney *U* tests were used. By conducting these inferential analyses of the data regarding design thinking mindsets with consideration of the results of each class's conceptual learning, it was possible to identify which class performed better and in which aspects of design thinking mindsets the higher-achieving class scored better than the lower-achieving class. Such results could imply that the higher-achieving class had and used such aspects of design thinking mindsets more often than the lower-achieving class. In other words, such aspects might play a more influential role in facilitating conceptual learning in the higher-achieving class than in the lower-achieving class. In all inferential analyses, the significance level of 0.05 was first used before lower levels of significance were considered.

Results

The descriptive analyses of the data regarding students' conceptual understanding of pulleys indicated, as can be seen in Figure 2, that both classes performed poorly prior to the design-based learning, as their mean scores on pretests were 2.75 (SD = 1.33) and 3.76 (SD = 1.72) out of 12 for the first and second class, respectively. However, after the design-based learning, both classes performed better, as they each achieved a mean score of 6.65 (SD = 1.90 and SD = 2.64 for the first and second classes, respectively). The inferential analyses confirmed that both classes demonstrated significant improvements in their understanding of pulleys: $z = 3.94$, $p = 0.000$ for the first class and $t(16) = 3.38$, $p = 0.004$ for the second class. Despite the same level of conceptual learning at the end of the design-based learning, it was notable that the first class performed considerably worse than the second class at the beginning, with the non-parametric Mann-Whitney *U* test indicating a marginally significant difference ($U = 111$, $p = 0.067$). Based on these results, it can be concluded that the first class showed a more significant learning improvement in the development of scientific understanding than the second class since the gap between the two classes decreased after the design-based learning.

Figure 2

Students' Mean Scores on Pretest and Posttest Regarding Conceptual Learning on Pulleys

