Visualizing and Modeling a Growth Mindset in an STEM design course

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"Visualizing and Modeling a Growth Mindset in an AutoCAD course."

Abstract

This Work-in-progress (WIP) study aims to assess Dweck's growth mindset framework for junior and senior engineering students, predominantly from civil, industrial, environmental & other engineering majors. The Technical Drawing and Visualization course aims to teach two-dimensional (2D) and three-dimensional (3D) visualization skills and computer-aided design (CAD) to first-time users. Forty-four students participated in the study in fall 2024. The students were asked to complete an adapted Growth Mindset Survey at the middle and end of the semester. The Survey includes questions that gauge students' beliefs in their ability to tackle challenges, willingness to try new approaches, confidence in their skills, and commitment to investing time in skill development. Using descriptive statistics, students' beliefs and actual course performance were explored. Findings showed that having small interventions promoting a growth mindset in the classroom can enhance and improve students' self-confidence and help them tackle and face challenges in a positive light. The study concludes with some recommendations for similar courses in engineering.

Introduction

This WIP paper explores how having a growth mindset in science, technology, engineering, and mathematics (STEM) is essential as it is shown to impact student performance and help them tackle challenging tasks [1-3]. In higher education settings, students often enter their first-year engineering programs with different levels of spatial skills. Spatial visualization is the ability to mentally manipulate, rotate, or twist spatial objects before bringing them to life, whether on paper or through software [4]. Students in higher education face numerous challenges as they navigate the complexities of learning advanced material as they transition from high school. Cognitive difficulties, ineffective teaching methodologies, coping with study materials, and avoiding distractions are primary hurdles they encounter [5]. Researchers Y. F. Chan and G. Sidhu further identified eight significant learning challenges in higher education, including cognitive struggles, becoming an active learner, managing extensive reading materials, instructional challenges, language barriers, time management, heavy assignment loads, and cultural differences. These challenges can eventually create a substantial issue for institutions with regard to retention[6].

Retention issues are particularly acute in engineering programs, often related to academic challenges, self-efficacy issues, and low self-confidence leading students to withdraw completely from engineering.

Researchers have identified six key factors influencing students' decisions to leave these programs, with poor grades and struggles in conceptual understanding being one major contributor[7]. Prior work indicates that dropouts in engineering programs can be linked to a fixed mindset [8]. This WIP research paper examines ways that a growth mindset teaching style may affect students' beliefs about their ability to overcome challenges, their willingness to attempt new methods, confidence in their skillsets, and ultimately their willingness to invest time to develop those skillsets in a CAD design course.

Literature Review

What Is a Growth Mindset?

According to Dweck [1], a growth mindset is the belief in the ability to develop skills that individuals may not be initially proficient in but hope to improve through practice, critical thinking, and problem-solving. On the other hand, a fixed mindset believes that our skills and abilities are innate and unchangeable [9]. Growth mindset is a powerful concept emphasizing the point that our abilities can be developed and improved through effort, perseverance, and dedication. In STEM education, cultivating a growth mindset can significantly enhance the motivation and performance of students, especially in overcoming challenging courses, assignments, or projects [10]. It also builds an encouraging environment where students feel able to ask for assistance when faced with challenges, promoting academic resilience and growth. Research has determined that the application of a growth mindset can aid in achieving more effective coping, resilience, and well-being[9]. Research has also found that growth mindset intervention has helped lower-achieving students approach challenges with persistence and resilience [11].

Relevance of spatial and visualization

Spatial visualization is essential for engineers, particularly in civil, architectural, and mechanical engineering, to visualize designs before creating them. Students have varying spatial visualization skills [4, 12], where some students are better than others, who might struggle to visualize complex structures. Activities like video games, puzzles, Jenga, or model building are likely to greatly enhance these skills, but all students might not have had these experiences in their childhood years [13, 14].

The Importance of Growth Mindset in Technical Drawing and Visualization

Studies show that effective spatial skills are tied to better performance in STEM courses and are essential in facilitating students' pathways into STEM participation [15]. Mastery of spatial and visualization skills is important for future engineers because they support problem-solving, and instill confidence in all students, particularly women. These skills are part of the technical work of design and the work students will do in their own professional lives [16-18]. However, it is not fully understood how this growth mindset can be applied to a technical design course focused on teaching students free-hand sketching skills, which helps students develop 3D spatial abilities [16].This WIP study evaluated how a growth mindset can be implemented in the classroom and how it may have influenced students' beliefs and overall classroom experience. This initial effort was driven by this research question: How can a growth mindset be incorporated into a technical drawing course and how does it affect students' beliefs about their ability in the course.

Research Overview

This research study was completed over a 16-week semester during fall 2024, which relates to the usual academic calendar in the United States. We collected two surveys, disseminated at the middle and end of the semester. The surveys included eight Likert scale questions inspired by Carol Dweck's growth mindset framework and two open-ended questions about participants' most significant learning experiences or strengths. Likert scale[19] was administered on a 1 to 5 scale with one being "strongly disagree" and five being "strongly agree." Beliefs of students for their growth mindset were assessed using the survey to identify their confidence, challenge tendency, and effort in increasing skills [19]. Sample survey items are indicated in Table 1. Descriptive statistics were utilized to examine data to identify whether students' scores on the growth mindset correlate with students' overall course experience.

