Work in Progress: Online Training in Spatial Reasoning for First-year Female Engineering Students

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Abstract

Spatial ability is defined as the capacity to accurately perceive visual images, build mental representations of non-linguistic information, and comprehend and manipulate an object's spatial relations[1, 2, and 3]. This ability can be used as a prognostication factor for achievement and attainment in science, technology, engineering, and mathematics (STEM)[4, 5]. It is well documented that 3D spatial skills can be developed through practice. Sorby has shown that a course aimed at developing the 3D spatial skills of first-year engineering students has a positive impact on student success, especially for women[6]. The research team has developed a semester-long online, spatial skills workshop. The content incorporates online resources related to mental rotation, 2D and 3D spatial visualization, and abstract reasoning. An experimental group of female first-year engineering students will participate in the weekly online workshop. To assess participants' spatial perception, mental rotation, and spatial visualization skills, both the experimental group and a control group will complete the Purdue Spatial Visualization Test (PSVT) before the online workshop, in the middle of the semester, and after completion of the workshop. Results of this pilot study will be analyzed to determine the value of offering online spatial reasoning content to all incoming engineering students. It is our hope to understand how to best increase spatial skills for women engineering students, and doing so early in their college careers might lead to increased retention, success, and self-efficacy. This research also aims to expand representation of women in engineering by creating resources that properly address specific academic challenges for this population. The desired outcome is for participants to acquire the skills needed to contribute to the successful completion of their coursework and ultimately their engineering degrees.

Introduction and Related Work

For years, educators and professionals alike have been trying to discover how to cultivate the best engineers, scientists, technologists, physicians, mathematicians, and programmers for Science, Technology, Engineering, and Mathematics (STEM) careers. Spatial skills, defined as the capacity to accurately perceive visual images, build mental representations of non-linguistic information, and comprehend and manipulate an objects spatial relations[1, 2, and 3], are widely believed to be part of the answer for identifying, training, and retaining the best STEM talent[5]. Lohman goes on to define spatial skills as "the ability to generate, retain, retrieve, and transform well-structured visual images"[7]. This ability can be used as a prognostication factor for achievement and attainment in

STEM[4,5]. Many studies have found that well-developed spatial skills are indicative of a propensity for STEM[5,3]; furthermore, students can improve their STEM-related skills through targeted training to reinforce their spatial skills[8,9]. However, there is a wide disparity between men and women's spatial skills[10], which has been a contributing factor to the lack of women in STEM careers[6].

Significant research has investigated spatial skills over the last 75 years; while many agree that spatial skills are crucial to develop the expertise needed to be successful in STEM fields[11,12], spatial skills are still largely overlooked in curriculum[13,14]. Regardless of its implementation, spatial skills are still widely researched. These abilities have been categorized into a number of different classification system; one of the most widely-accepted systems was proposed by Linn and Petersen[2]. Their system groups spatial skills into three main categories: (1) spatial perception, the ability to determine spatial relationships with respect to the orientation of their own bodies, (2) spatial visualization, the ability to successfully follow complicated, multi-step manipulations of spatially presented information, and (3) mental rotation, the ability to rapidly and accurately mentally rotate a two or three dimensional figure. In addition to a variety of definitions and categorizations of spatial skills, there have also been a number of tests created in order to evaluate different aspects of an individual's spatial skills[5,15]. The Mental Cutting Test (MCT), Purdue Spatial Visualization Test (PSVT), The Mental Rotation Test (MRT), The Lappan Test, and The Paper Folding Test (PFT) are all examples of tests designed to evaluate various spatial skill levels[6,9].

An individual's spatial skills prowess can offer insight into their knowledge sets, skills, and predilections. High scores on spatial skills have been found to have significant correlation to higher overall grades[6], better STEM skills[16], and higher retention rates in college STEM majors[10]. When young students exhibit high scores on spatial skill assessments, they are much more likely to pursue STEM careers[5]. Additionally, many students utilize spatial skills to better communicate, learn, reason, and represent various ideas in a variety of subjects[17]. While spatial skills are widely accepted as being necessary to excel in STEM fields, they may also be the key to helping make STEM fields more diverse. One of the most notable subjects when discussing spatial skills is how women consistently and significantly score lower than men on almost all spatial skills assessments[6, 13, 18, and 19]. Many researchers have investigated why this disparity exists; Metz, Sorby, and Jarosewich[10] concluded that "these differences have been tied to environmental factors, differences in math performance, and a combination of factors, including the type of toys a child played with, the type of sports they participated in, the type of K-12 courses a student enrolled in, or the types of computer games they played." Tzuriel and Egozi[20] found that children in first grade who completed spatial skills training significantly improved their spatial performance and the initial gap between the boys and girls was significantly mitigated. Many researchers, including Sorby[6] have asserted that training dedicated to improving female students' spatial skills would increase retention rates for women in STEM fields.