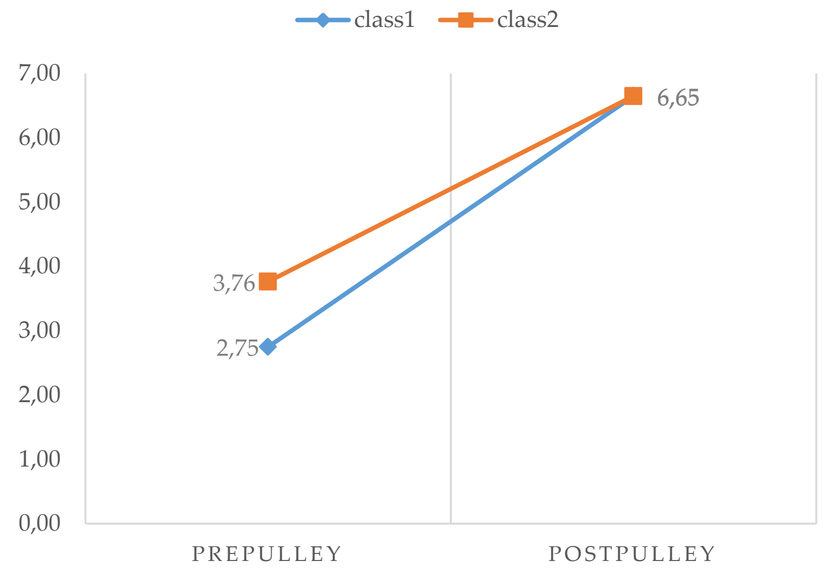


Figure 3

Students' Design Thinking Mindsets before Engaging in Design-Based Learning

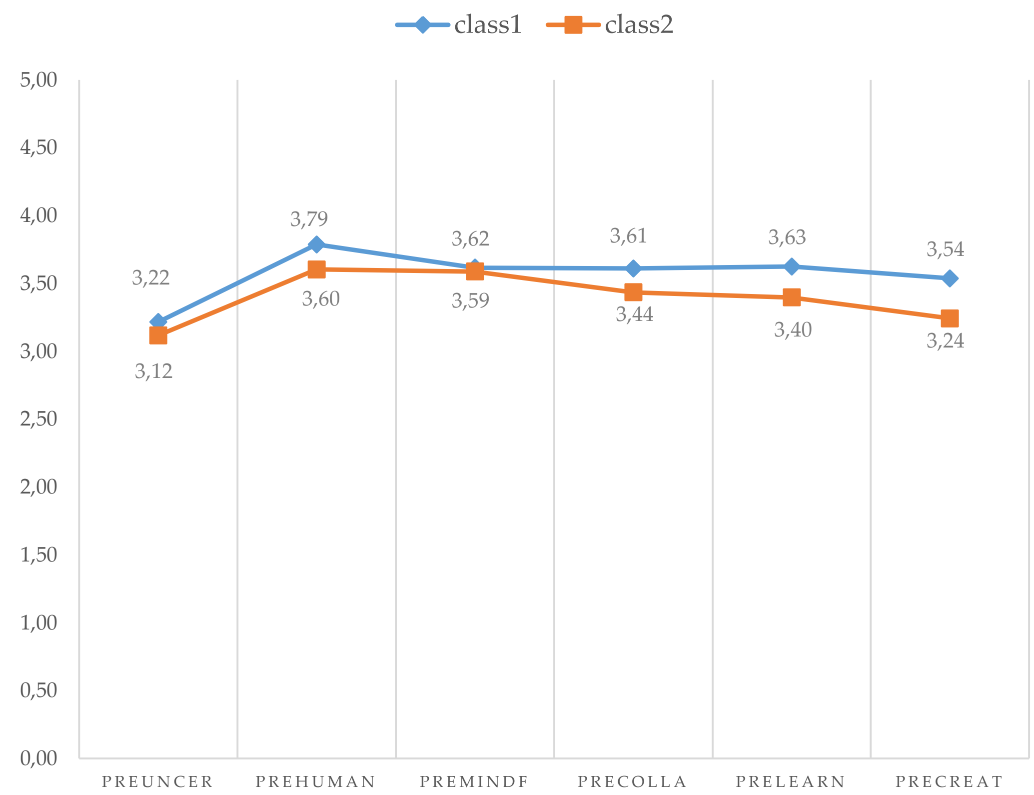
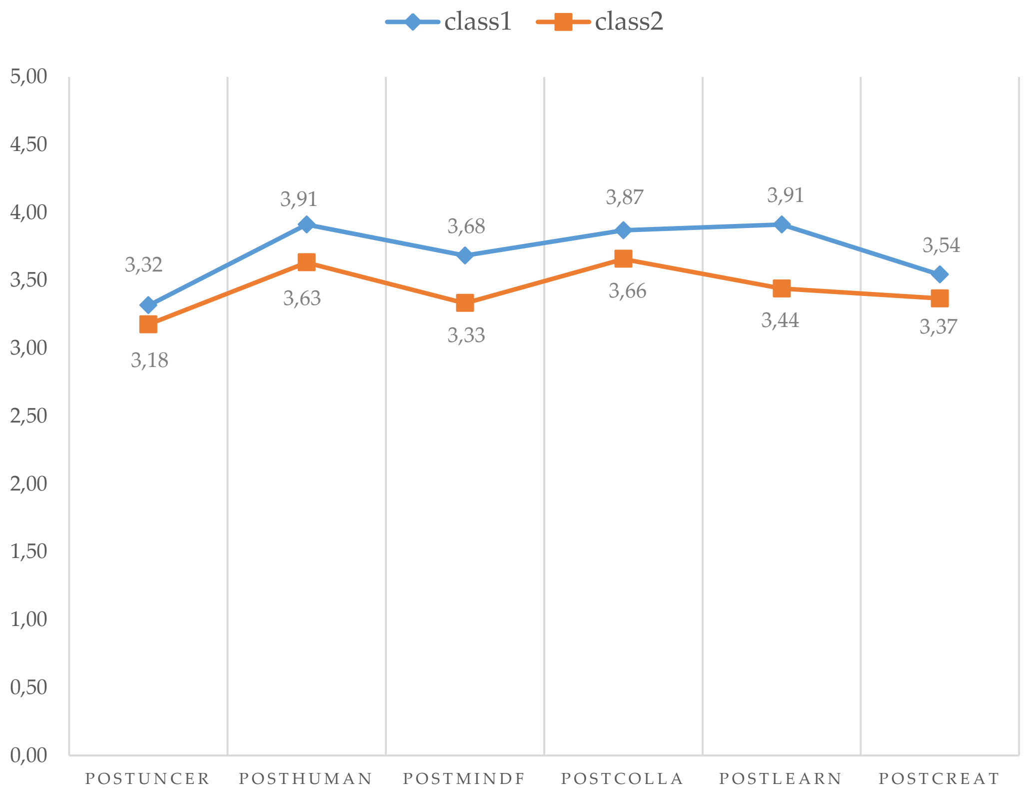


