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Engineering Self-Efficacy and Spatial Skills: A Systematic Literature Review

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Abstract

[Blinded University] administers the Purdue Spatial Visualization Test: Rotations (PSVT:R) to incoming First-Year engineering students at orientation. Students who score less than 60 percent on the PSVT:R are required to take a spatial visualization skills intervention course, ENG1002 Intro to Spatial Visualization. In the fall semester of 2022, approximately 15 percent of students enrolled in the First-Year Engineering Program were required to enroll in ENG1002. This resulted in five class offerings of ENG1002 with approximately 30 students per class.

Questions exist as to why engineering students who complete Intro to Spatial Visualization at [Blinded University] attain higher average grades in their other courses, such as Calculus I and II, and Chemistry [1], and why the retention rate, especially of women, is higher historically for students who have taken Intro to Spatial Visualization [2]. One possible explanation is related to students' feelings about and confidence in their abilities to gain the skills they know to be important to engineers and attain their goals (self-efficacy) of becoming an engineer after overcoming the obstacle of failing an assessment of 3-D spatial visualization skills administered at the onset of their engineering program. Researchers believe self-efficacy is related to academic performance and retention [3], leading to the completion of a degree. As Bandura [4] contended, "Unless people believe they can produce desired results and forestall detrimental ones by their actions, they have little incentive to act or to persevere in the face of difficulties" [4, pp. 10]. Students with higher self-efficacy believe they have the ability to increase their skills. There are experiences and activities that increase the self-efficacy of undergraduate engineering students, as found by Usher, et al. in [5]. Interestingly, these are all outlined in Bandura's Social Cognitive Theory [6], including positive feedback on skill development, receiving positive affirmations from trusted others, viewing others working in careers of interest, and experiencing the work they are interested in themselves. Kennedy [5] studied the effects of each of these experiences and found them all to increase self-efficacy in engineering skills. Furthermore, researchers have identified spatial ability as important for engineering modeling and design [7]. This systematic literature review examines the relationship between spatial abilities and self-efficacy in engineering.

INTRODUCTION

Developed by Lent [8], the Social Cognitive Career Theory (SCCT), based on Bandura's Social Cognitive Theory [6], posits that self-efficacy is critical to later career success. The building blocks of SCCT are self-efficacy, outcome expectations, and goals. However, learning experiences and external factors, such as background, race, and gender, also affect self-efficacy. The SCCT has models including the interest, choice, and self-management models, and the "the self-management model emphasizes the factors that lead people to enact behaviors that aid their own educational and occupational progress (e.g., planning, information-gathering, deciding, goal-setting, job-finding, self-asserting, preparing for change, negotiating transitions) beyond field or job selection alone" [9, pp. 558].

General self-efficacy refers to our beliefs about our ability to attain positive outcomes and meet our goals. According to psychologist Albert Bandura [10] the first proponent of the concept, self-efficacy is the product of past experience, observation, persuasion, and emotion. A link exists between self-efficacy, academic achievement, and the ability to overcome phobias. Experiences like successes and failures, specific feedback, and scaffolded learning experiences may increase or decrease self-efficacy in a particular skill set, which can change outcome expectations, motivation, and future goals [11].

Spatial visualization has been defined in many different ways. This work utilizes Bodner and Guay's [12] definition of "spatial orientation factor as a measure of the ability to remain unconfused by changes in the orientation of visual stimuli," and states, "The spatial visualization factor measures the ability to mentally restructure or manipulate the components of the visual stimulus and involves recognizing, retaining, and recalling configurations when the figure or parts of the figure are moved" (pg. 6). Sorby [2,7] discusses the difference between "spatial abilities" and "spatial skills" and refers to spatial abilities as innate abilities and skills as learned abilities; however, both terms are often used interchangeably. Individuals with the aptitude and perceptual skills necessary to perceive and interpret objects can learn spatial visualization through experience, education, and effort.

RESEARCH QUESTIONS

This systematic literature review surveys current research in engineering education to examine the relationships between self-efficacy, spatial abilities, and achievement, concerning college students' success in engineering programs. Of specific interest is the change in spatial abilities and self-efficacy of students at the college level and relationships to academic performance and retention in engineering.