Targeted training to better promote spatial skills has been found effective in a number of studies[6, 21, and 22]; additionally, curriculum that takes longer to complete and that incorporates a variety of diverse training methods have also been determined to be more effective[8,23]. As technology rapidly advances, scholars and educators have also begun to incorporate computer programs and online resources in their training methods. These techniques have been found effective, are often more relevant to today's professional landscape, and are easy for students to use[15,22]. As today's expansive engineering and technology fields continue to rapidly grow, students' development of spatial skills are paramount to their success, and may also be one important key to reducing the gap between the number of men and the number of women in STEM careers.

The goal of this work is to find new ways to help educate and retain women enrolled in STEM majors. As part of a first-year seminar course that focuses on encouraging women in engineering, this research team incorporated an online spatial skills development component into the curriculum. Over the course of a semester, 31 female undergraduate engineering students voluntarily took part in the study, which included exercises designed to develop these skills.

Spatial Reasoning Workshop

The online spatial reasoning workshop consisted of 12 one-hour modules: four origami-based modules followed by eight orthographic perception-based modules that utilized Computer-Aided Design (CAD). The content of each module built upon the previous one, and increased in complexity and difficulty in each iteration.

Origami, the Japanese art of paper folding, was selected as a workshop tool because research shows that origami has a positive impact on spatial visualization skills[1,24]. Origami instructions incorporate numerous multi-step transformations of a square piece of paper that, if manipulated correctly, lead to a 2-dimensional (2D) or 3-dimensional (3D) finished product (Figures 1 and 2). The four origami modules provided origami design instructions, basic symbol explanation, nomenclature used, and the origami task. Participants were required to physically fold a square piece of paper into the origami model by following the provided instructions.

Participants were also required to create 3D CAD drawings from given orthographic drawings. Sorby[6] states that sketching 3D drawings has a significant influence in the development of spatial skills. Hsi, Linn, and Bell[12] also found that a one-day workshop on 3D and 2D sketching led to an enhancement in spatial strategies to solve engineering problems. The software SketchUp was utilized by workshop participants to create the 3D CAD drawings because this software can be downloaded for free, provides tutorials on basic capabilities, and runs in both Mac and Windows environments. Each of the eight CAD modules contained three to four drawing activities (Figures 3 and 4) and the correct answers for the previous module.

Participants had one week to complete each module and submit the appropriate task deliverable. The deliverable for each origami-based module was a photograph of the object they created (whether they were successful or not) (Figure 2). The deliverable for the CAD-based modules was a SketchUp file of their final drawing (Figure 4).

Methods

Research Questions

This research is guided by the following research question:

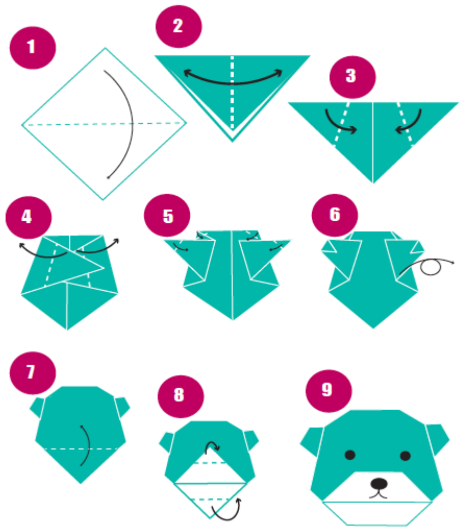

Figure 1: Example of origami folding instructions for module one (Origami task)

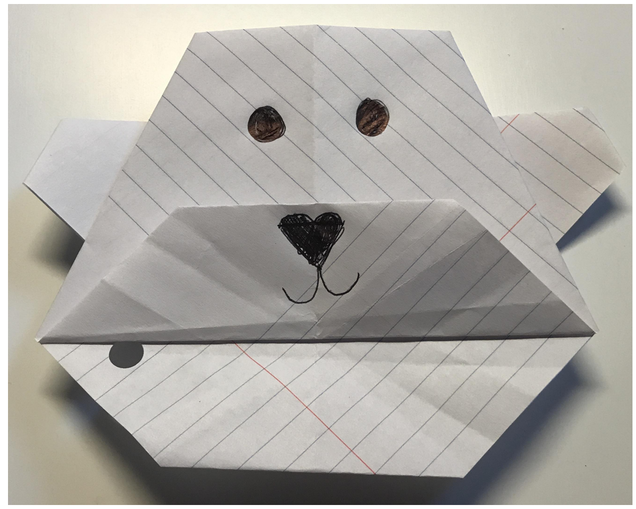

Figure 2: Deliverable of module one (Origami task)

