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Application of Online Visual-Spatial Training to Increase Visual-Spatial Ability and Growth Mindset of Engineering Students*

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The preponderance of growth mindset intervention studies focus on elevating a growth mindset by teaching students that the mind is like a muscle and that it grows stronger through rigorous mental exercise. But, there is also the potential to elevate a growth mindset via strengthening intelligence. Spatial visualization promotes successful engineering performance and many college students would benefit from improved visual-spatial ability. The primary objective of this study was to examine whether a brief online workshop that teaches visual-spatial skills (e.g., mental rotation) would increase both visual-spatial ability and a growth mindset for spatial intelligence. This study included 296 undergraduate mechanical, systems, industrial, and aerospace engineering students that participated in a total of 3.5 hours of a workshop that trained students in visual-spatial thinking over the course of 7 weeks. Outcome measures included pre/post Purdue Spatial Visualization Test-Visualization of Rotations (PSVT:R) and pre/post growth mindset for spatial intelligence. Paired sample t-tests indicated that students improved significantly from pre to post-workshop on both mental rotations (Cohen's $d = 0.38$) and growth mindset ($d = 0.33$). Women improved as much as men on both measures. This study suggests that an online visual-spatial intervention can efficiently promote stronger visual-spatial ability and a growth mindset.

Keywords: growth mindset; visual-spatial ability; STEM; college students; intervention

1. Introduction

1.1 Importance of Growth Mindset Interventions and a New Alternative

A growth mindset can be promoted by college instructor statements, such as "everyone can learn statistics if they try" [1]. Other growth mindset interventions include discussing stories of famous people who overcame challenges to achieve success, while also recognizing that failure is not an indication of intelligence [2]. Most growth mindset interventions involve psychoeducation, such as explaining that the mind is like a muscle that grows stronger with rigorous mental exercise. In some cases, neuronal growth and neuroplasticity are explained to help students understand that their brain develops through learning and memory. After learning about growth mindset and neuronal development participants are often asked to write a letter to encourage younger or future students who are struggling in school and may feel that they lack adequate intelligence [3, 4]. Writing a letter to other learners is a form of indirect framing, which has led to stronger effects than direct framing (e.g., "Would you like to be smarter? In this program we share how to make your brain smarter" [4]). The indirect intervention is stealthy in that the participant is engaging in self-persuasion, while thinking that they may be helping someone else rather than feeling like the researcher is trying to persuade them to have a growth mindset. This indirect

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framing feels less controlling thereby preventing resistance and supporting autonomous motivation [5]. These growth mindset interventions via live workshops and online have been effective in numerous studies with students in elementary school, secondary school, and college [3, 6, 7], and in particular with middle school girls in STEM [8]. Namely, growth mindset interventions have helped students overcome fixed mindsets (the belief that intelligence is immutable) and strengthen their belief that intelligence can be changed. Students with a growth mindset experience a plethora of educational and psychological benefits, such as the increased likelihood of setting learning goals, which, in turn, is associated with greater intrinsic motivation, academic engagement, and achievement [3, 6, 9]. In order to pursue their learning goals, students with a growth mindset pay more attention to corrective feedback after failure, such that they learn more from their mistakes [10]. However, the limited studies of growth mindset with engineering students, such as Dringenberg and Kramer [11], suggest that affecting mindset requires thoughtful and in-depth intervention.

Although they have created valuable ways of increasing growth mindset, the established growth mindset interventions do not fully address concerns that some astute students, scientists, and professors have such as the fact that genetics play a significant role in determining intelligence (suggesting a mix of heritability and malleability) [12] and that intelligence tests demonstrate rather high stability over many years [13, 14]. Perhaps one of the most convincing ways to promote a growth mindset (a.k.a. an incremental theory of intelligence) [15] would be to help students increase some aspect of their intelligence. This leaves the self-persuasion up to the individual, but the idea is that they will say to themselves something like, "my visual-spatial ability just increased over the course of this workshop, therefore visual-spatial ability is malleable". This may be an even more indirect and stealthy form of growth mindset intervention than those employed by Aronson and colleagues [3] involving writing letters to future struggling students about how to overcome feeling stupid in the face of failure.