This systematic literature review aims to address the following questions:
RQ1: How have self-efficacy, engineering self-efficacy, and spatial visualization been measured?
RQ2: What are the statistically significant relationships between engineering self-efficacy, spatial visualization, and student success (i.e. academic achievement and retention) in engineering programs?

METHODS

Borrego et al. [13] provide guidance on how to perform literature reviews in engineering education. A systematic literature review aims to objectively review current research on a topic to inform future research by synthesizing past research efforts, identifying findings across studies, and identifying gaps in knowledge. They note that, unlike fields such as medicine and education that seek the efficacy of interventions, engineering education research is a relatively new body of research that draws practices and theories from various disciplines, including cognitive psychology, education, and engineering. Borrego et al. [13] outlined the steps of a systematic literature review of engineering education, including a search across recommended databases using key terms, using an iterative process with a team of researchers to include and exclude research that is either relevant or irrelevant to the research question(s) previously developed by the team. Included research is assessed for quality, and findings are summarized. A final synthesis of the literature is done for overall results, and a discussion of findings identifies results across studies and gaps in knowledge.

This review included studies that use self-efficacy and spatial visualization measures for quantitative assessment. The researchers excluded qualitative studies from the focus of this literature review. The review surveyed peer-reviewed studies of engineering students published in English between 2003 and 2023. All studies employed a quasi-experimental design to include quantitative data in sufficient detail to determine the statistical significance of differences between groups. Table 1 shows the inclusion and exclusion criteria for this literature review.

Included studies	Excluded studies
Post-secondary students in a formal engineering program leading to a degree	PK, middle school and HS students/teachers
Quasi-experimental design (quantitative data)	Qualitative data alone, meta analysis, systematic literature review, instrument validity studies
Self-efficacy and/or spatial visualization as student outcomes	Leadership self-efficacy, metacognitive strategies, anxiety scales, homework style, etc.
Published between 2003 and 2023 (20 yrs)	Published previous to 2003

Table 1: Inclusion and Exclusion Criteria

This systematic literature review was completed by a research team using the key terms "spatial" AND "self-efficacy" AND "engineering" to search the databases of ERIC, SCOPUS, Web of Science, and SEE Peer Repository for peer-reviewed journal articles from the last two decades. When searching the SEE Peer Repository, a fourth search term, “quantitative,” was added to the search terms to narrow the search to relevant studies of the 242 studies resulting from a search of “spatial” AND “self-efficacy” AND “engineering” only.

