Changes in Students' Design-Thinking Mindsets after Design-Based Learning with Respect to Gender and Prior Experiences in Design

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Abstract

This study examines the influence of design-based learning on 25 eighth-grade students' design-thinking mindsets, that is, on the mental outlook that they adopt habitually when they engage in design thinking. It also compares changes in design-thinking mindsets across individuals of different genders and different levels of experience in design. We collected data by using a self-reported Likert-scale questionnaire. We used Wilcoxon signed-rank tests to compare the students' design-thinking mindsets before and after design-based learning. We utilized Mann-Whitney *U* tests to identify differences between male and female students and between students with different levels of prior experience. The results indicate that the influence of design-based learning on design-thinking mindsets depends on gender and prior experience Careful scaffolding is necessary to enable all students to develop their design-thinking mindsets when they collaborate in design-based learning.

Keywords: design-based learning, design experience, design-thinking mindsets, gender

Introduction

Recent reforms in K-12 education (e.g., NGSS Lead States, 2013) have highlighted the importance of an integrated method of learning science, technology, engineering, and mathematics (STEM). These reforms suggest that students should engage in engineering design processes in which they solve authentic human problems (Kelley & Knowles, 2016). Consequently, design-based learning (DBL) has become established as a pedagogical approach to integrated STEM education. DBL typically involves stages such as "defining the problem and identifying the need, collecting information, introducing alternative solutions, choosing the optimal solution, designing and creating a prototype, and evaluation" (Doppelt et al., 2008, p. 24). These stages require students to engage in design thinking, which is "a way of finding human needs and creating new solutions using tools and mindsets of design practitioners" (Kelley & Kelley, 2013, p. 37). Scholars have argued that design thinking not only makes STEM education humanistic (Bush et al., 2022) but is also "important for every student to develop and have in the 21st century" (Li et al., 2019, p. 94).

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According to Kelley and Kelley (2013), design thinking calls for particular mindsets. A mindset can be defined as "a habitual mental outlook that determines how one interprets and responds to situations and is separate from cognitive competence and logic that are highlighted in the process aspects of design thinking" (Gaim & Wahlin, 2016, p. 41). Design-thinking mindsets (DTMs) are "distinct from the processual and methodological aspects of design thinking but at the same time evolving and influenced by them" (Vignoli et al., 2023, p. 2). A DTM entails empathy, a willingness to take action to help others, eagerness to learn, a desire to communicate and collaborate, openness to diverse perspectives, awareness of design processes and one's own mode of thinking, tolerance to ambiguity and uncertainty, creativity, confidence, optimism, and resilience (Dosi et al., 2018).

Students' DTM can be fostered by DBL. Conlin et al. (2015) found that students would overcome their fear of failure in DBL by discussing the importance of generating multiple prototypes and by seeking constructive criticism. Marks and Chase (2019) noted that students develop a fail-forward mindset after exposure to DBL when tenets of design thinking (e.g., try early and try often) are made explicit. However, DBL can create conditions that undermine some aspects of the DTM. Chusinkunawut et al. (2021) observed that students encountered conflict with peers during DBL. Such conflicts can inhibit the development of the collaborative aspect of the DTM (Ladachart, Khamlarsai et al., 2022). Moreover, different students are likely to approach DBL differently (McLean et al., 2020), because of variations in empathic ability (Toussaint & Webb, 2005) and attitudes to collaboration (Bear & Woolley, 2011). In general, the questions of whether and how students with different characteristics can develop a DTM when they engage in DBL collaboratively are poorly understood.

According to Datta (2007), "clear gender differences have emerged in students' learning dispositions, how they approach the design problem, where they experience learning, and how they perceive their learning experience" (p. 30). This observation aligns with existing studies on gender differences in characteristics that are associated with the DTM. For example, Stump et al. (2011) found that female students tend to engage in significantly more collaboration than male students; thus, the presence of female students in groups can enhance group collaboration and performance (Bear & Woolley, 2011). Moreover, given that women tend to be more empathetic than men (Toussaint & Webb, 2005), female students are likely to show greater concern for clients and their needs in design-based projects (Laeser et al., 2003). Little is known about the effect of these gender differences on the development of DTMs in the context of DBL.

One goal of STEM education is to increase the availability of STEM-qualified labor (Promboon et al., 2018). The feasibility of that objective depends on the number of individuals who pursue STEM education (Blackburn, 2017).

