Understanding Interrelated Growth Mind-set and Academic Participation & Performance

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Towards Understanding Interrelated Growth Mindset and Spatial Visualization Skill Training

Abstract

Spatial Visualization skills is a key predictor of students' academic performance in STEM classes, retention rate in STEM majors, and future career choice. Previous research focusing on students' spatial visualizations skills has impacted educational practice, including the formation of targeted training to help students overcome difficulties in overall visualization skills. Research in developmental psychology shows individuals with the growth mindset are often more actively engaged in the training process and as such gain higher improvement in skills of study. However, students' mindsets in spatial visualization skills were rarely studied. To understand and describe the relationship between mindset and (1) willingness to participate in a skill-development workshop and (2) visualization skills growth, in this paper, we studied 490 students from three first-year engineering courses that heavily emphasized their spatial visualization skills. We assessed all students' spatial visualization skills via the Purdue Spatial Visualization Test: Visualization of Rotations pre and post the course and collected their final course grades. We also collected survey regarding mindsets toward spatial visualization skills for all students (n = 289) who participated in the online workshop. Our results indicate 1) students who actively engaged in the training process reported having a high growth mindset, 2) having a growth mindset will bring better learning outcomes, and 3) mindset about spatial visualization skills is malleable. We believe our findings provide strong evidence for integrating growth mindset interventions in spatial visualization training programs that may benefit students academic performance in engineering education and future career.

Introduction

Spatial visualization skills, which refers to the ability to visualize and manipulate 3D objects in the mind, has been shown in previous research as one of the most important predictors of success in engineering education and future careers [7, 8, 11]. Students with good spatial visualization skills demonstrate better performance in understanding and solving complex engineering problems [12]. Because of this importance, a lot of effort has been invested in equipping college engineering students with compatible spatial visualization skills [12, 13, 14, 15, 16, 19]. Current attempts in curriculum design, personalized workshops, and intelligent training platforms have shown promising results in skill-training and STEM retention rates [7, 11, 14, 16].

With the goal of further improving the quality of spatial visualization training, in this paper, we looked at students' mindsets regarding spatial visualization skill. Mindset, coined by Dweck, indicates one's belief of where ability comes from [4]. Mindset research indicates two categories of mindsets, Growth Mindset versus Fixed Mindset [4]. Individuals who hold a growth mindset often believe their intelligence or abilities can grow if they exert more effort or try new learning approaches whereas individuals who hold a fixed mindset often believe no matter how hard they try, their intelligence or abilities will not change since they are fixed. Research has shown that individuals who have a growth mindset more readily participate in training programs, enjoy the learning process more, and eventually perform better after training programs [1, 4, 5, 6, 10, 17]. Research also suggests individuals' mindsets are malleable as well [4, 18]. Growth mindset intervention has been developed and examined in multiple domains [2, 3, 4, 18]. Therefore, understanding students' mindsets is important in building an effective training program.

Although some research shows individuals' mindsets are global beliefs about abilities in general, most recent research shows that individuals' mindsets are domain specific [1, 4, 5]. For example, some individuals believe intelligence is fixed while believing their mathematical ability can be improved through learning. Although research has studied individuals' mindsets in different domains such as intelligence, emotion, mathematical capability [1, 4, 5, 9], to our best knowledge, we are the first study investigating an individual's mindset regarding spatial visualization skills and association with the spatial visualization training process.

Our study is set to understand students' mindsets about spatial visualization skills and how students' mindsets are associated with their training outcome of spatial visualization skills. We conducted a field study with 490 students in the real-world learning environment at a big public university. We assessed students' spatial visualization skills as a pre and post-test in three entry-level engineering courses that strongly emphasized students' spatial visualization skills. A subset of students (N = 289) voluntarily participated in a 7-week long online spatial visualization workshop. We assessed those students' mindsets concerning spatial visualization skills twice: at the beginning and end of the workshop. We then performed a series of analyses investigating students' spatial visualization skills and their mindsets.

We found 1) in general students tend to hold a growth mindset toward spatial visualization skills, 2) Students who hold a growth mindset gain more improvement from the online workshop, and 3) Students' mindsets about spatial visualization skills changed toward a growth mindset after the training program. We believe our study shows a promising future for integrating growth mindset intervention into the current spatial visualization training workshop to further improve the training effect that will eventually benefit students for their future learning and career success.

Method

Participants

Study participants were students from three entry-level engineering courses at a big public university. All three courses aim to expose students to the standards of engineering design graphics, computer-aided design techniques, and basic skills for engineering sketching. We targeted those courses because students' spatial visualization skills are strongly emphasized in those courses according to instructors' previous experience. In other words, lacking adequate spatial visualization skills usually causes learning difficulties in those classes. A total of 490 students consented to join our study. Out of those 490 students, 289 students completed the online workshop and answered a survey assessing their mindset about their spatial visualization skills. For students who completed the online workshop, 171 are male and 118 are female. 181 are freshmen, 68 are sophomore, 40 are junior and beyond.