Table 1: Sample Growth Mindset Survey Questions [20]

Number	Survey questions
1	With effort, I can improve my skills and knowledge.
2	I can influence and change my development in general.
3	I can change my skills and knowledge through practice.
4	I like to take on challenges and try new things.
5	Learning is my goal.
6	Effort makes me stronger.
7	I want to spend more time and work on an area/theme/skill to develop my skills and knowledge.
8	I have faith in my own skills and abilities.

Class intervention using a growth mindset

Before the surveys were disseminated, several classroom interventions were employed to help students understand the importance of a growth mindset, as most students were unfamiliar with the concept. The interventions included discussions on motivation and encouragement, and growth mindset learning about the belief that any skill can be learned and developed through practice and efforts. The discussions took place at the beginning of class and lasted about 10-15 minutes per session. The course employed brief student discussions to offer a welcoming and inclusive environment in which they could ask questions, embrace their mistakes, collaborate with other students, and focus on building on incrementally in the areas of their knowledge, skills, and competencies. According to Table 2, the discussion happened at the start of class and the spatial skills activities were implemented in the middle of the class. The students were encouraged to work with their table-mate friends and sketch on a board in a game-like manner. This playful experience motivated more students to join in and learn through trial and error, observations, and feel more confident and safer to experiment and try things in a supportive environment.

Table 2: List of Interventions

Fun Icebreaker Questions	Spatial Skills Topics - Class Game
Travel/Summer plans	Orthographic views- Practice
Would you rather questions	Isometric views- Practice
Weekend plans	Practice cross-section views- Practice
Fun facts about themself	Auxiliary views- Practice

Bucket list	2D- CAD Skills- Practice
Life lessons/ Mentoring	3D- CAD Skills- Practice
Skills outside of school	

Fun Icebreaker Questions

To make the students comfortable, relaxed, and engaged with each other, we start each class with a non-serious icebreaker question before moving on to technical issues. The questions for the initial several weeks are on non-serious and lighthearted topics so that students become familiar with and relate to each other. Some of the icebreaker questions we use are:

1. If you were to have dinner with any famous person from the past, who would it be?
2. What is the oddest food combination you enjoy?
3. What is the top thing on your bucket list?
4. If money was not a problem at all, where would you travel?
5. Would you prefer to travel to space or the bottom of the ocean?
6. What are your plans for fun this weekend?
7. Share something interesting about yourself.
8. What skill may you have that may not be particularly useful?

These questions get students connected, at ease, and more willing to share in the classroom. They also create a positive classroom environment and reinforce real-world communication skills useful in engineering graphics and CAD applications. By mid-semester, we started to add spatial abilities activities to pair with the visualization and problem-solving activities. Since the course is designed for students to learn 2D and 3D modeling, spatial skills are mixed with 3D concepts that begin post-mid-semester.

Spatial Skills

We introduce perspective projections through humorous, approachable conversations to gain students' interest. We then begin with light questions such as spring break or summer plans and whether they had creative or optical illusion photography photos, such as of them swallowing a train or of them pushing on the Leaning Tower of Pisa. Next, we discuss orthographic projections, learning about different images and how to approach them. We also talk about gaming, and we have students disclose their favorite games before we discuss how gaming can be used to improve spatial abilities. This also leads into a discussion of visualization practice as the students are reminded, even if their spatial abilities start low, practice over time will strengthen abilities because practice makes the process or characteristics smoother and stronger. During the semester, we will engage students in different hands-on exercises that allow them to practice their visualization ability, boost confidence in their ability, and, in a safe and comfortable environment, improve spatial reasoning ability.

Site and Participants

During the fall 2024 semester, we gathered data from 44 STEM undergraduate students from the University of Florida. The type of class that we are studying is Technical Drawing and Visualizing, a STEM class focused on 2D, and 3D design with AutoCAD [21]. In this design class, students learned about several skill sets some of which were challenging, thus learning them required perseverance. Although a growth mindset was not explicitly taught as an idea, we mentioned it briefly in the first week and discussed the benefits of a growth mindset for engineering and life in general. The weekly activities were all presented to promote perseverance, problem-solving, and adaptability which are the foundational building blocks for developing a growth mindset.

We meet two times a week for two hours. Most students in the course were students majoring in civil engineering and were primarily sophomores or juniors. Other students participating in this course were junior and senior students in other engineering disciplines, such as industrial engineering and environmental engineering. We conducted the classes in person, and course materials were shared via Canvas, a learning management system (LMS) [22, 23]. The students had two examinations focused on testing their knowledge of the materials and one that tested their ability to use the software to create a 3D object. All of these examinations were held in person.

Data Cleaning and Descriptive Statistics

The mid-semester survey included 44 participants, and 31 participated in the end-of-semester survey. The data was analyzed using Microsoft Excel, and pie charts showing the distribution of Likert scale values in the classroom were generated after the data were cleaned and organized. Microsoft Excel and SPSS v29.0 were utilized as analytical tools for the data analysis. We calculated the mean values and standard deviations for each survey question, which were used to create graphical representations and to draw assumptions based on the visualizations. We organized the eight Likert scale questions with mid-semester and end-of-semester scores placed side by side for statistical analysis. This enabled us to complete a paired t-test analysis to substantiate whether the differences that we observed were statistically significant. Prior to this, a non-parametric distribution of the data was assessed. The paired t-test is a statistical procedure for comparing two associated groups and is particularly appropriate for our study because it compares the same subjects utilizing two different time points.