1.2 STEM and Spatial Visualization Skills

Spatial reasoning promotes emotional intelligence, achievement in STEM subjects, and success in engineering [16–24] as students with lower visual-spatial ability are more likely to struggle with applied physics, engineering mechanics, and engineering graphics [25]. Visual reasoning is important to the engineering profession and engineering education in general. Core engineering undergraduate courses such as calculus (e.g., derivatives and integrals in three dimensions) and mechanics of materials (e.g., load analysis, stress analysis) are difficult concepts that are greatly improved from sketching and visualizing. Researchers have established factors including general intelligence, problem-solving ability, and previous experiences in games and drawings are directly related to spatial skills [26]. Unfortunately, visual-spatial ability generally declines steadily between the ages of 20 and 70 [27, 28]. Moreover, some researchers have established a gender gap in visual-spatial skills at both pre-test and post-intervention (e.g., [19, 29]) while others noted the gender gap can be addressed with intervention [30, 31]. These findings suggests that interventions that can increase visual-spatial ability could be vital to rich intellectual functioning during college and when entering STEM fields and might help close the gender gap. This suggests that interventions that can increase visual-spatial ability could be vital to rich intellectual functioning during college and when entering STEM fields

1.3 Interventions to Increase Visual-Spatial Skills

A meta-analysis of visual-spatial ability interventions revealed a moderate training effect, with a Hedge's g of 0.47 [30]. They also found that neither age (children vs. adolescents vs. adults) nor training type (course vs. videogame vs. special tasks) was associated with the magnitude of the effect. This indicates that visual-spatial skills can be trained at different ages with various methods, suggesting a moderate malleability of visual-spatial skills.

Many visual-spatial interventions have been delivered in laboratories, resulting in limited sample size and questionable ecological validity. For instance, in spite of a large training effect, Feng et al. [31] only recruited 20 students in the intervention (with 10 in the control group and 10 in the treatment group), a sample size that makes it hard to meet the assumptions of many inferential statistics tests. Other studies have involved course-based interventions, which often last one-semester long and tend to have a larger sample (e.g., [19]). One common practice of this type is engineering graphics courses [30], where students are frequently exposed to 3D rotation or modeling work. However, due to the semester format, the length of each session is relatively long (usually 60 to 90 minutes a week for 10–15 weeks) [19, 24, 32, 33]. Other larger studies of over 200 international students incorporated pilots of multiple technologies such as virtual and augmented reality [34]. More recently, interventionists have attempted to deliver training through an online platform, which seems to be more scalable [35]. The treatment group improved significantly more than a passive control group; however, as the treatment group consisted of only

17 low-ability students and gender was not considered, more efforts are needed to truly identify its effectiveness.

1.4 The Current Study

This study will shed light on whether brief online visual-spatial training can promote a growth mindset, while also strengthening visual-spatial ability among engineering students. In particular, this will help to see if just 30 minutes of this weekly training online over the course of seven weeks (3.5 hours total) can help mechanical, civil, systems, industrial and aerospace engineers increase a crucial ability and mindset.

The following hypotheses were made: (a) students participating in the spatial visualization workshop would develop significantly stronger visual-spatial ability over the course of 7 weeks; and (b) students participating in the workshop would significantly improve on growth mindset for spatial intelligence.

2. Method

2.1 Participants

This research took place at a large Midwestern University in the United States in four introductory engineering design and graphics courses in the Fall of 2018. The 296 students in the workshop were predominantly first-year students in Aerospace Engineering (AAE), Civil & Environmental (CEE), Industrial & Systems Engineering (ISE), and Mechanical Science and Engineering (MechSE). Out of the 296 students (65.7% male, 34.3% female), 68.5% were freshmen, 16.7% were sophomores, 11.5% were juniors, and 3.3% were seniors.