Figure 4

Students' Design Thinking Mindsets after Engaging in Design-Based Learning



Regarding design thinking mindsets, the descriptive analyses indicated that both classes were initially positive in all aspects, as their mean scores were above 3.00, as can be seen in Figure 3. However, despite the less scientific understanding of pulleys, the first class was slightly more positive than the second class. The non-parametric Mann-Whitney *U* tests indicated that these differences were not significant ($p > 0.05$). Only the aspect of "being confident and optimistic to use creativity" was marginally significant: $U = 113$, $p = 0.085$. After the design-based learning, in which the first class first showed a more significant learning improvement than the second class, it was apparent that the first class also tended to develop design thinking mindsets slightly more, as the gaps between the two classes in Figure 4 are larger than those in Figure 3. The non-parametric Mann-Whitney *U* tests confirmed that there were significant differences in some aspects of design thinking mindsets between the two classes. Specifically, the first class was more positive than the second class in terms of "mindfulness to process and impacts on others" ($U = 85$, $p = 0.007$) and "orientation to learning by making and testing" ($U = 90$, $p = 0.014$). Also, a marginally significant difference in "human-centeredness" was detected ($U = 108$, $p = 0.060$).

To better understand the changes in both classes' design thinking mindsets after design-based learning, non-parametric Wilcoxon signed-rank tests were conducted to examine whether the changes in each aspect were significant. The results revealed that the first class significantly developed their design thinking mindsets in the aspect of "orientation to learning by making and testing" ($z = 2.09$, $p = 0.036$), while the changes in other aspects were not significant, even at the 0.1 significance level. By contrast, the second class' design thinking mindsets in the aspect of "mindfulness to process and impacts on others" decreased from 3.59 to 3.33, which was marginally significant ($z = 1.65$, $p = 0.098$), while the changes in other aspects were not significant, even at the 0.1 significance level. Therefore, based on these results, the first class developed their orientation to learning by making and testing along with developing their conceptual learning, which did not occur in the second class. Compared to the first class, moreover, being less mindful of the process and impacts on others during design-based learning might have inhibited the second class's potential to develop their conceptual understanding of pulleys.

More specifically, to identify which items had contributed to the significant differences in design thinking mindsets with the aspects of "mindfulness to process and impacts on others" and "orientation to learning by making and testing" in the posttest, non-parametric Mann-Whitney U tests were conducted to compare students' responses to each item belonging to these aspects between the two classes. It was found that there were two items belonging to "mindfulness to process and impacts on others" that made the difference. These two items stated that "I easily empathize with the concerns of other people" (U = 104, p = 0.045) and that "I am well aware when to be open-minded and when to focus on something" (U = 107, p = 0.023). Regarding the aspect of "orientation to learning by making and testing," one item stating that "I like transforming a hypothesis into something to be tested" (U = 99, p = 0.022) made the difference. However, another item seemed to contribute marginally to the difference as well. This item stated that "I am often curious about what I do not know and try to find answers" (U = 112, p = 0.080). Altogether, these items contributed to the differences in the design thinking mindsets, and thereby different learning gains, between the two classes.

Discussion

A recent movement in STEM education has led science teachers and educators to increase attention to design-based learning as it combines science and engineering in an integrated way to promote meaningful learning in students. This study confirms the results of many previous studies that design-based learning facilitates students' development of scientific understanding (e.g., Apedoe et al., 2008; Chusinkunawut et al., 2021; Fortus et al., 2004; Kolodner et al., 2003). However, students' conceptual learning can vary within the context of design-based learning, depending on several factors, not only related to the teacher's instructional practice (Capobianco et al., 2018) and scientific concepts of the lessons (Wendell & Rogers, 2013), but also to students' characteristics, such as their prior knowledge and misconceptions (Dankenbring & Capobianco, 2016; Schnittka & Bell, 2011), perceptions on the goal of design-based activities (Schauble et al., 1991), quality of communication within groups (Chusinkunawut et al., 2021), and strategies used to achieve design-based tasks (Apedoe & Schunn, 2013). This study contributes to the literature that the design thinking mindsets that students bring into design-based learning can also play an influential role in facilitating their conceptual learning.

By comparing two classes of students concerning their conceptual learning gains and design thinking mindsets, this study was able to identify that orientation to learning by making and testing was influential in facilitating conceptual learning. Students, especially in the first class, were eager to learn what they did not yet understand, which was required to help them accomplish the design-based task. With an awareness of their current ideas, missing knowledge, and the goal they aimed to achieve through design-based learning where the engineering design process and scientific investigation were integrated (Ellefson et al., 2008), the students were able to search for the necessary knowledge and/or transform their potential ideas into hypotheses which they could test empirically by creating prototypes. This is what Schweitzer et al. (2016) called "experiential intelligence" that "depicts a preference for trying out ideas by making mock-ups, drawing what thoughts or ideas may look like, building models or creating something tangible to experiment with as a way of transforming ideas into something that can be experienced and tested" (p. 79). Sung and Kelly (2019) demonstrated that these cognitive activities occur repeatedly when students engage in design-based activities, where they can obtain critical feedback to improve their understanding (Blizzard et al., 2015).