Results

T-Test Statistics

The results of the paired t-test for the eight Likert scale questions indicated that only one question, **"I can influence and change my development in general,"** has a statistically significant result with $p = 0.01$ of the $p < 0.10$ significance level. All other questions were not statistically significant suggesting non-influence from the experimental program, as shown in Table 3.

Table 3: T-Test Statistics for Survey Questions

Question	t-value	p-value	Significance Level:	Significant/ Non-Significant
I know that with effort, I can improve my skills and knowledge	-1.65	0.11	p > 0.10.	Non-Significant
I can influence and change my development in general	-2.79	0.01	p < 0.10.	Significant
I can change my skills and knowledge through practice	-1.65	0.11	p > 0.10.	Non-Significant
I like to take challenges and try new things	-0.75	0.46	p > 0.10.	Non-Significant

I see learning as my goal	1.32	0.20	p > 0.10.	Non-Significant
Effort makes me stronger	-0.22	0.83	p > 0.10.	Non-Significant
I want to spend more time and work more on an area/theme/skill to develop my skills and knowledge	-0.20	0.85	p > 0.10.	Non-Significant
I have faith in my own skills and my possibilities	-0.93	0.36	p >0 .10.	Non-Significant

When looking at the open-ended entries to the Likert scale entries, participants reported a mix of slight differences across a number of the items. However, while these differences were not statistically significant, they maintained observed differences, as seen in Table 4. The most noticeable trends emerged for the three prompt items which were as follows:

- "*I know that with effort I can improve my skills and knowledge*" (Increase from 4.72 to 4.87), reflecting a 3% increase in this category.
- "*I can influence and change my development in general*" (Increase from 4.52 to 4.77), showing a 5.5% improvement.
- "*I can change my skills and knowledge through practice*" (Increase from 4.72 to 4.87), demonstrating a 3.78% positive change.

One area of concern is the slight decline in responses to ***"I see learning as my goal,"*** which warrants future research should help us further understand the reasons for this decline. Knowing these reasons may assist in designing interventions that lead to better, more consistent outcomes across all domains of a growth mindset. The decline may result from students pursuing more compelling opportunities, travel, or skills perspectives as goals over learning a course. By reshaping the course to develop valuable skills rather than "just to learn" the course, students may come to appreciate and see the course more favorably, resulting in better outcomes and greater alignment with their personal goals.

Table 4: Mean and Standard Deviation of Likert-Scale Responses for Survey Questions

Questions	**Mid**	**End**
I know that with effort, I can improve my skills and knowledge	4.73 ± 0.45	4.87 ±0.34
I can influence and change my development in general	4.52 ± 0.62	4.77 ± 0.49
I can change my skills and knowledge through practice	4.73 ± 0.45	4.87 ± 0.34
I like to take challenges and try new things	4.25 ± 0.68	4.42 ± 0.66
I see learning as my goal	4.48 ± 0.58	4.32 ± 0.69
Effort makes me stronger	4.57 ± 0.54	4.61 ±0.55
I want to spend more time and work more on an area/theme/skill to develop my skills and knowledge	4.48 ±0.58	4.55 ± 0.66
I have faith in my own skills and my possibilities	4.23 ± 0.76	4.39 ± 0.66