2.2 Procedure

Students were given the opportunity to participate in the study by reviewing and signing the consent form, filling out a brief background questionnaire, and completing a pre-test and post-test measure. This study was approved by the university Institutional Review Board (IRB). As part of each of the four engineering courses, students completed the Purdue Spatial Visualization Test-Visualization of Rotations (PSVT:R) at the start of the semester. Results of the PSVT:R were visible to students immediately after completion. This class assignment of the pre-PSVT:R was graded for completeness (i.e. binary) rather than for performance. Students were offered a small number of extra credit points for taking the PSVT:R at posttest. All students in the four courses were invited to participate in a seven-week long online workshop designed to promote students' spatial visualization skills [35]. Students were incentivized to join the online workshop with the potential to develop their visualization skills as well as extra credit worth about 1% of their overall course grade. Students who participated in the online workshop completed a pre/post Growth Mindset for Spatial Intelligence test. This study focuses on those students who completed the online workshop.

2.2.1 Workshop Description

This workshop was concurrent with the courses, with content mirroring what was covered in each course. The workshop contains seven diverse topics designed to improve students' spatial visualization skills. 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 online seven-week workshop, whereas other similar course-based interventions usually last 1 to 1.5 hours per week for 10 weeks or more [24].

The spatial visualization workshop was hosted online and required students to complete weekly exercises. The workshop is designed for the first-year engineering students to learn and improve their spatial visualization skills. The total length of the workshop is eight weeks. The first seven weeks contain training materials that aimed at different aspects of the spatial visualization skills, and the last week is the second PSVT: R assessment to assess students' growth in spatial visualization skills.

The materials for the seven weeks of training are adapted and modified from an existing spatial visualization workshop and a well-known spatial visualization training workshop ([35]; Sorby, 2011). The series of weekly exercises span seven diverse related topics in spatial visualization skill training, including (1) Surfaces and Solids of Revolution, (2) Combining Solid Objects, (3) Isometric Drawings & Coded Plans, (4) Orthographic Drawings, (5) Flat Patterns, (6) Inclined and Curved Surfaces, and (7) Rotation of Objects About a Single Axis or Multiple Axes (See Table 1). In this study, students completed one topic per week in the same order mentioned above. Most of the exercises contain a set of multiple-choice questions regarding the week's topic. For Orthographic Drawings, Inclined and Curved Surfaces, and Rotation of Objects About a Single Axis or Multiple Axes, free-hand sketching questions are included. Students need to use the sketching tool provided by the online platform to complete those free-hand sketching questions. Fig. 1 is a sample of the online platform. The left figure shows the homepage of the online workshop. The two figures on the right show examples of two question types, multiple choice and freehand sketching, supported by the online platform.

The weekly exercise takes about 30–40 minutes to

Table 1. Workshop topics and learning objectives

Workshop Topics	Learning Objective
Surfaces and Solids of Revolution	Students will learn how surfaces and solids are formed when a 2-D shape is revolved about an axis and practice visualizing revolutions.
Combining Solid Objects	Students will learn how two overlapping objects can be combined to make a new object by joining, cutting, or intersecting.
Isometric Drawings & Coded Plans	Student will learn how to represent and draw 3-D objects on a 2-D plane. Orthographic Drawings. Students will learn rules in orthographic projection and practice creating orthographic views with 3-D objects.
Flat Patterns	Students will learn how to form a 3-D object by folding up a 2-D flat pattern.
Inclined and Curved Surfaces	Students will learn creating orthographic projects for 3-D objects with inclined and curved surfaces.
Rotation of Objects About a Single Axis or Multiple Axes	Students will practice their spatial visualization skills by mentally rotating a 3-D object about a straight line.