One promising approach is to introduce students to DBL at an early age (Capobianco et al., 2015). However, those students can encounter a stereotypical bias in favor of male engineering students (Bell et al., 2003), which is common in Thailand (Ladachart et al., 2020), a country with a historically patriarchal sociocultural ideology (Tantiwiramanond, 1997). Female students' engagement in and contribution to DBL may therefore be limited (Wieselmann et al., 2020). This problem can be aggravated by teachers who are unaware of gender bias and mainly rely on masculine design-based activities (Okudan & Mohammed, 2006). This bias may hinder attempts to recruit and retain more female STEM students.

This study aims to investigate whether and in what respects the gender differences that are associated with the DTM are present when students engage in DBL about pulleys. The instructional activity is likely to be considered more masculine than feminine—Jones et al. (2000) found that "more males than females reported prior experiences outside of school with a variety of tools and objects, including … pulleys" (p. 185). Given that "the representation of women in STEM matters" and that "diversity in the workforce contributes to creativity, productivity, innovation, and success" (Blackburn, 2017, p.236), a deeper understanding of gender differences can provide insights into the development of DTMs during DBL. Furthermore, since prior experience in design can vary between students, it is also useful to inquire whether and in what respects the DTM of the experienced differs from the inexperienced. The three research questions follow.

(1) Do boys and girls differ in terms of DTM before DBL, and, if so, in what respects?

(2) Do students with more experience in design and students with less experience in design differ in terms of DTM before DBL, and, if so, in what respects?

(3) Do initial gender- and experience-related differences in design change after DBL?

Method

To address these research questions, we utilized a quasi-experimental study with a one-group pretest–posttest design (Chiang et al., 2015). Specifically, we measured students' DTMs before and after DBL in order to address the third research question, and we compared the DTM of boys and girls and those of more and less experienced students in order to address the first two research questions.

Context

This study was conducted in a secondary school in northern Thailand. Although it is only 16 kilometers from the nearest city, the school is surrounded by agricultural areas. Consequently, parents of means (e.g., businessmen and government officers) prefer to send their children to the more privileged school in the city. Most of the students at the school are from lower-income local families (e.g., the families of agricultural workers and laborers). There are 49 teachers in the school of whom 13 teach science, including the second author. At 56 years of age, she has accumulated 30 years of teaching experience. She participated in the study due to her interest in STEM education and DBL. She was responsible for teaching physical science for two cohorts of eighth-grade students and to four cohorts of four ninth-grade students.

Students

A class of 25 eighth-grade students (9 boys and 16 girls) participated in the study voluntarily. The students engaged in DBL about pulleys in five self-selected groups of five. There were two female-only groups and three gender-mixed groups. In the three gender-mixed groups, the ratios of boys to girls were 4:1, 3:2, and 2:3. The students were asked to report on their prior experience in design on a 1–4 scale (“never,” “rarely,” “often,” and “always”). Seven boys indicated that they had little experience in design, while the other two boys noted they had considerable experience in design. In contrast, 10 girls reported that they had considerable design experience, while the other six assessed their experience as limited. As summarized in Table 1, the members of each group differed in terms of gender and prior experience in design. The students who reported that they had been exposed to design “rarely” were labeled as possessing less experience, and the students who reported that they had been exposed to design “often” were labeled as possessing more experience.

Design-Based Learning

We chose Apedoe et al.’s (2008) model as our pedagogical framework (Ladachart, Chaimongkol et al., 2022). This model initially has the students design pulley setups by drawing on their prior knowledge. Zubrowski (2002) asserted that “this beginning exploration is a critical one that often is undervalued” (p. 59). Then, students’ pulley setups are tested empirically. The designs are compared to help the students notice critical differences in operation (Chase et al., 2019). By noticing the ways in which a pulley can be set up (i.e., fixed or moveable) and the impact of the setup on the effort that is necessary to lift an object, the students can explore issues and generate hypotheses for scientific investigation (Malkiewich & Chase, 2019). Once the students complete the scientific inquiry, they are asked to apply the results by redesigning their setups.