According to Demirbas and Demirkan (2007), students' academic performance in design education can be influenced by their learning styles in favor of converging students who "prefer to experiment with new ideas, simulations, laboratory assignments, and practical applications" (Kolb & Kolb, 2005, p. 197). This result is supported by Lau et al. (2012), who observed that groups whose member is a converging student achieve the highest performance in design-based tasks because the converging student can help his or her group "find practical uses for ideas and enjoy experimenting with new ideas" (p. 297). As the converging style of learning reflects "experiential intelligence" (Schweitzer et al., 2016), it can be inferred that the orientation to learning by making and testing as a dimension of design thinking mindsets can influence students to use a converging style of learning, which is beneficial to their learning of scientific concepts in the context of design-based learning. Moreover, as design-based learning is rooted in constructionism, which asserts that learning occurs by constructing artifacts (Tas et al., 2019), students who are oriented to learning by transforming ideas in order to make and test prototypes tend to benefit from learning using design-based activities.

In addition to orientation to learning by making and testing, it is evident that students' mindfulness of the process, or lack thereof, comes into play to facilitate or limit their scientific understanding in design-based learning. According to Schweitzer et al. (2016), mindfulness to the process "depicts awareness about the work that one does, how one does that work, why one does it in a particular way, and about how one will improve the methods being used" (p. 78). Thus, in the context of design-based learning, it means that mindful students are aware of what they are doing in the process of designing (Dosi et al., 2018). For example, they may be aware of when they need to be highly generative to create as many solutions as possible and when they need to converge on a single solution. Moreover, mindfulness to process may include awareness of the goal that the process of designing aims to achieve (Schweitzer et al., 2016). Therefore, given that the design-based task in this study aimed to help an elderly person, being aware of this goal may have created "task value" or "the students' evaluation of how interesting, important, and useful the task is" (Lawanto, 2010, p. 119), which reinforced their intrinsic motivation for problem-solving and learning (Mayer, 1998). With more mindfulness to the process and impact of designing, the first class perhaps achieved more significant learning improvement about scientific concepts than the second class.

While the data available in this study were indeed limited to making a claim about students' metacognitive ability when they were engaging in design-based learning, the results of this study can be related to the literature on metacognition, given that the mindfulness to the process of designing and orientation to learning were highlighted. Research has indicated that metacognition, which is often referred to as "the ability to think about thinking" (Lawanto, 2010, p. 117), plays a crucial role in students' learning of design (Kavousi et al., 2020b), as it helps them become "(a) more aware of and attentive to their thinking processes […], (b) more goal-driven in their performance, and (c) more cognizant of strategies they can call upon as needed" (Kavousi et al., 2020a, p. 712). In addition, research has indicated that metacognition plays a key role in a students' learning of science (Anderson & Nashon, 2007; Antonio & Prudente, 2021; Zohar & Barzilai, 2013). Taking these two areas of research together considering the results of this study, it is highly likely that metacognitive ability, manifesting via mindfulness to the process and orientation to learning, facilitated the first class achieving conceptual learning at the same level as the second class at the end of the design-based learning.

This hypothetical explanation of the relationship between design thinking mindsets, metacognition, and conceptual learning of science concurs with the results of Carroll et al.'s (2010) study, indicating that design thinking can be a tool that fosters metacognition, as this mode of thinking provides a means for students to be cognizant of where they are in the process, thus creating the students' metacognitive awareness. It also aligns with the results of Tas et al.'s (2019) quasi-experimental study, which compared two classes of seventh-grade students in terms of their metacognitive ability and scientific understanding as a result of engaging in either design-based learning (i.e., the experimental group) or curriculum-oriented instruction (i.e., the control group) during a lesson on electrical energy. It was found that students in the experimental group achieved higher levels of metacognitive monitoring and scientific understanding than students in the control group. Based on these results, it can be inferred that in the context of design-based learning, design thinking mindsets (e.g., mindfulness of the process and orientation to learning) help students to use, develop, and benefit from metacognitive ability (e.g., awareness and monitoring), which fosters their learning of scientific concepts.