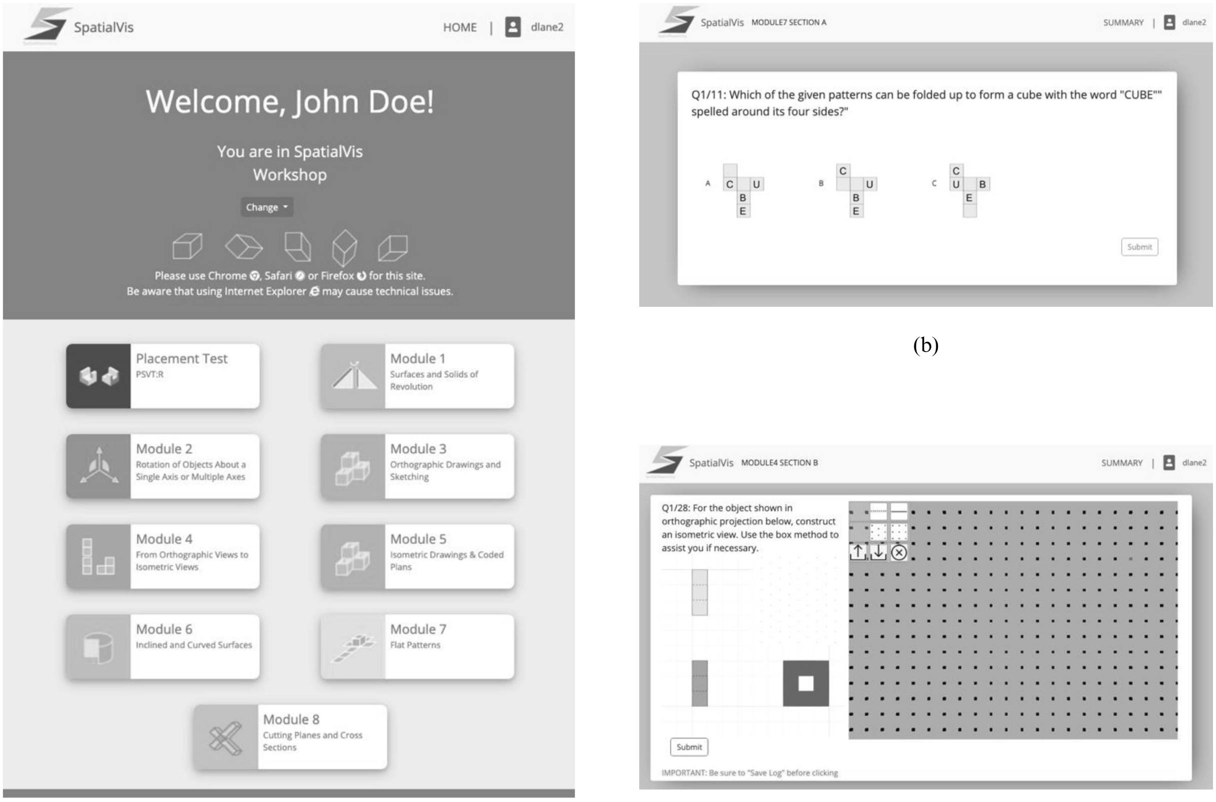

Fig. 1. The Web Interfaces of the Online Workshop. (a) Student's homepage that shows the workshop content. (b) An example interface for multiple-choice questions. (c) An example interface for free-hand sketching questions.

finish. The exercise is released on the first day of the week, and students are instructed to finish by the end of the week. The online workshop restricts students to complete each week's material in order. Students who completed all seven week's exercises and the last week's assessment were considered complete.