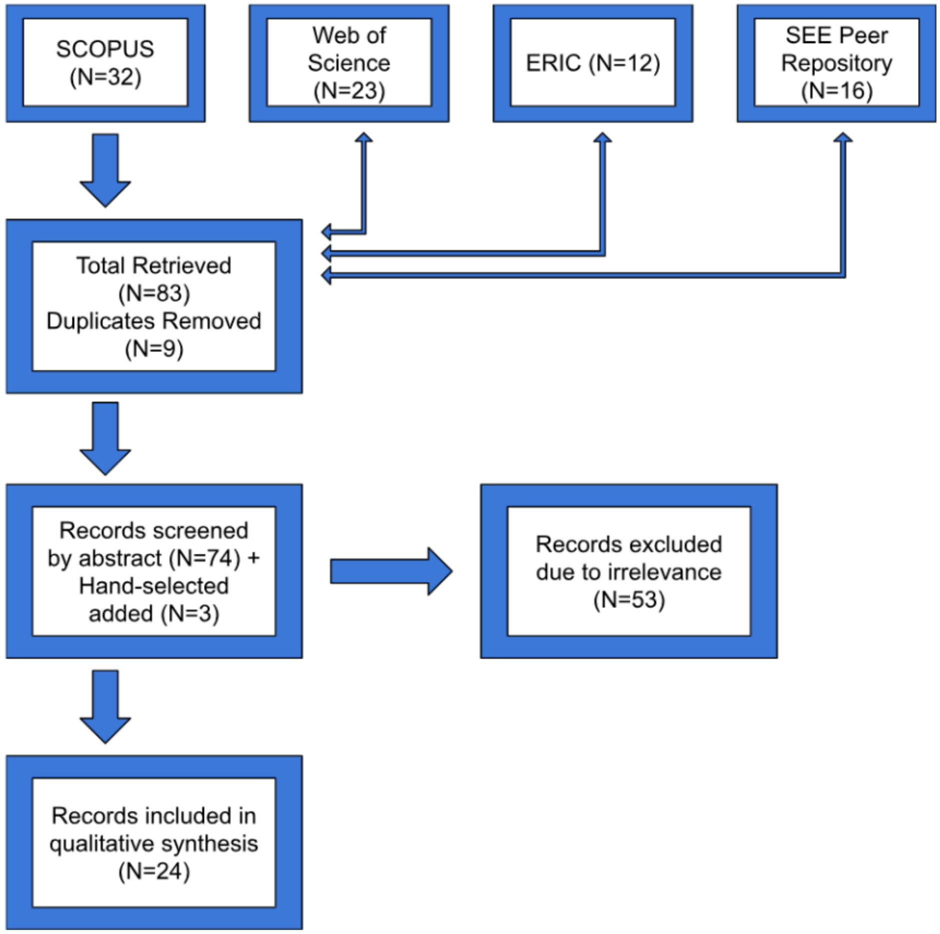

Figure 1: Systematic search process

As shown in Figure 1, a total of 83 articles were a result of the search of the databases. After reviewing the search results, the researchers removed nine articles due to duplication. The researchers then reviewed the article abstracts, and 53 articles were removed based on exclusion criteria in Table 1. Three articles were hand-selected and added from references of papers reviewed. This search yielded 24 relevant studies, reviewed and summarized in the results section.

Positionality statement

Positionality is important in qualitative, as well as quantitative engineering education research, according to Hampton et al. [14]. It provides information about the researchers' personal, political, and social positions as they relate to the study's context. We acknowledge the vital role that we as researchers play throughout the process of research design and implementation, as we analyze and synthesize data and disseminate the results [15]. Our team includes a diversity of perspectives in terms of academic career stages, including an undergraduate researcher, a Ph.D. student with decades of K-12 teaching experience, and an assistant professor. We include perspectives from the psychology, cognitive and learning sciences, and engineering disciplines. Two of the team members have taught the SV course at (BLINDED) University. Our team is composed completely of female researchers, one of whom was recognized for her spatial abilities early in life, one with early experiences in drafting and later with reading prints and residential building, and one who self-reportedly measures low in spatial ability.

RESULTS

The articles reviewed in this systematic literature review were all studies of engineering college students that focused on self-efficacy, spatial ability outcomes, or both. Fourteen of the 24 studies reviewed by the research team used the PSVT or PSVT:R to measure spatial visualization. Nine studies reviewed compared first-year engineering students with sophomores, juniors, and seniors. Pertinent details from each article are summarized in Table 2, including each article's authors, year of publication, title, instruments used, and number of participants included in the studies.

Author, date	**Title**	**Measures used**	**Number of Participants**
Watson, M. K., Davis, W. J., Mays, T. W., Welch, R. W., & Ryan, J. C., 2019	Measuring Undergraduate Student Design Self-Efficacy within an Undergraduate Civil Engineering Curriculum	Design Self-Efficacy, Motivation, Outcome Expectancy, Anxiety	N= 153
Jordan, K. L., Amato-Henderson, S., Sorby, S. A., & Donahue, T. L. H., 2011	Are There Differences in Engineering Self-Efficacy Between Minority and Majority Students Across Academic Levels?	The LAESE (Longitudinal Assessment of Engineering Self-efficacy) and APPLES	N=394
Jordan, K. L., & Sorby, S. A., 2014	Intervention to Improve Self-Efficacy and Sense of Belonging of First-Year Underrepresented Engineering Students	LAESE, APPLES scores, pre-post Self-Efficacy w/ video	Three phases: Small sample size in phase 1, phase 2: N= 63, 36 M and 26 F, phase 3: N=344
Snyder, M. E., & Spenko, M., 2014	Assessment of Students Changed Spatial Ability Using Two different curriculum approaches	PSVT:R	Technical drawing course, N=42; Engineering Design , N=38
Hilton, E. C., Linsey, J., Li, W., & Hammond, T., 2018	Effectively teaching sketching in engineering curricula	PSVT:R pre- and post, MRT, Design Self-Efficacy	N=694
Kinsey, B., Towle, E., Hwang, G., O'Brien, E. J., Bauer, C. F., & Onyancha, R. M., 2007	Examining Industry Perspectives Related to Legacy Data and Technology Toolset Implementation	PSVT:R and Self-efficacy Scale	N=278 ME, EE, Civil, for first year and upperclass