Table 1
Students' Genders and Reported Experience in Design

Group	Experience in design	Gender	
		Boys (N = 9)	Girls (N = 16)
1	Less	3	0
	More	1	1
2	Less	2	1
	More	1	1
3	Less	0	0
	More	0	5
4	Less	2	3
	More	0	0
5	Less	0	2
	More	0	3

In order to situate this DBL and integrate design thinking into it, the students were introduced to the design challenge by viewing a YouTube clip in which a male elder struggles to lift a water bucket from an agricultural well in a rural area that has no electricity. This clip was chosen for two reasons: it is relevant to the students' personal lives and it can trigger empathy. We expected that the students' altruistic feelings would be engaged. Each group was provided with four pulleys, a roll of string, and a rail. They were challenged to lift an object to a certain height with minimum force. The mass of the water corresponds to the object's weight, the depth of the well corresponds to the height that the object must be lifted, and the maximum effort of the elder represents the minimum force required to lift the object. The students engaged in this DBL for three weeks, with each weekly session lasting for two periods of 50 minutes.

Instrument

We used a Likert-scale questionnaire to measure DTM. We translated Dosi et al.'s (2018) 70 items, which cover 19 aspects of DTMs. Our translation was checked and rechecked by a team of teachers who could read and write English. We then conducted factor analyses with approximately 900 students. This process yielded 30 items that represent six characteristics of DTM, namely (1) collaboration with individuals with diverse backgrounds, areas of expertise, and perspectives (five items), (2) confidence and optimism about the use of creativity to solve complex problems (eight items), (3) aptitude for learning by making and testing (four items), (4) awareness of a process and its impacts on others (three items), (5) tolerance of uncertainty and risks (six items), and (6) human centricity (four items). The loading factors were 0.852, 0.822, 0.879, 0.974, 0.784, and 0.979, respectively (see Ladachart, Cholsin et al., 2022 for details). The Cronbach's alphas for the pretest and the posttest were 0.860 and 0.925, respectively.

Data Collection and Analysis

The students completed the pretest in December 2020, but DBL was not implemented until January 2021 because some students had to be quarantined due to the COVID-19 pandemic. The posttest was administered in February 2021. At each measurement, the students would complete the DTM questionnaire along with a conceptual test on pulleys (12 multiple-choice items) within 50-minute period. Once the data had been collected, we calculated the mean scores and the standard deviations of each DTM-related characteristics. Then, we used Wilcoxon signed-rank tests to examine potential differences between the mean scores on each test. We used Mann-Whitney *U* tests for each such score in order to identify gender and experience-related differences in DTMs. We set the significance threshold at .0. If any differences were found, we would calculate the rank-biserial correlation as an effect size. All analyses were conducted by using JASP (Goss-Sampson, 2020).

Results

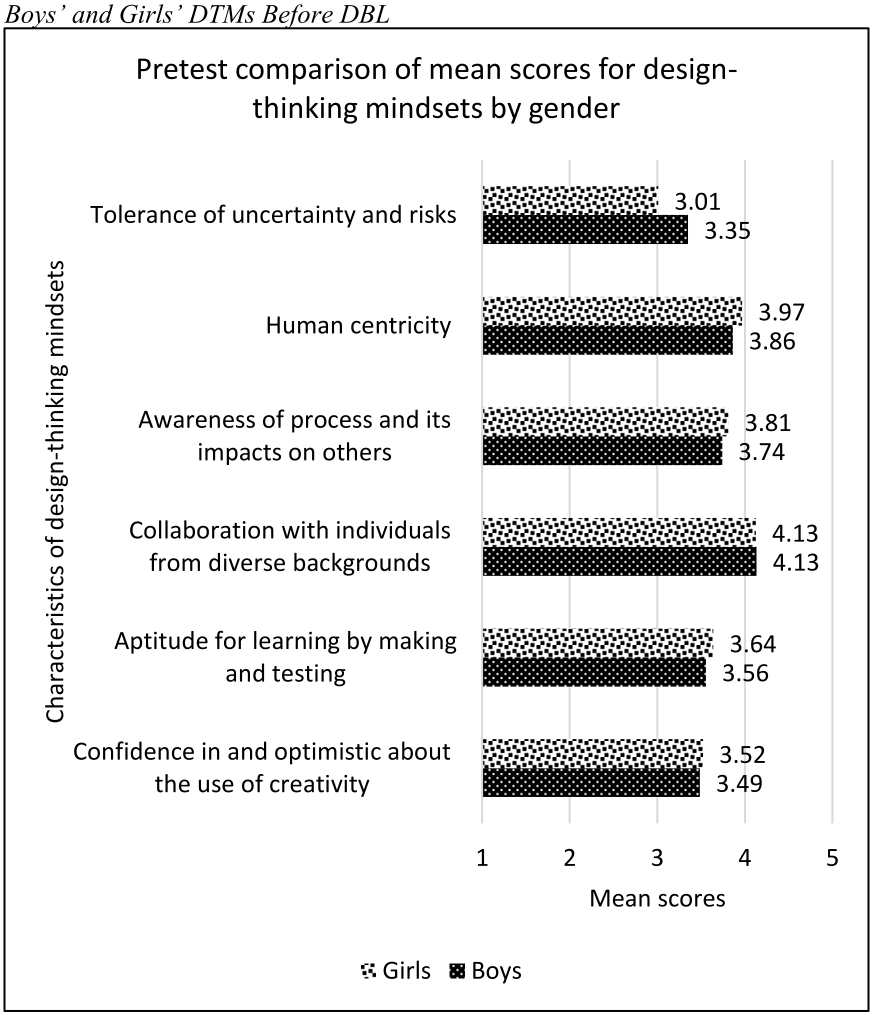
The descriptive analyses (see Figure 1) indicate that, before DBL, the girls received higher scores than boys for human centricity, awareness of a process and its impacts on others, and aptitude for learning by making and testing. However, the girls were less comfortable with uncertainty and risk. The scores for collaboration with individuals from diverse backgrounds were equal. The Mann-Whitney *U* tests suggest that none of these gender differences are significant ($p > .05$). After DBL, the girls' scores exceeded those of the boys on all of the dimensions under observation (see Figure 2), including collaborating with individuals from diverse backgrounds and tolerance of uncertainty and risk. However, the gender differences were not significant ($p > .05$). Therefore, there were no gender differences in DTMs, either before and after DBL.