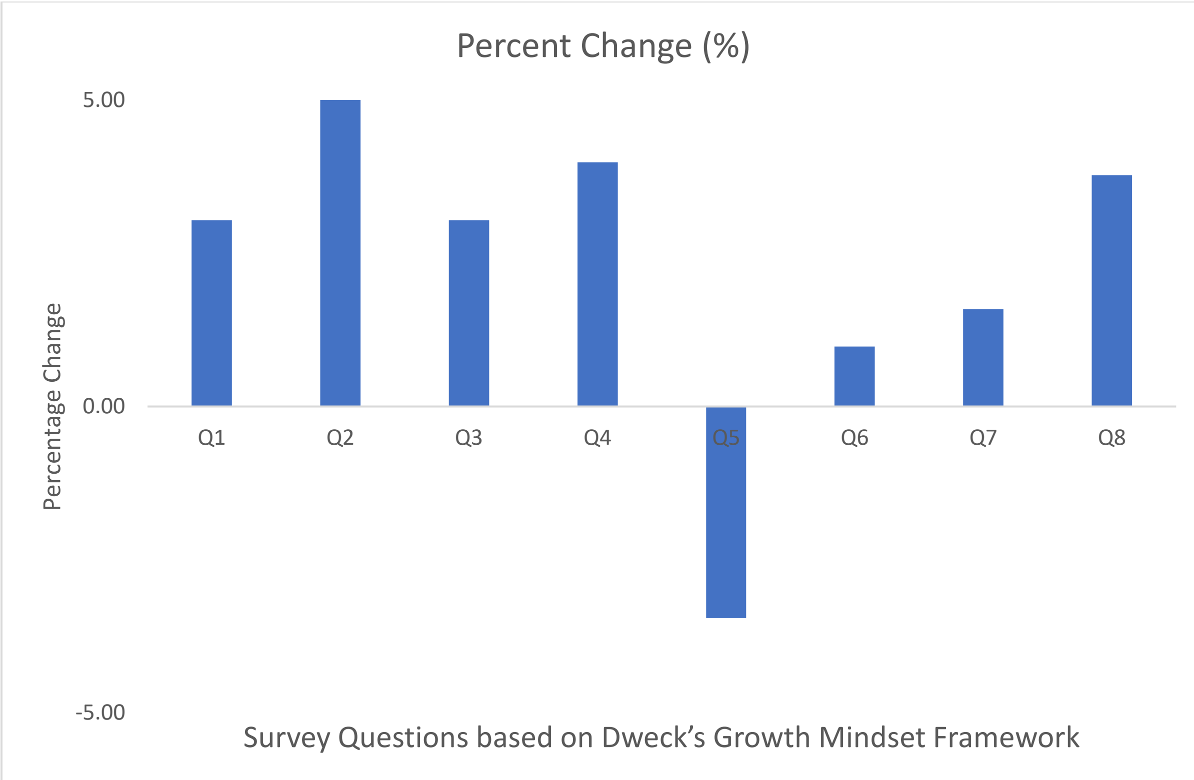

Figure 1: Percentage Change in Responses from Mid to End Surveys by Question

Open-ended Questions in the Survey

1. Which activity in our class has most helped you build confidence in your visualization skills?

Before: Students felt that hands-on lab assignments helped build confidence in their visualization skills**.** They learned from live in-class demonstrations and real-time drawing exercises**,** reinforcing learning and connecting theory to practice**.** Students also found the form assignments valuable, as they focused on visualization skills**.** Troubleshooting and independent practice further strengthened their ability to visualize designs and use engineering and architectural scales as shown in Figure 2**.**

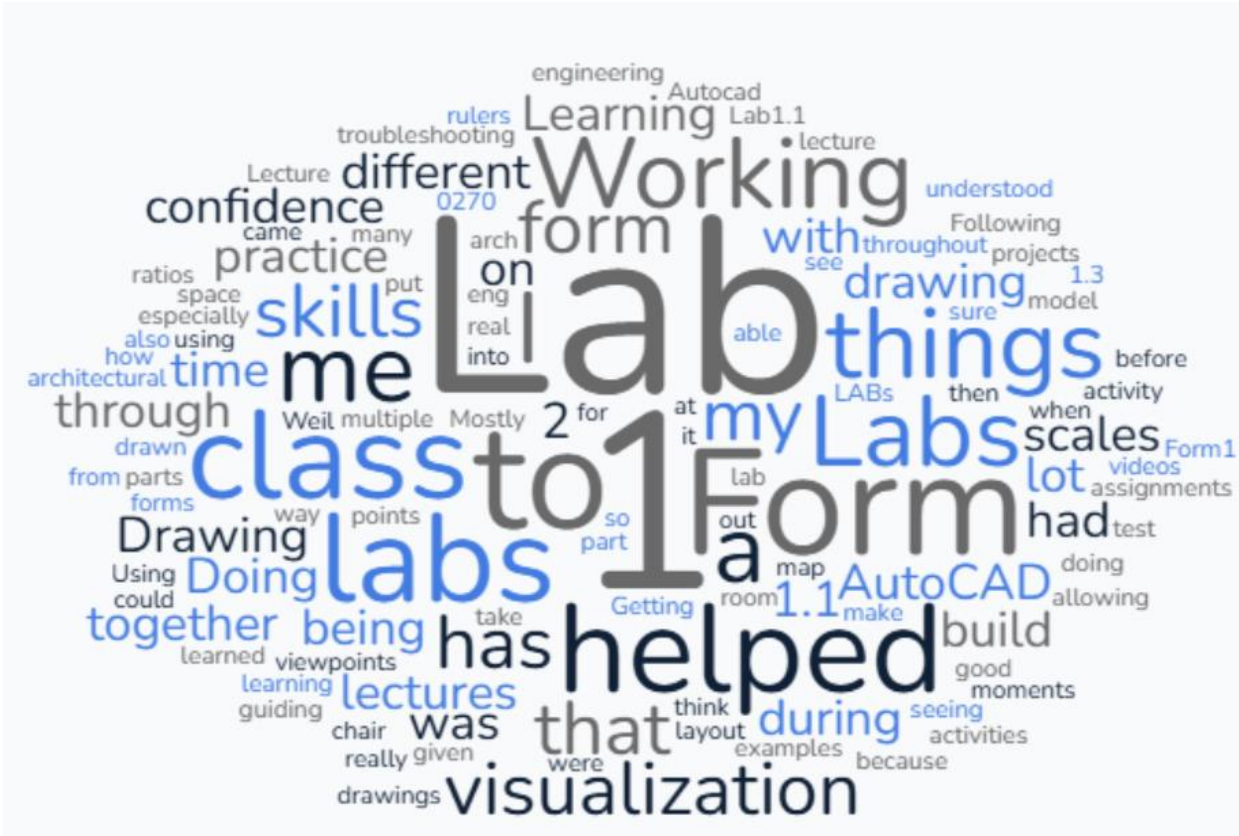

Figure 2: Activities that Built Confidence in Visualization Skills Before Survey

After: Students felt the forms problems helped them visualize and draw objects, particularly the isometric and orthographic projections. Students felt that in-class hands-on drawing exercises helped them develop spatial sense through guided exercises. Students also felt that the labs facilitated improvements in their 3D modeling ability by combining multiple views. Additionally, they felt that class lectures and examples provided different types of perspectives and visualization techniques as shown in Figure 3.