2.3 *Measures*

2.3.1 *Growth Mindset for Spatial Intelligence*

The growth mindset for spatial intelligence scale was adapted from [15] and involves four Likert items on a one to six scale (e.g., "You have a certain amount of spatial intelligence, and you can't really do much to change it", reverse coded, and "No matter who you are, you can significantly change your level of spatial intelligence"). The measure in [13] has demonstrated validity in many studies by predicting learning goals, intrinsic motivation, and achievement. In the present study, internal consistency was strong for pretest growth mindset (Chronbach's alpha = 0.80).

2.3.2 *Purdue Spatial Visualization Tests: Visualization of Rotations (PSVT:R).*

A computer-based PSVT:R was administered at pre- and post-intervention. It involves 30 multiple choice questions that require examinees to mentally rotate complex 3-D shapes. PSVT:R is a well-developed and widely-used assessment for spatial visualization skills [36, 37]. Internal consistency (alpha reliability) is good, ranging from 0.81 to 0.86 in studies of college students in mathematics, engineering, and a broad array of majors (Maeda & Yoon, 2013). The PSVT:R is moderately correlated with other tests of visual-spatial ability, such as the Mental Cutting Test (MCT; $r = 0.53$) [21]. Students were only allowed to take the test once in both assessments and the time cap for the test is 20 minutes.

2.3.3 Gender

Students shared their gender (1 = Female; 0 = Male). Because gender often affects response to visual-spatial interventions [19, 30], it was important to see if women improved just as much as men.

2.4 Data Analysis

Paired sample t-tests were conducted in order to see if students improved significantly from pretest to posttest on growth mindset and visual-spatial ability. Cohen's d was calculated as a measure of effect size for the difference from pre- to post-workshop.

3. Results

3.1 Preliminary Analyses

See Table 2 for the means, standard deviations, and range of mental rotation and growth mindset scores at pre- and post-treatment. The average growth mindset score at pre-treatment was lower than the average score of science majors at the University of Connecticut (mean = 4.04 out of 6 [38]) and lower than the average of thousands of incoming freshmen at Michigan State University (mean = 4.76 [39]). A score of 3.5 or above is considered indicative of a growth mindset [40]. At pre-treatment, 38.2% of students had a growth mindset. At post-treatment 48.7% of students had a growth mindset.

Out of 296 students that joined the workshop, 289 completed the study for an attrition rate of 2.4%. Two hundred and forty-five students filled out both the pretest and posttest for growth mindset with 17.3% not filling one or the other. A one-way ANOVA indicated that women had lower scores on PSVT:R at pre-treatment: $F(1, 266) = 5.73, p < 0.05$. On the other hand, women and men exhibited no significant difference in growth mindset for spatial intelligence at pre-treatment: $F(1, 266) = 0.69$, $p = 0.41$.

3.2 Treatment Effects

Paired sample t-tests were conducted in order to examine the workshop participants' progress in terms of the post-treatment minus pre-treatment difference scores.

Confirming hypothesis one, students improved significantly from pre to post-treatment on visual-spatial ability. Confirming hypothesis 2, students improved significantly from pre to post-treatment on growth mindset for spatial intelligence (see Table 2). The effect size for the workshop was small for both measures (Cohen's $d = 0.38$ for the PSVTR and 0.33 for growth mindset) indicating that the treatment group improved by about one-third of a standard deviation on both outcomes.

Women and men showed no difference in post-treatment minus pre-treatment scores on the PSVT:R $F(1, 259) = 0.22$, $p = 0.64$, indicating that both sexes grew equally well. Likewise, women and men showed no difference in post-treatment minus pre-treatment scores on growth mindset $F(1, 242) = 0.07$, $p = 0.79$, indicating that both men and women improved equally well in terms of growth mindset for spatial intelligence.

Interestingly, grade level was negatively related to post-treatment minus pre-treatment difference scores on the PSVTR ($r = -0.15$, $p < 0.05$). Fig. 2 shows that freshmen and sophomores improved by well over 2 points, whereas juniors and seniors improved by less than half a point. Grade level was not significantly related to post-treatment minus pre-treatment on growth mindset ($r = 0.06$, $p = 0.39$), suggesting that students of various grades responded equally well to the workshop, insofar as growth mindset is concerned.