Study Procedure

All 490 students' spatial visualization skills were measured at the beginning and end of the semester. Although the interval between the two assessments is about 16 weeks, to reduce the test-retest effect, similar to [14], we randomize the order of the question for each of the students in both assessments.

After the initial assessment, students can see their results immediately. We then invited all students to participate in a seven-week long online workshop that was designed to promote a student's spatial visualization skills. This workshop was co-current with the course. To incentivize students to join the online workshop, upon the completion of the workshop, instructors of the three courses offered extra credits worth about 1% of the overall course grade. Similar to another recent study [16], the workshop contains seven diverse topics designed to improve students' spatial visualization skills. The order of each week's material is different for students from different courses in order to match their course progress. All seven topics were covered or partially covered in all three entry-level engineering classes. For each of the topics, students were required to complete a set of exercises through the website. On average, students spent about 30 minutes each week on the workshop.

At the start and the end of the workshop, students were given a set of questions to measure their mindset about spatial visualization skills. Additional questions were asked at the end of the workshop to ask their learning and user experience about the online workshop.

Measures

Pre-course & Post-course Spatial Visualization Skill Assessment. Both assessments were the standard PSVT: R test [19] with 30 multiple choice questions. PSVT:R is a well-development and widely-used assessment for spatial visualization skills [19]. Students were only allowed to take the test once in both assessments and the time cap for the test is 30 minutes.

Students' Mindset about Spatial Visualization Skills (Mindset Score). We adopted the mindset measurement from Dweck and colleagues [4] and modified the wording of each item to make the measurement more tailored toward spatial visualization skills. Specifically, we changed the phrase "intelligence" or "abilities" in the original scales to "spatial visualization skills", which yielded a 4-item survey on students' mindset about their spatial visualization skills. For each of the item, students will rate on a 5-point Likert scale from "Strongly Agree" to "Strongly Disagree". The final aggregation score for each student is from 1 - 5 where 1 means "strong inclination to a fixed mindset" and 5 means "strong inclination to a growth mindset.

Results

The focus of our analysis was to understand how students' mindsets about their spatial visualization skills were associated with their learning outcomes in the online spatial visualization workshop and the potential of growth mindset intervention in spatial visualization skills training.

Students' Mindset About Their Spatial Visualization Skills

Before students started the workshop, their spatial visualization skills mindset was assessed. The average Mindset Score was 3.27, SD = 0.78, N=289, which indicates a tendency toward a growth mindset. Although the overall result indicates students tend to believe their spatial visualization skills were malleable, trainable and changeable, 34% of students lean towards a fixed mindset (Mindset

Score < 3) about their spatial visualization skills. A student's mindset score does not significantly differ by gender (Male Students: M = 3.24, SD = 0.81; Female Students: M = 3.33, SD = 0.73; $t = -0.86$, $p = 0.39$).

Students' Learning Outcome

In this section, we examine students' spatial visualization learning outcomes. To show students' learning outcomes, we compared students' spatial visualization assessment score at the beginning and the end of the semester. There were two groups of students in our analysis; one group of students took the class (N = 201, 45% female students) while another group of students took both the class and the online workshop (N = 289, 41% female students). For students who only took the class, the average post-course PSVT:R score (M = 24.14, SD = 4.39) is significantly higher than their pre-course PSVT:R score (M = 23.10, SD = 4.68); $t = 2.31$, $p < 0.05$*. This suggests that the engineering courses impacted students' developing spatial visualization skills. Similarly, for students who took both the class and the online workshop, the comparison between pre- (M = 21.92, SD = 5.50) and post- (M = 23.96, SD = 5.25) course PSVT:R score also shows significant improvement; $t = 4.53$, $p < 0.01$**. Both results demonstrated students;' improvement in terms of their spatial visualization skills over the semester. Note that students who opted to participate in the optional online workshop (M = 21.92, SD = 5.50) scored lower at the beginning of the semester than those who did not participate (M = 23.10, SD = 4.68); $t = -2.54$, $p<0.05$*. Although students who did not participate have less room for improvement, only 11 out of 289 of them got the full mark (30 out of 30) at the post-course assessment comparing to 19 out of 201 students who took the workshop and got the full mark.

Furthermore, we compared the improvement between two groups of students. The results show that students who took both class and online workshop (M = 2.04, SD = 4.68) gained significantly higher improvement in their spatial visualization skills than those who only took the class (M = 1.04, SD = 4.19); $t = 2.43$, $p < 0.05$*. The result demonstrates the utility of the online workshop in training students' spatial visualization skills. We believe such improvement will further benefit students in their future learning and career.