- What is the effect of performing origami-based tasks followed by orthographic projections-based tasks on ones spatial perception, mental rotation, and spatial visualization abilities?

Data Collection and Assessment Instrument

The spatial ability data was collected before starting the online training (pre-survey), after the completion of the first four (origami) modules (mid-survey), and after the completion of all 12 modules (post-survey).

The Purdue Spatial Visualization Test (PSVT) was used as the assessment instrument (pre-, mid-, and post-survey) in this research. The PSVT is divided in 3 sections: (1) Rotations which evaluates mental rotation abilities (refer to Figure 5), (2) Developments which examines spatial visualization (refer to Figures 7 and 8), and (3) Views which assess spatial perception (refer to Figure 6)[25]. Each test section contains 30 multiple-choice items. Participants had 12 minutes to complete the PSVT-Rotations, 18 minutes for PSVT-Developments, and 20 minutes for PSVT-Views[26], which were administered through an online portal.

Participants

The study sample was recruited among the students of a first-year engineer seminar course that focuses on encouraging success in women students. The course is offered each Fall semester and enrolls predominantly female first-year engineering students. All students in the course were required to complete the PSVT surveys as part of the assigned class work. However, only the students that enrolled for the study had access to the online workshop resources. Additionally, study

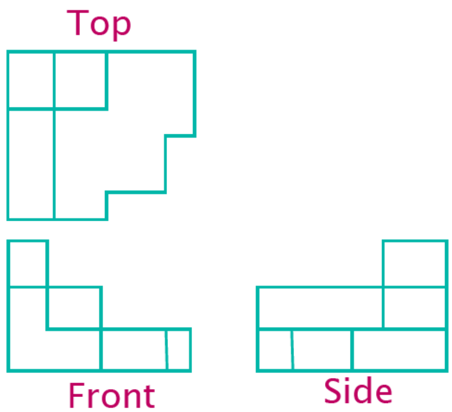

Figure 3: Example of orthographic drawings instructions for module eight (Computer-Aided Design task)

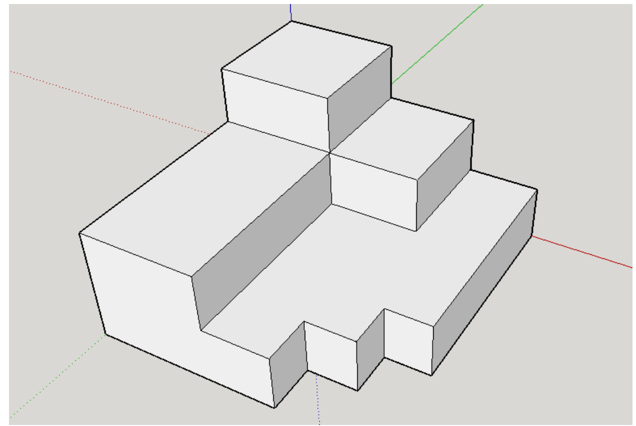

Figure 4: Deliverable of module eight (Computer-Aided Design task)

participants that completed five or more workshop modules received a $40 gift card at the conclusion of the data collection phase.

The experimental group had total of 33 female engineering students who participated in the workshop. The remainder of the course enrollees, 152 students, were considered the control group. After data-cleaning, the experimental group was reduced to 31 and the control group to 67 participants.

Demographics

In the control group, 94.03% (63) of the participants were domestic and 5.97% (4) international. The experimental group had 93.55% (29) domestic and 6.45% (2) international participants. Self-reported race/ethnicity information of the domestic participants was collected (refer to Table 1). The race/ethnicity make-up of the experimental group was 79.31% (23) White/Caucasian, 13.79% (4) Asian, and 3.45% (1) of both African American/Black and Multiracial. The race/ethnicity make-up of the control group was 92.06% (58) White/Caucasian, 4.76% (3) Multiracial, and 1.59% (1) of both Middle Eastern and Asian.