Turning to experience, the descriptive analyses indicate that the more experienced students had higher scores for the characteristics under observation than the less experienced ones before DBL (see Figure 3). The Mann-Whitney *U* tests indicate that the differences are insignificant ($p > .05$). After DBL, despite the similarity to the pre-DBL pattern, a significant difference was detected in the scores for human centricity ($U = 41.0$, $p = .038$, $r = 0.41$). A comparison between Figure 3 and Figure 4 reveals that this significant difference resulted from a decrease in human centricity scores among the less experienced. Possibly, a lack of experience in design might impel students to perceive DBL negatively when they are asked to solve problems for others.

To understand the changes in the students' DTMs after exposure to DBL, we conducted Wilcoxon signed-rank tests. Regardless of gender and prior experience, DTMs did not improve significantly on any dimensions ($p > .05$).

Figure 1

Boys' and Girls' DTMs Before DBL



The only significant changes were that the girls became more comfortable with uncertainty and risks (z = 1.996, p = .046, r = 0.50) and that the more experienced students saw their aptitude for learning by making and testing decrease (z = −2.080, p = .038, r = 0.60). Therefore, DBL can have both positive and negative influences on DTMs. The nature of the effect depends, in some way, on gender and prior experience.

Figure 2
Boys' and Girls' DTMs After DBL

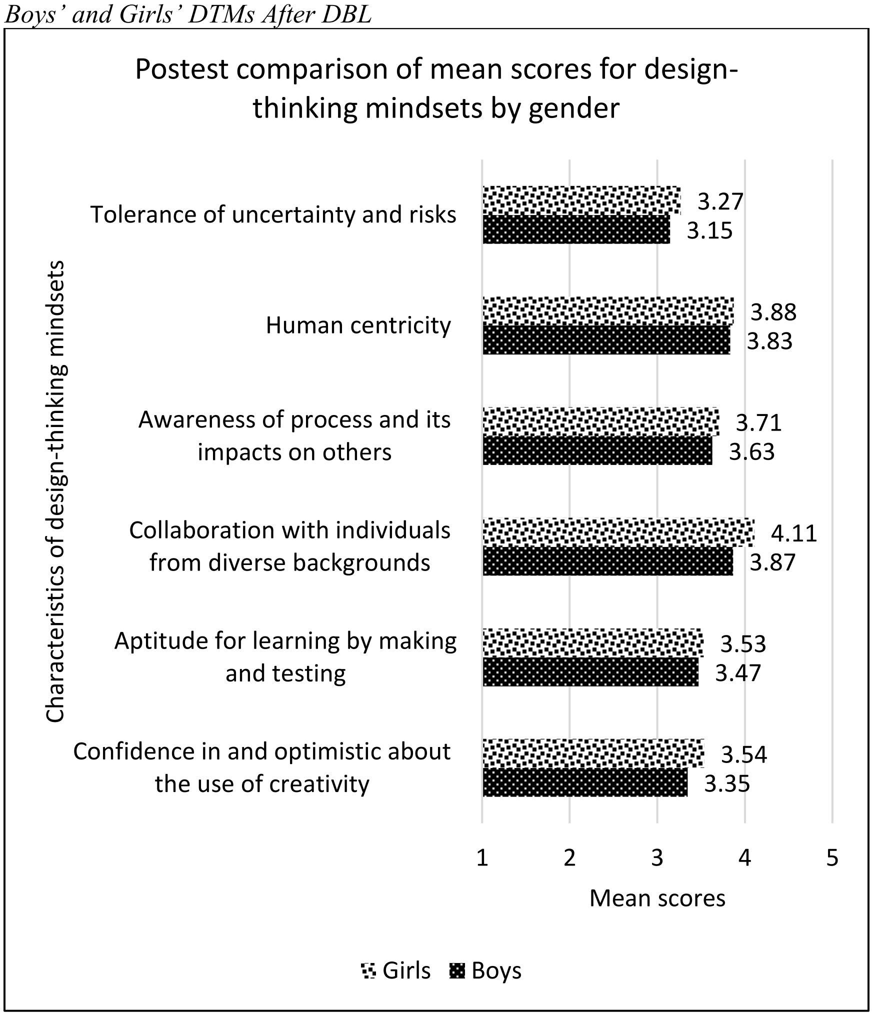


Figure 3

DTMs of Students with More Experience and Students with Less Experience Before DBL

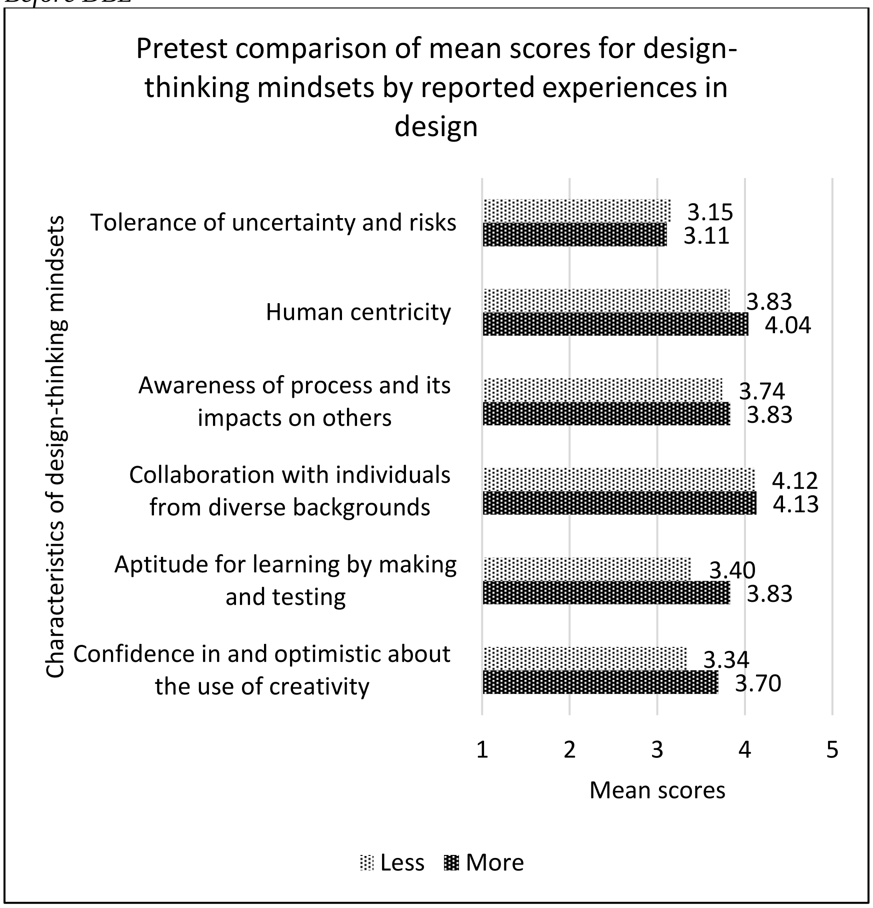
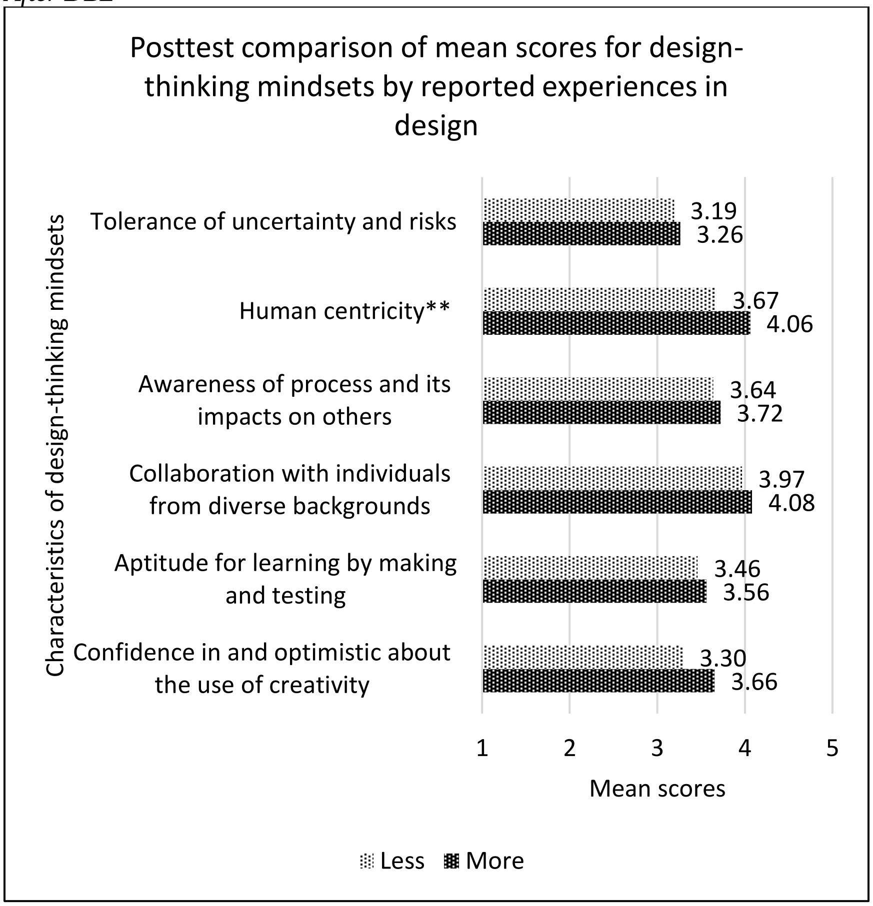