Conclusions

With the strength of quasi-experimental research using the pretest-posttest design, this study was able to compare two classes of students with different learning gains in scientific understanding in order to identify important dimensions of design thinking mindsets that make such a difference. These dimensions include: (1) the orientation to learning by making and testing, and (2) the mindfulness to the process and impact on others. The first dimension can manifest as a converging style of learning (Lau et al., 2012), where the higher-achieving class demonstrates more improvement than the lower-achieving class. The second dimension can appear as a metacognitive ability where the students monitor and control their cognitive process (Tas et al., 2019), with the higher-achieving class demonstrating a slight improvement while the lower-achieving class demonstrating a decrease. Thus, these results suggest that the orientation to experiential learning can better facilitate the learning of scientific concepts, especially when there is mindfulness of the process. In other words, the lack of mindfulness of the process can limit conceptual learning, even though students are exposed to experiential learning. As the human-centered and collaborative dimensions improved, though not significantly, in both classes, these dimensions cannot be ignored as contributing factors to the students' conceptual learning.

Implications

This study has some implications for design-based learning that can be used to promote students' scientific understanding. While previous studies have focused on finding an appropriate number (Apedoe et al., 2012) and composition (Laeser et al., 2003) of students within a group, the current study suggests that the design thinking mindsets that students bring into the classroom should be taken into consideration when design-based learning is implemented. By considering students' design thinking mindsets, science teachers and educators should ensure that each group has members who have desirable dimensions of design thinking mindsets so that they can learn and influence other members to learn when working together. Some students may need support to become more aware of their own ideas that can be used in the process of designing. With such awareness, it will be more likely that students engage in creating and testing prototypes as a representation of their ideas and do so more meaningfully. Through this process, it seems beneficial to support students to be mindful of what they are doing and that the results can be used as critical feedback to improve their current understanding. With such mindfulness of the process, students could likely conduct a scientific inquiry as a part of design-based learning to learn scientific concepts more intentionally.

Limitations and Future Research

It is critical to note that the results of this study were based on only two classes of eighth-grade students completing one conceptual test and one Likert-scale questionnaire. Thus, its results cannot be fully generalized to the students in different grades or different contexts. Future research is indeed required to verify and elaborate on these results, especially the role that design thinking mindsets can play in facilitating students' conceptual learning of scientific concepts. Future research should also be conducted with a larger population of students, which may allow comparing the conceptual learning of scientific concepts between students with more or fewer design thinking mindsets in specific aspects. Since this study was quantitative, future research could include qualitative data, such as students' discussions and interviews, for better insight into how students use design thinking mindsets when engaging in design-based activities. Design thinking mindsets in some regards can be interpreted as reflecting the learning styles and the metacognitive abilities of the students, therefore future research should explore the relationships between design thinking mindsets, learning styles, and metacognitive abilities. Such future research may provide useful insights into the implementation of effective design-based learning.

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Appendix

Items	Design thinking mindsets
1) I feel comfortable with what is unknown. 2) I prefer new contexts to familiar ones. 3) I am comfortable dealing with problems that I cannot solve yet. 4) I enjoy when a solution does not result in what I expect. 5) I do not worry while solving problems that I do not know if it will be successful. 6) I like taking many chances, even if it leads me to make mistakes.	Being comfortable with uncertainty and risks. (UNCER)
7) I actively involve users in diverse phases of the design process. 8) People are a source of inspiration when identifying the direction of the design solution. 9) During the design process, I try to understand what users need. 10) I can tune into how users feel rapidly and intuitively.	Human-centeredness. (HUMAN)
11) I easily empathize with the concerns of other people. 12) I am well aware when to be open-minded and when to focus on something. 13) I understand what the impacts of the proposed solution on the external environment might be.	Mindfulness to the process and impacts on other people. (MINDF)
14) I am comfortable to share my knowledge with my teammates. 15) I think in a team it is preferable to have different competences. 16) I am comfortable to work with people having diverse perspectives from mine. 17) I am comfortable to change my original opinions after listening to others. 18) I am open to collaborating with people having different backgrounds.	Collaboratively working with diversity. (COLLA)
19) I am comfortable transforming ideas into something tangible. 20): I like transforming a hypothesis into something to be tested. 21) I am often curious about what I do not know and try to find answers. 22) In new situations, I generally seek as much information as I can.	Orientation to learning by making and testing. (LEARN)
23) I can foresee different outcomes of designing the same thing. 24) I am comfortable to use prototypes to represent new ideas. 25) I think I can use my creativity to solve complicated problems. 26) I am sure I can solve problems requiring creativity. 27) I believe in my ability to creatively solve a problem. 28) I desire to create valuable things via designing new products. 29) I think I can overcome difficulties by using creativity. 30) I can see problems or crises as opportunities.	Being confident and optimistic to use creativity. (CREAT)