Table 1: Experimental and control groups' self-reported race/ethnicity

	Group	
Race/Ethnicity	Control	Experimental
Multiracial	3	1
White - Caucasian	58	23
Middle Eastern	1	
African American - Black		1
Asian	1	4
Total	63	29

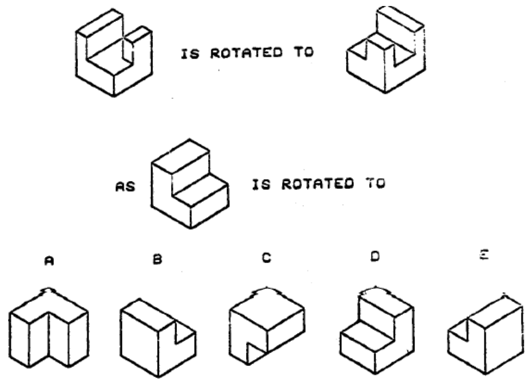

Figure 5: Sample question PSVT-Rotations, the correct answer for the example shown above is D.

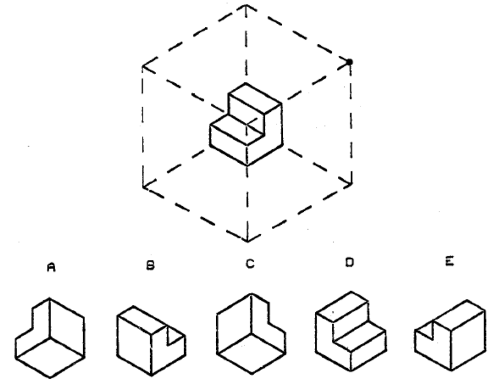

Figure 6: Sample question PSVT-Views, the correct answer for the example shown above is E.

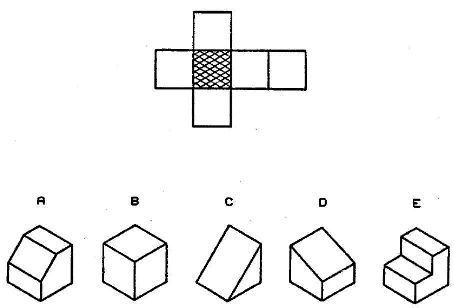

Figure 7: Sample question PSVT-Developments part 1, the correct answer for the example shown above is B.

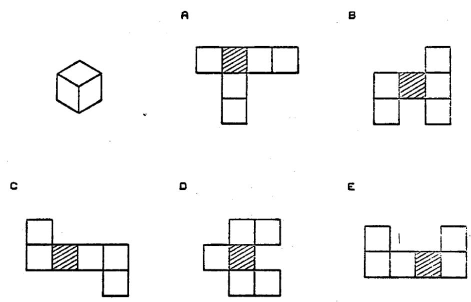

Figure 8: Sample question PSVT-Developments part 2, the correct answer for the example shown above is C.

Participants were also asked to identify their dominant hand (refer to Figure 9). The experimental group was formed by 19.35% (6) left-handed, 77.42% (24) right-handed, and 3.32% (1) of the participants did not provide information. The control group had 1.49% (1) ambidextrous, 5.97% (4) left-handed, and 92.54% (62) right-handed participants.

Data Analysis

At the time of this publication, all pre-, mid-, and post-survey data have been collected and are being prepared for analysis. Inconsistent data were excluded from control and experimental data pools. Data were labeled as inconsistent if the score was below 10 and the time used to complete the survey was less than or equal to one-third of the allowed time. Additionally, only data from first-year engineering students were considered for this study. Note that participants in the control group who did not attempt all three surveys were removed. Of the 33 participants in the experimental group, two were removed as a result of the examination of data inconsistencies. Of the remaining 31, all completed the pre-survey, 29 completed the mid-survey, and 26 completed the post-survey. Of the 152 participants in the control group, 67 remained after the examination of data for inconsistencies. The research team is confident in the validity of the remaining data set.