Figure 4
DTMs of Students with More Experience and Students with Less Experience After DBL



Note: ** indicates a significant difference at the .05 level.

Discussion

This study explored how gender and design experiences relate to differences in self-reported DTMs among eight grade students in Thailand. Moreover, we inquired whether DBL can improve DTM among students. Both before and after DBL, the scores for collaboration with individuals from diverse backgrounds were the highest and the scores for tolerance of uncertainty and risk were the lowest, regardless of gender and prior experience. These results should not be surprising given that “collaborative relationships have been established well in Thai science classrooms” (Chang et al., 2018, p. 11), where learning is limited mainly to "memorizing subject content" rather than encouraging solving unstructured problems (Dahsah & Coll, 2007, p. 228). While students might prefer working and learning in collaboration, they might feel uncertain about and uncomfortable with engineering design-based problems.

It should be noted that "pulleys are … often challenging for … students to set up on their own" (Sullivan et al., 2017, p.1579). Furthermore, students commonly entertain misconceptions about pulleys (Myneni & Narayanan, 2012), such as the beliefs that "the more pulleys there are in a setup, the easier it is to pull to lift a load" and that "the longer the string is a pulley setup, the easier it is to pull to lift a load" (p. 75). Thus, the students may have initially thought that they were likely to fail and that they would be judged by others accordingly. Before DBL, this perception was more pronounced among girls, who were less comfortable with uncertainty and risk, than among boys. One candidate explanation is that the boys might be unaware of those risks or less willing to acknowledge them (Jordan, 2015). Another is that the gender difference might have resulted from the common perception that engineering, as a discipline, is more masculine than feminine (Ladachart et al., 2020). Consequently, the girls may have formed the belief that engineering design-based activities are not suitable for them (Agogino & Linn, 2015).