Rafi, A., & Samsudin, K. A., 2007	The Relationships of Spatial Experience, Previous Mathematics Achievement, and Gender with Perceived Ability in Learning Engineering Drawing	self-efficacy scale	N=225, F=75, M=149
Connollu, P., Blasko, D. G., & Holliday-Darr, K., 2006	Multiview Drawing Instruction: A two-location experiment	pre- and post-test, survey data, student scores	Purdue U. - M=16,F=29 education majors w/ no drawing exp. Penn State M=69, F=8 intro to engineering class
Kinsey, B. L., Towle, E., O'Brien, E. J., & Bauer, C. F., 2008	Analysis of Self-efficacy and Ability Related to Spatial Tasks and the Effect on Retention for Students in Engineering	PSVT and Self-efficacy measure	N= 497, males = 447, females=50
Jordan, K. L., Sorby, S., Amato-Henderson, S., & Donahue, T. H., 2011	Engineering self-efficacy of women engineering students at urban vs. rural universities	LAESE	N=113 women
Marra, R.M., Rodgers, K.A., Shen, D., & Bogue, B., 2013	Women Engineering Students and Self-Efficacy: A Multi-Year, Multi-Institution Study of Women Engineering Student Self-Efficacy	LAESE	N=196 women
Kinsey, B., Towle, E., Hwang, G., O'Brien, E. J., & Bauer, C. F., 2006	The effect of spatial ability on the retention of students in a college of engineering and physical science	PSVT and Self-efficacy measure	N = 497, M=447, F=50
Zurn-Birkhimer, S., Serrano, M. I., Holloway, B. M., & Baker, R. A., 2018	Work in Progress: Online Training in Spatial Reasoning for First-year Female Engineering Students	spatial reasoning abilities of the first-year female engineering students through origami or CAD assignments	N = 92 (63 experimental/ 29 control)

Onyancha, R., & Kinsey, B., 2007	The Effect of Engineering Major on Spatial Ability Improvements Over the Course of Undergraduate Studies	PSVT and Self-efficacy measure	First year: M=173,F=10,Seniors: M=70,F=6
Miller, D. I., & Halpern, D. F., 2011	Spatial Thinking in Physics: Longitudinal Impacts of 3-D Spatial Training	Mental Rotation Test, mental cutting, spatial working memory, physics grades, physics self-efficacy scores directly after training and 8 months later	N = 55, F=22, M=33
Van Den Einde, L., Delson, N., & Cowan, E., 2019	Freehand Sketching on Smartphones for Teaching Spatial Visualization	PSVT	Elective sem: N=11, two sems of required: N=27 and N=41.
Hilton, E., Li, W., Newton, S. H., Alemdar, M., Pucha, R., & Linsey, J., 2016	The Development and Effects of Teaching Perspective Free-Hand Sketching in Engineering Design	PSVT visualization, drawing quiz, and self-efficacy scores	N = 368
Hilton, E. C., Linsey, J. S., Paige, M. A., Williford, B., Li, W., & Hammond, T. A., 2017	Engineering Drawing for the Next Generation: Students Gaining Additional Skills in the Same Timeframe	pre and post measures of Design Self-Efficacy, quiz, and paper-based quiz, PSVT:R and Mental Rotation Test	N = 332 for PSVT:R and MRT; N = 73 for sketch
Bairaktarova, D., Reyes, M., Nassr, N., & Carlton, D. T., 2015	Spatial Skills Development of Engineering Students: Identifying Instructional Tools to Incorporate into Existing Curricula	PSVT:R and self-efficacy	N = 289, First year: N=120, junior/senior mix:N=120, graduate engineering students N=20, practicing engineers N=29
Minear, M., Lutz, L., Clements, N., & Cowen, M., 2017	Individual and Gender Differences in Spatial Ability and Three Forms of Engineering Self-efficacy	Tinkering and Design Self-Efficacy, Math self-efficacy,PSVT:R,MR subtest of Differential Aptitude Tests, grades from HS, demographic questions re: family education	N=310, M=252, F=58, 141 less than 24 credits or less and 169 more than 24