Although growth mindset for spatial intelligence at pre-treatment was not related to post-treatment minus pre-treatment difference scores on the PSVT:R ($r = 0.03$, $p = 0.67$), growth mindset at

Table 2. Descriptive Statistics and T-Test Results for Spatial Visualization (Rotations) and Growth Mindset Before and After Intervention

	Pretest		Posttest		95% CI					
Outcome	***M***	***SD***	***M***	***SD***	**Lower**	**Upper**	***r***	***t***	***df***	***d***
Rotations	21.92	5.51	23.95	5.25	1.49	2.57	0.62*	7.36*	288	0.38
Mindset	3.27	0.77	3.54	0.86	0.14	0.40	0.21*	4.07*	244	0.33

* $p < 0.001$. Rotations = PSVT:R ($N = 289$). Mindset = Growth Mindset ($N = 245$). The 95% CI is for the mean difference (posttest minus pretest).

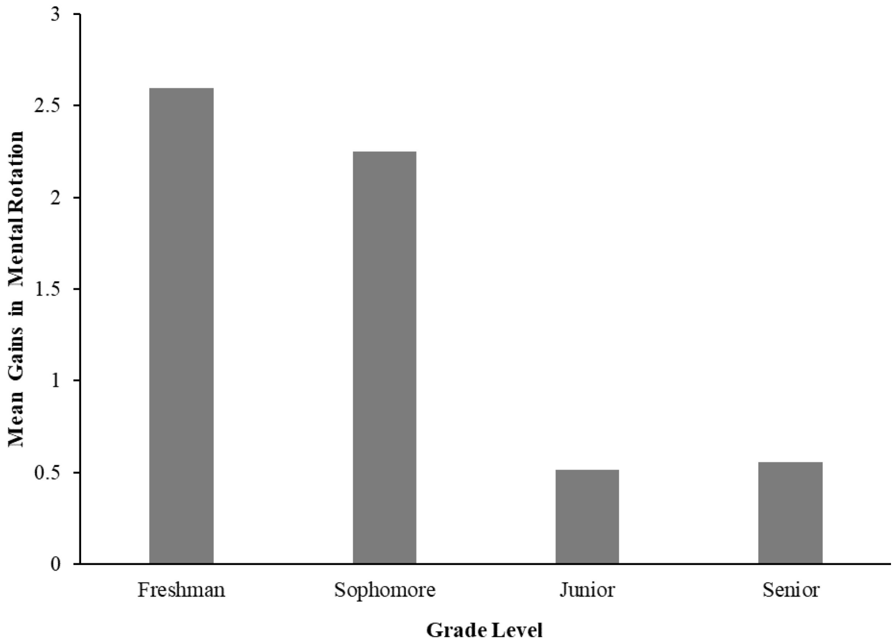

Fig. 2. Bar Graph of Mean Posttest Minus Pretest Mental Rotation Score by Grade Level

post-treatment was related to difference scores on the PSVT:R ($r = 0.13$, $p < 0.05$). This suggests that growth mindset at pre-treatment is unlikely to predict responses to the visual-spatial ability training, but that those who experience improvements in visual-spatial ability from training are more likely to endorse a growth mindset for spatial intelligence. Taken together, these findings suggest that the online intervention to increase visual-spatial skills increases both visual-spatial ability and a growth mindset for spatial intelligence. Those that experience more growth in visual-spatial skills are more likely to experience a greater improvement in growth mindset; however, the average effect for the intervention is just above one-third of a standard deviation.