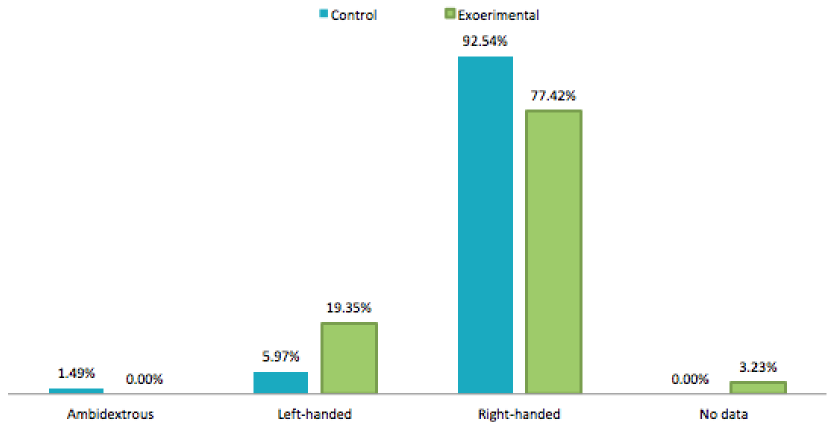

Figure 9: Dominant hand percentages for control and experimental groups.

Information about origami and CAD levels of experience was collected for the experimental group. Participants were asked to rate their level of experience before the initial workshop and after the final workshop. The following definitions were provided for origami: None, Beginner (know how to read diagrams, know how to do basic folds such as mountain and valley, complete figures up to 20 steps), Intermediate (complete figures up to 40 steps, explore new techniques of origami), and Advanced (complete figures with more than 40 steps, perform circular packing and tiles). For rating their CAD experience, participants were provided the following definitions: None, Beginner (opening files, change colors, drawing lines), Intermediate (import figures, draw 2D sketches, add text, add scale), and Advanced (draw 3D sketches, do revisions, use dynamic menu).

Data between control and experimental groups will be contrasted using univariate analysis of repeated measures, thus avoiding issues of correlation between repeated measurements from the subjects[27]. JMP software will be utilized for data analysis.

Results

The participants in the experimental group were tasked with completing an online module each week for 12 weeks. Completion of a module was denoted by a participant turning in a task deliverable, whether that deliverable was correct or not. Module completion rates range from 100% on module 1 down to 48.39% on modules 10 and 12 (Figure 10).

The research team will look for statistically significant differences between the assessment scores for the experimental group and the control group. A statistical analysis should provide evidence on differences between treatments, influence of workshop content (origami versus CAD), workshop impact on spatial ability, and the effect of workshop completion on participants' spatial abilities.

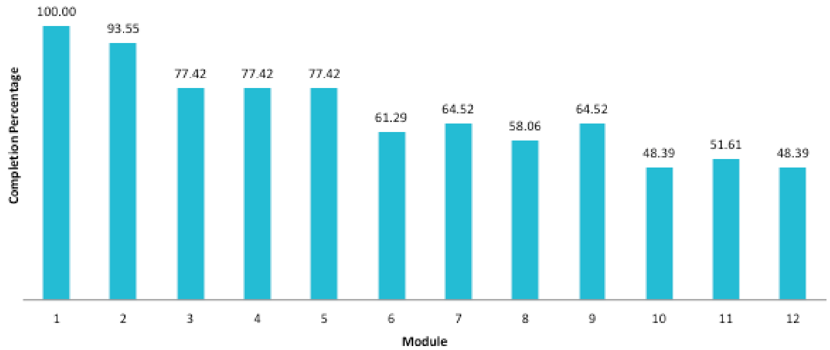

Figure 10: Detailed completion percentage for each module

Origami and CAD experience

Data on level of experience in both origami and CAD was collected only for the participants in the experimental group (refer to Table 2). For origami, 35.71% (10) of the participants signaled that they had no experience with origami, 57.14% (16) considered themselves as beginners, and 7.14% (2) consider themselves to have an intermediate skill level. After the workshop, 53.57% (15) of the participants evaluated themselves as beginners, 42.86% (12) as intermediate, and 3.57% (1) as advanced.

Before the workshop 42.86% (12) of the participants had no experience with CAD, 17.86% (5) rated themselves as beginners, 28.57% (8) considered their abilities to be intermediate, and 10.71% (3) rated their abilities as advanced. After the workshop, 5.56% (1) of the participants scored their CAD ability as null, 50% (9) as beginner, and 22.22% (4) at both the intermediate and advanced levels.

Table 2: Experimental Group's self-assessed skill level for origami and CAD before and after workshop

	Origami		CAD	
	Before Workshop	After Workshop	Before Workshop	After Workshop
None	10		12	1
Beginner	16	15	5	9
Intermediate	2	12	8	4
Advanced		1	3	4
Total	28	28	28	18

Figures 11 and 12 show the changes in participants' level of expertise for origami and CAD. Participants maintained (10) or increased (18) their level of skill in origami. With regard to CAD, six participants maintained their skill, nine increased their skill level, and three noted that their skill level decreased.