The design task may have also contributed to the initial gender difference in uncertainty aversion. Pulleys, being simple machines, can be perceived as more masculine than feminine. Jones et al. (2000) noted that pulleys, like batteries and fuses, are tools that boys are more likely to have used outside of school. This hypothesis is sensible in the present context because we conducted the study in a rural area of Thailand, where men are traditionally responsible for outdoor work such as agricultural labor and construction, while women are expected to attend to household chores, such as cooking and cleaning (Vichit-Vadakan, 1994). The girls might have perceived DBL as being more suitable for boys (Okudan & Mohammed, 2006), which may have decreased their self-efficacy (Gunay et al., 2020) and caused them to doubt their ability to complete the task.

However, after DBL, the girls were more comfortable with uncertainty and risks that arise during engineering design processes. The initial difference seemed to have disappeared by the end of the design-based activities. If the girls recognized uncertainty and if they were better prepared to address it (Jordan, 2015), they likely managed it more successfully. Since the girls were likely to have been collaborative and the boys were likely to have been competitive (Schnittka & Schnittka, 2016), the former might have made better use of both internal strategies (e.g., developing confidence through practice and experience) and external strategies (e.g., seeking additional information, collaboration, and feedback) (Tracey & Hutchinson, 2018). Since collaborative relationships are emphasized in Thai science classrooms (Chang et al., 2018), peer interactions might have been more helpful to the girls than to the boys (Jordan & McDaniel, 2014).

The insignificant experience-related difference in human centricity became significant after DBL. The change was driven not by an increase in the corresponding scores among the more experienced students but by a decline in the results of the less experienced students. Some students may have simply viewed “design for others” as service (Zoltowski et al., 2012). Therefore, the less experienced students may have failed to comprehend fully why they had been asked to solve a problem for another individual. Moreover, they might have thought that user needs create additional and perhaps unnecessary constraints that complicate the design process. The students might also have been unwilling to help the elder from the video due to increasingly negative attitudes toward those who are more advanced in age (Sharps et al., 1998), especially among low-income individuals (Yoon et al., 2017). This negative result warrants more research on students’ perceptions of solving problems for others.

Beyond the post-DBL change in risk and uncertainty tolerance, we found no other significant differences between the boys and the girls. Despite the literature indicating that women tend to be more empathic (Toussaint & Webb, 2005) and collaborative (Stump et al., 2011) than men, the girls and the boys exhibited no differences in these characteristics. Likewise, even though men have been said to be more creative than women (Proudfoot et al., 2015), we found no gender differences in confidence in and optimism about the use of creativity to solve problems. Similarly, the results for awareness of the process and its impact on others and for aptitude for learning by making and testing were the same for both genders. Prior experience seems to have been more influential than gender. After DBL, the DTMs of students with different levels of design experience deteriorated on different dimensions (i.e., human centricity for the less experienced and experiential learning for the more experienced).

Implications

Since STEM education become a part of K–12 curricula, DBL has been considered as a pedagogical approach that equips students with the ability to solve not only their own problems but also those of other individuals. Therefore, cultivating a DTM among students is essential. However, the development of DTMs among students within the context of DBL was complex and challenging. The DTMs of students with specific attributes such as gender and prior experience, change in different ways. Consequently, teachers may wish to use scaffolding with circumspection when designing, planning, and implementing design-based activities. Without appropriate scaffolding, DBL is likely to undermine students’ DTMs because they may not know how to navigate the challenging (e.g., uncertain) situations that arise during the design process productively. We thus recommend that design-based activities be framed in a manner that ensures that students with diverse characteristics can engage in, contribute to, and benefit from DBL equally. Teachers, if they are mindful of diversity, can impel students to share and negotiate their DTMs productively.

Limitations

This study has several limitations. First, it focused on a single class of eighth-grade students who were inhabiting the same geographical and cultural environment. The results cannot fully be generalized to students in different circumstances or to younger or older students at the same location. Second, since the quantitative data were collected through a self-reported questionnaire, much depended on the student's interpretations of the questions and the available responses, which may have been driven by humility or apprehension. Deeper insights into the changes in the students' DTMs were not available. Qualitative data are needed for a more comprehensive explanation of the changes in DTMs that result from DBL are to be understood more profoundly. As a consequence, the results on gender and experience-related differences need to be verified and refined with a larger and more diverse sample. Despite these limitations, this study offers several useful insights into the nature of the DTM and into the ways in which it can be cultivated in the context of DBL.

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