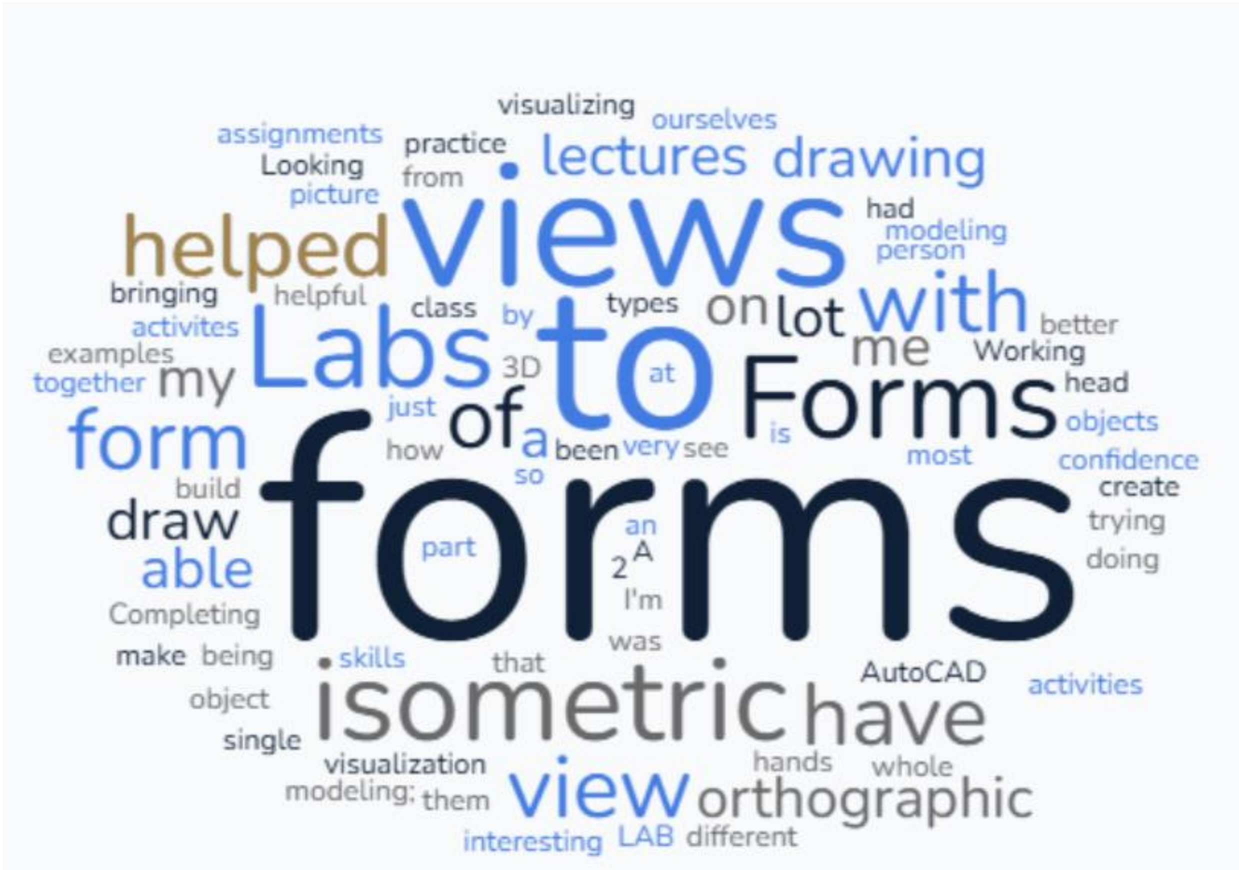

Figure 3: Activities that Built confidence in Visualization Skills After Survey

2. Which activity in our class has most helped you build confidence in your 2D and3D modeling skills?

Before: Students felt that practicing in labs gave them hands-on experience with 2D and3D modeling, making key concepts more concrete. Watching step-by-step in-class demonstrations made supported their skills development. They also felt that the direct application of these new skills improved learning, understanding, and confidence. Testing different toolbars made them more precise in modeling and competent overall as shown in Figure 4.