4. Discussion

This study suggests that visual-spatial interventions show promise for increasing growth mindset, as well as visual-spatial ability. This adds an intriguing and indirect option to the arsenal of interventions that can promote a growth mindset, as promoting a growth mindset in the classroom is a key way to facilitate STEM identity development and retention [41]. In fact, this online workshop might prove to be more effective than in-class introductions to growth mindset theory [11]. In a world in which so many people think that intelligence is purely based upon genetics or otherwise hold a fixed mindset, it is valuable to know that training one in intellectual skills can also increase their growth mindset. Perhaps some people will only develop an incremental theory of intelligence if they experience their own intelligence increasing through rigorous training and effort.

The finding that women and men exhibited no significant difference in pre-treatment growth mindset for spatial intelligence is in accordance with recent research, which found growth mindsets in underrepresented students, such as women and minorities majoring in STEM fields [42]. Our findings extend their finding by adding that women improved their mindset just as well as men in response to an intervention for STEM students. Additional studies have linked STEM students' growth mindsets with positive academic outcomes (including normal levels of anxiety, persistence, and good study habits) [43]. Therefore, an impact on growth mindsets for both males and females is a promising result and has potential to improve positive outcomes in STEM for all students, and especially females who are underrepresented.

Visual-spatial ability is important for thriving in engineering and promotes success in various aspects of life [16, 21, 24]. Our intervention is especially promising because it can be delivered briefly (3.5 hours of total training) and online, whereas most prior studies of course-based interventions lasted at least three times as long. This intervention was also briefer than video game-based visual-spatial interventions that have been successful with college students (e.g., 10 hours in [44, 45]). Furthermore, women improved just as much as men on both visual-spatial ability and growth mindset. Qua visual-spatial ability, the intervention was more effective with freshmen and sophomores than with juniors and seniors, suggesting that it may need to be refined for students that take the workshop in the latter part of their college training. These courses are all 100-level with an intended audience of first-year engineering students, and upper level students who take these classes have likely had more opportunities to improve their visuo-spatial skills from other engineering coursework (e.g., calculus and dynamics), reflected in their slightly higher pre-PSVT:R but lower overall improvement. However, students of all grades responded equally well in terms of growth mindset.

The attrition rate in this study was 2.4%, which is far lower than the average attrition rate for psychological interventions and comparable to the low attrition rates found in positive psychology interventions and interventions that elevate autonomous motivation [46, 47]. Perhaps elevating growth mindset made the intervention more enjoyable for participants, as growth mindset is associated with enjoyment and zeal for learning [6].

5. Limitations

Without a randomly assigned control group, we cannot be sure that the significant improvements in visual-spatial ability and growth mindset were due to the workshop; we only know that students improved significantly on both measures. It would be reasonable to assume that many students in a class that involves a lot of spatial reasoning would improve, although previous research has indicated that those students who participate in our online workshop improve significantly compared to their non-workshop classmates [35]. Future studies could seek to employ random assignment, perhaps by randomly assigning students to either the workshop or a wait-list group that receives the workshop the following semester. However, young adults usually experience a decline in visual-spatial ability with age [28]. Thus, it is rather convincing that the treatment group improved by one-third of a standard deviation on growth mindset and visual-spatial ability.

6. Conclusion

Visual-spatial ability is important for various aspects of life for all people and a vital ability for the daily work of many engineering students and engineers while a growth mindset is linked with academic achievement that might foster retention in STEM fields. This study of 296 undergraduate engineering students demonstrated that after 30 minutes weekly of high quality online visual-spatial training, students improved significantly on both mental rotations and growth mindset. Visual-spatial interventions show promise for increasing growth mindset, as well as visual-spatial ability. Because this is a rather stealthy growth mindset intervention, future studies may wish to investigate whether indirect framing of growth mindset knowledge (e.g., writing a letter to encourage new students that they can improve their spatial abilities with rigorous exercise and training) combined with our visual-spatial intervention leads to a larger effect on both growth mindset and visual-spatial ability. Future work could also explore other STEM interventions outside of visual-spatial training to understand if similar interventions show promise for encouraging growth mindset in engineering undergraduate students.

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