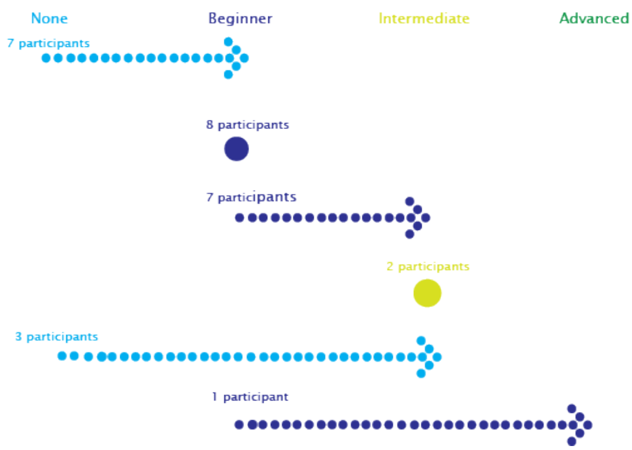

Figure 11: Origami experience levels

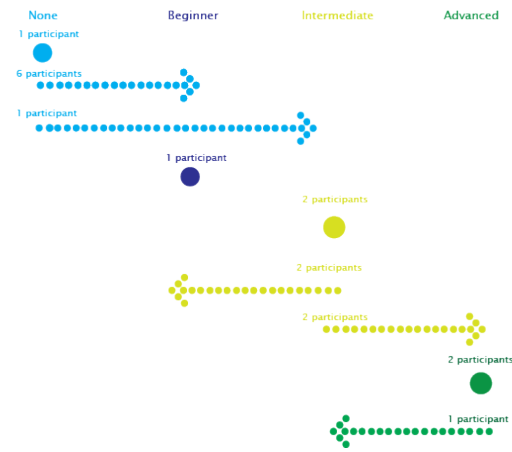

Figure 12: CAD experience levels

Discussion

The online workshop was comprised of origami and CAD modules where participants had to interpret and implement a set of written or graphic instructions. Origami-based instructions were utilized because they introduce concept vocabulary and spatial transformations as part of the training[28]. To address the other facets of spatial abilities (i.e. mental rotation and spatial perception), the workshop included modules focused on creating 3D models from orthographic drawings. It is known that sketching hand-held models is especially helpful for developing spatial skills[29]. However, the team decided to have the participants create their 3D models online. The use of computer-aided design software is prevalent in engineering, and it still requires participants to imagine objects, determine orientation relationships, and perform mental transformations.

Previous work on handedness is divided on the suggestion that right-handed individuals perform better than left-handed individuals in visual-spatial domains[30]. The number of left-handed participants in this study is not sufficient to obtain valid conclusions. However, a low number of left-handed individuals was expected, given that in the United States 12.2% of the population is estimated to be left-handed[31]. In future iterations of this study, the sample population will increase and we may then be able to examine the issue of handedness and spatial ability.

Participant self-evaluation of origami skill level followed an ideal trend, given that expertise was either maintained or increased after the workshop (refer to Figure 11). However, in some cases, CAD experience levels (Figure 12) decreased after the workshop. This can be explain by the Dunning-Kruger effect in which “poor performers in many social and intellectual domains seem largely unaware of just how deficient their expertise is”[32].

Limitations

This study presented the following limitations: (1) participants completed the PSVT online and several of the answers collected were not thoughtful and had to be excluded; (2) workshop modules were voluntary and there was a steady decrease in the completion rate as the semester progressed;

and (3) accounting for external factors that may also lead to increased spatial skills over the course of a semester.

Future Work

The initial analyses indicate that spatial skills are improved with the 12-week online workshop intervention. If these results hold up under further statistical analyses, the next step is to then optimize the online workshop. For this iteration, participants attempted 4 modules of origami followed by 8 modules of CAD each increasing in difficulty and complexity. Next we propose to develop 3 additional online workshops to examine if spatial skills improve under different intervention scenarios. Workshop 1 will be the same as delivered during this iteration. The order of the modules will the switched for Workshop 2 such that the participants will complete 8 CAD modules first and then the 4 origami modules. Workshop 3 will consist of 12 origami modules and Workshop 4 will consist of 12 CAD modules with each module increasing in complexity and difficulty. All 4 workshops will be deployed in Fall 2018 to first-year female engineering student. It is estimated that there will be 50 - 75 participants in each workshop cohort.

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