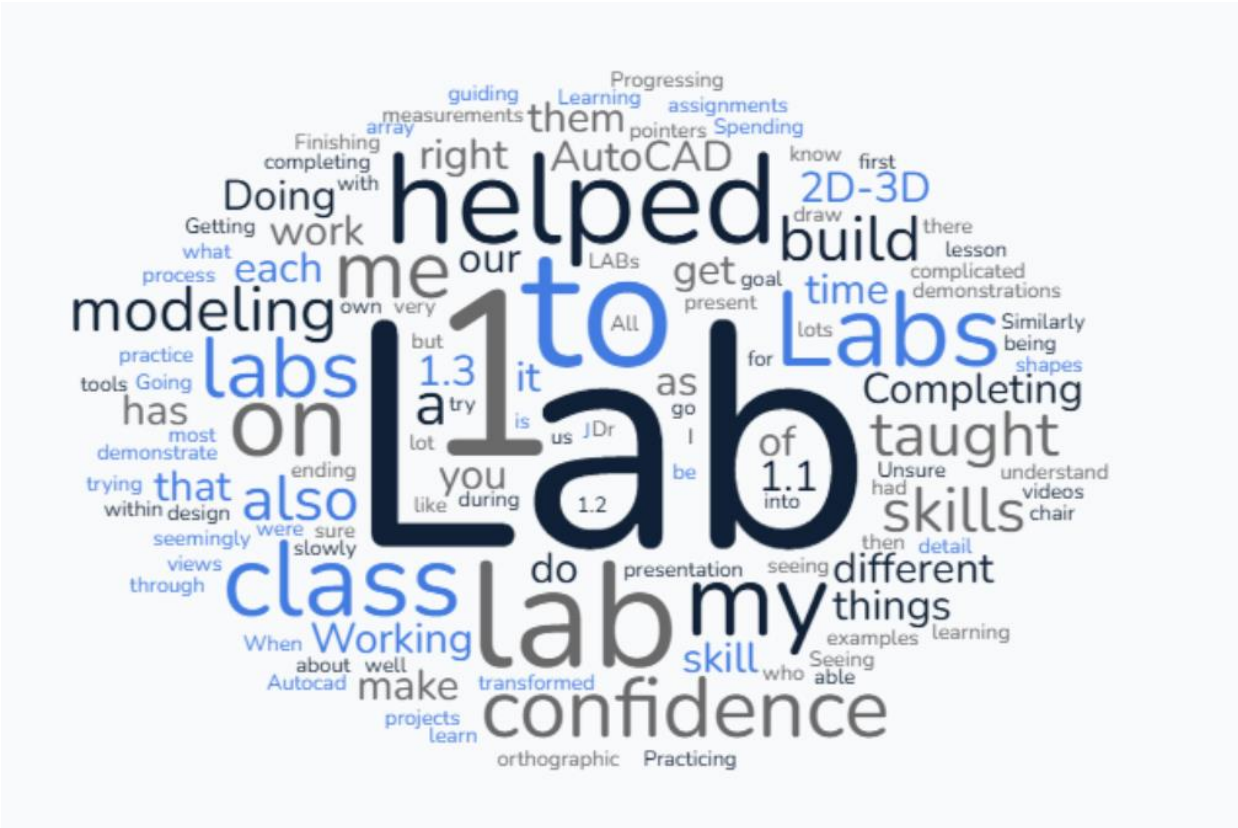

Figure 4: Activities that Built Confidence in Modeling Skills Before Survey

After: Overall, students felt that working in the labs enhanced their problem-solving ability and ability to break down complex designs**.** Independent practice was valuable**;** troubleshooting made them confident and technically more capable. They also felt that the form assignments enabled them to develop their 2D and 3D visualization skills as shown in Figure 5.

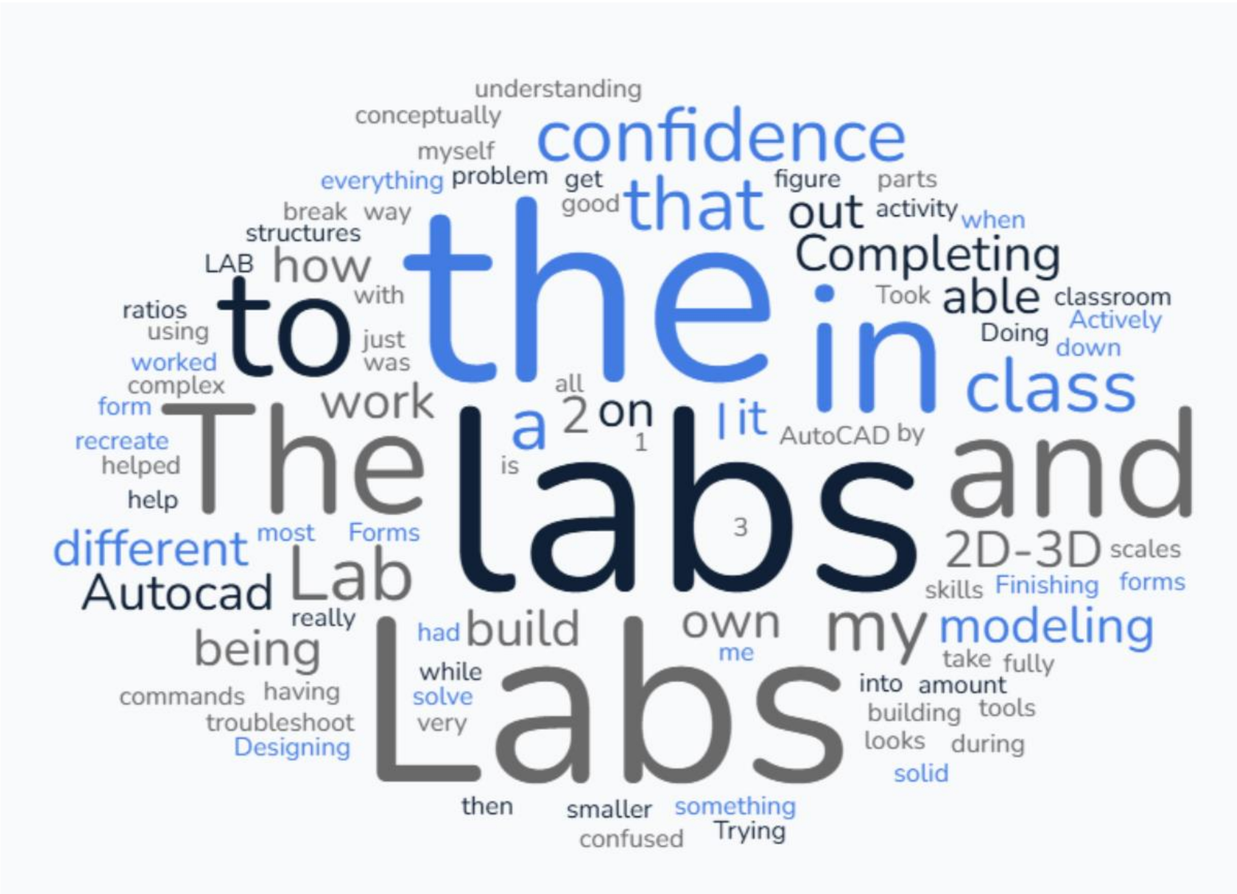

Figure 5: Activities that Built Confidence in Modeling Skills After Survey

3. Which activity in class has helped you the most in building personal confidence, growth, and belief in yourself?

Before: Students felt that completing lab assignments made them feel successful, reinforcing learning and progress. Independent practice gave them confidence, and seeing their progress and mastery of AutoCAD boosted their self-confidence. Classroom and pre-class discussions promoted learning and learning from mistakes, and time management taught them the value of hard work**.** Real-life applications were at the center of building confidence as shown in Figure 6.