Potential for Growth Mindset Intervention

In this section, we look at how students' spatial visualization skills mindset relates to their learning outcomes from the online workshop and how their mindset changes over the training process.

First, no significant correlation was found between workshop students' spatial visualization assessment and their Mindset Score at the beginning of the semester ($r = -0.02$, $p = 0.70$). Although previous research [6] shows students who have fixed mindset about their ability will not actively engage with the training process, we believe the extra credit offered by course instructor served as a strong incentive for students to complete the workshop. We further examined the relationship between students' mindsets and their learning outcomes. We found students' Mindset Score at the end of the workshop positively correlated with their spatial visualization skill improvement and further Pearson correlation test indicates the correlation is significant ($r = 0.13$, $p < 0.05$*). In other words, students who have a growth mindset about the spatial visualization skills at the end of the online workshop tended to gain more from the online workshop. Further analysis shows students' gender has no significant moderation effect on the correlation. The result is aligned with the previous research that students with a growth mindset about their ability often gain more from the learning process.

Second, to see if students' mindset about spatial visualization change throughout the training process, we compared students' mindset at the beginning and the end of the workshop. The results show a significant change towards growth mindset ($M_{pre} = 3.27$, $SD_{pre} = 0.78$; $M_{post} = 3.50$, $SD_{post} = 0.85$; $t = -3{,}31$, $p < 0.01$**), which indicates when students engaged in the spatial visualization training process, their belief also changed as well. The difference is not differentiated by students' gender either. When students are making progress in the study, they may see skills they previously believed to be fixed improving which leads to a change in mindset. The evolution of the mindset suggests using the online workshop as a growth mindset intervention or implementing other growth mindset intervention in the workshop to further improve students' spatial visualization skills.

Discussion

Research has shown the importance of spatial visualization skills in engineering education [7, 8, 11]. Although researchers have explored various spatial visualization training methods, the role of mindset has not been fully understood. In our study, we aimed to understand how students' mindsets about their spatial visualization skills associates with spatial training, especially through the online workshop, a recent innovative method to train spatial visualization skills at scale [16]. Our findings show in general, students who participated in the workshop tended to believe spatial visualization skills can be changed with effort. Moreover, students who have a stronger growth mindset gained more through the online workshop which aligns with previous studies that a growth mindset can benefit learning outcomes. Similar to the previous research on the mindset about intelligence and mathematical capabilities, we found spatial visualization skills mindset is also changeable which indeed opens the possibility for intervention opportunities. We believe an effective spatial visualization training program will make students be more confident and motivated to tackle engineering problems that rely on spatial skills. Further research can test to what extent such intervention may be useful to increase retention rates in engineering, especially for at-risk students.

Limitation and Future Work

We also want to point out several limitations of our study. First of all, although we collected demographic information of students who participated in the online workshop, we may have a more comprehensive understanding of our results if we can collect the demographic information of all students who only took the class. Second, we only measured the mindset of students who participated in the online workshop. If we can know all the students' mindset about spatial visualization skills, we can a better understanding of students' mindset and test if the workshop can be served as an effective growth mindset intervention. Third, although previous studies showed that spatial visualization skills training can benefit students in their overall engineering learning, our studies were limited to students' performance in entry-level engineering graphic courses. If we can track students' performance in other classes, the data will help us better understand how growth mindset in spatial visualization training can benefit students in a long term.

According to our results, students' mindsets about spatial visualization skills can also change, which gives us the opportunities to design and develop growth mindset interventions specifically for spatial visualization capabilities. Another research direction is integrating growth mindset intervention in spatial visualization training. As our results show, students who have a growth mindset improved more after taking the online workshop. Before or during the course of the workshop, instructors can intervene with a certain growth mindset intervention, such as activities that aimed to tell students on how effort and struggle increase academic capabilities, to change students' mindset for better learning outcomes. Moreover, building upon previous research on the intelligent spatial visualization training platform [14,16], we believe the growth mindset intervention can be personalized as well. With machine learning algorithms, the platform can deliver the most effective growth mindset intervention based on students' individual characters such as learning style and personality types.

Conclusion

With the motivation for improving a spatial visualization training program and understanding students' mindset about their spatial visualization skills, this research revealed several student attitudes regarding the topic. Through a study with about 500 students in a real learning environment, we found that most students believe spatial visualization skills are a trainable ability, having a growth mindset about the spatial visualization skills can benefit students with more improvement of their spatial visualization skills after the training program, and students' mindset changes as the training progresses. Our findings can serve as a sound basis for the integration of growth mindset intervention in the future spatial visualization training program to motivate students to join the training process, engage with the learning materials actively, acquire better spatial visualization skills, and eventually succeed in their engineering education and future careers.

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