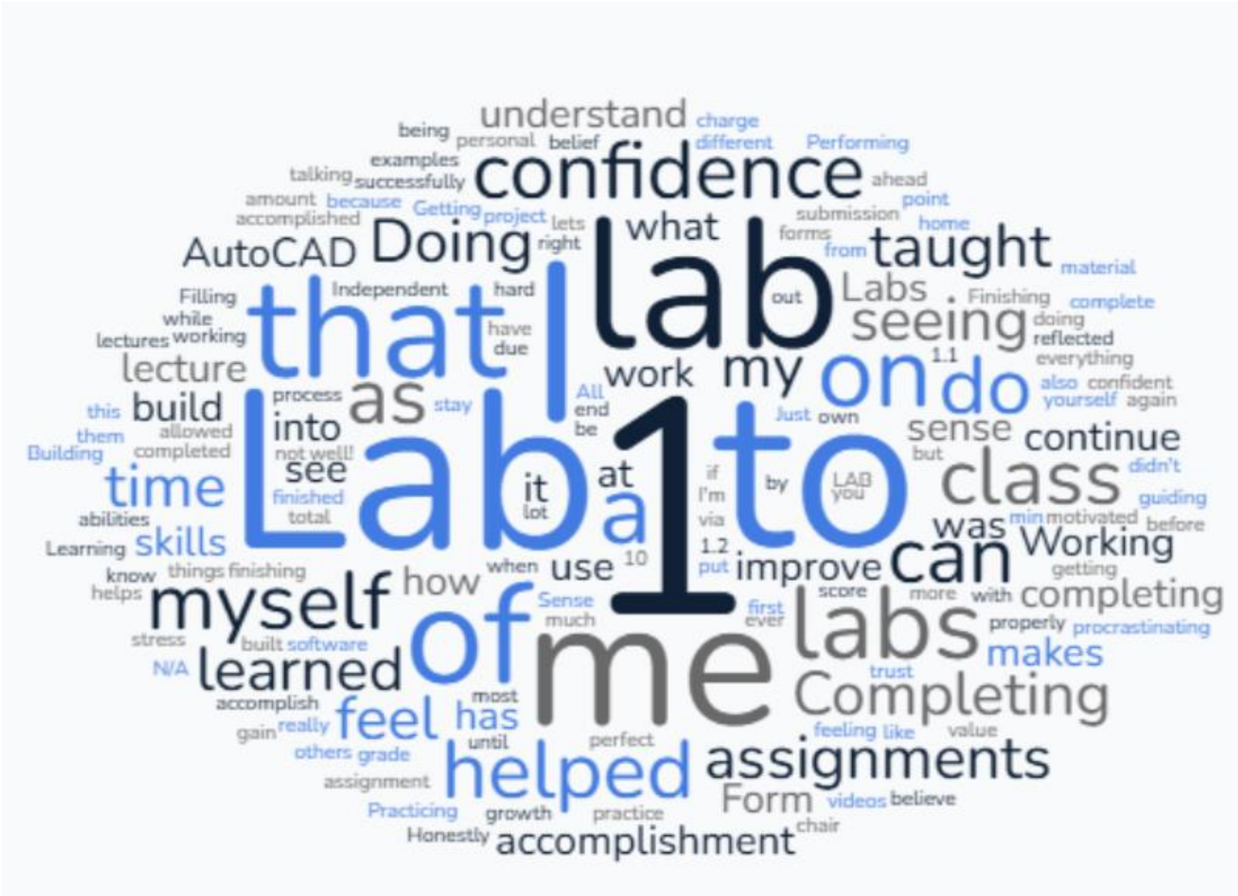

Figure 6: Activities that Built Personal Confidence and Growth Before Survey

After: Students felt that completing labs made them feel successful, made problem-solving **s**tronger, and built confidence**.** Students believed that hands-on practice and actual application of tools in lectures and labs improved 2D and 3D modeling skills. Students also felt that trial-and-error learning helped them overcome lab challenges, enhancing self-confidence and individual growth. Additionally, they included that learning together and communicating with others enabled them to learn and grow together as shown in Figure 7.

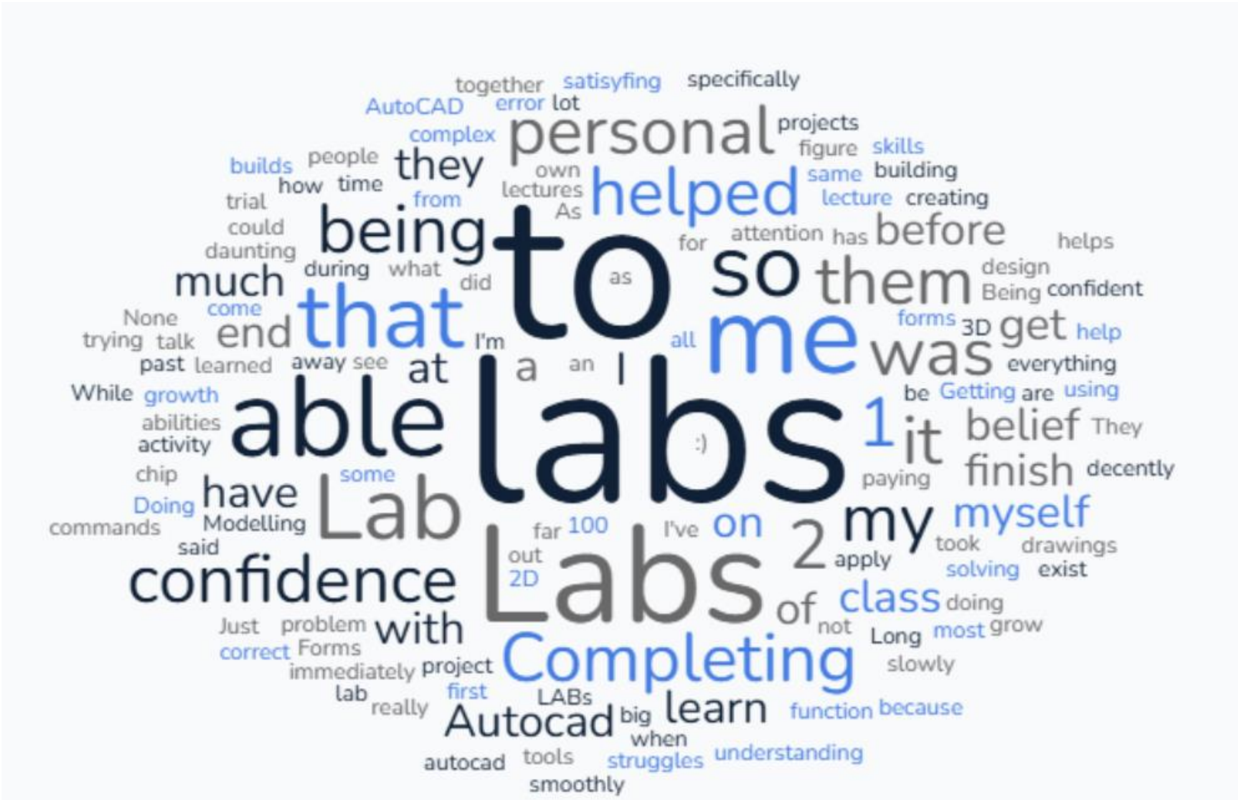

Figure 7: Activities that helped build personal confidence and growth after Survey

Conclusion

The results of this study indicate that students' growth mindset improved, in general, in all measured areas compared to the "Before" chart, suggesting that the interventions had a positive influence. Most notably, improvements occurred in:

- "I know that with effort, I can improve my skills and knowledge" (3% increase).
- "I can influence and change my development in general" (5.5% increase).
- "I can change my skills and knowledge through practice" (3.78% increase).

Despite these observed improvements, paired t-test analysis revealed that only the statement *"I can influence and change my development in general"* demonstrated statistical significance ($p = 0.01$ at the $p < 0.10$ level). The other statements were not statistically significant, suggesting the positive changes were not sufficiently measurable within the semester. Additionally, a slight decline in responses to *"I see learning as my goal"* raises questions for further exploration. Investigating the factors contributing to this decline will be critical in refining future interventions to maintain consistent improvements across all dimensions of a growth mindset.

We discovered in the before Survey that students relied heavily on hands-on practice, in-class demonstrations, and structured exercises to enhance their understanding. While form assignments, troubleshooting, and independent practice were deemed helpful, they had not yet fully developed their skills. The earlier results were more generalized regarding skill development and did not specify how each activity contributed to learning.

In the follow-up survey, the answers were more detailed, clearly articulating the forms assignments on isometric and orthographic views led to greater spatial awareness. The results further support the notion that students benefited from developing problem solving skills, learning from trial-and-error and collaborative learning. Discussions with peers and working through challenges were essential to building confidence and developing personally, which was absent in the first survey results. This suggests that having engaged in growth mindset exercises benefitted students in creating peer support systems.

Limitations

One limitation of this study is the lack of a pre-survey data collection; data were collected mid-semester instead of collecting a baseline at the beginning of the semester. As a result, the observed improvements were not as statistically significant as anticipated. Collecting data during the first week of the semester would provide a more apparent baseline and allow for a more comprehensive assessment of the interventions' full impact, capturing the entire range of changes throughout the course. These findings underscore the importance of both the timing of data collection and continuous refinement of interventions to support better students' growth mindset development in technical drawing and beyond.

Future Work

In the future, we plan to deploy this protocol with the data collected at the beginning of the semester and expand this study to examine whether the improvement in growth mindset is linked to specific outcomes such as academic performance and student engagement. Also, more deeply connecting specific technical and spatial ability activities to additional surveys offered before and after an activity may offer a more nuanced perspective of how a growth mindset may support the development of these skills in real-time. In addition, subsequent studies might contribute to address limitations by analyzing data for multiple courses, expanding the sample to a greater range of STEM courses, and examining different instructors' influences on student attendance and performance.

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