			credits
Romanella, S., & Novoa, C., 2017	Keeping the "Spark" alive - Investigating effective practices in the retention of female undergrads	self-efficacy, PSVT:R, grades, retention	N=18
Miller, D. I., & Halpern, D. F., 2013	Can spatial training improve long-term outcomes for gifted STEM undergraduates?	Mental cutting, Lappan test, Mental Rotation Test, Paper Folding, online surveys, STEM grades, physics learning outcomes, self-efficacy of physics skills	F=28, M=49
Ernst, J. V., & Clark, A. C., 2012	At-risk visual performance and motivation in Intro Engineering design graphics	PSVT:R and MSLQ (motivated strategies for Learning Questionnaire	N=91, 21 at-risk and 70 not-at-risk
Towle, E., Mann, J., Kinsey, B., O'Brien, E. J., Bauer, C. F., & Champoux, R., 2005	Assessing the Self-Efficacy and Spatial Ability of Engineering Students from Multiple Disciplines	PSVT:R and self-efficacy measure	N=219, M=191, F=28, underclass= 194, upperclass= 21

Table 2 Summary of studies included

Assessment Scales

This section presents the results of RQ1, investigating the literature about scales for measuring self-efficacy, engineering self-efficacy, and spatial visualization. Mamaril [16] found three types of self-efficacy measures in engineering - academic, general, and skill-specific. Within the literature reviewed, the LAESE (Longitudinal Assessment of Engineering Self-Efficacy) [21] is used to measure engineering self-efficacy encompassing academic areas specific to engineering and coping self-efficacy, whereas the Design Self-efficacy measures skill specific engineering skills, ie. design process skills. The remainder of the scales used measured skill specific self-efficacy, including the Tinkering, physics, and other non-standardized self-efficacy measures [17, 18, 19, 20].

Self-Efficacy Scales

The LAESE [21] assesses the following five constructs: academic STEM (i.e. science and math) self-efficacy assessing the ability to complete academic requirements for an engineering degree, engineering career success expectations, coping self-efficacy, and mathematics outcome expectations. The LAESE does not include engineering-specific skills, such as spatial rotation, tinkering skills, physics [22, 23], or engineering drawing skills. Jordan & Sorby [24] and Jordan et al. [25] used both the LAESE and the APPLES (Academic Pathways of People Learning Engineering Survey) [26] in their studies but did not measure spatial skills specifically. The APPLES measures the following constructs: 1) Motivation: Financial, 2) Motivation: Parental Influence, 3) Motivation: Social Good, 4) Motivation: Mentor Influence, 5) Intrinsic Psychological, 6) Intrinsic Behavioral, 7) Confidence in Math and Science Skills, 8) Confidence in Professional and Interpersonal Skills, 9) Confidence in Solving Open-ended Problems, 10) Perceived Importance of Math and Science Skills, 11) Perceived Importance of

Professional and Interpersonal Skills, 12) Curriculum Overload, 13) Academic Involvement- Liberal Arts Courses, 14) Academic Involvement - Engineering- related Courses, 15) Frequency of Interaction with Instructors, and 16) Satisfaction with Instructors. The APPLES also measures outcome expectations related to a career in engineering [26]. Eleven of the 16 constructs in the APPLES were used in the study by Jordan et al. [25] in combination with the LAESE, because it addresses engineering student motivation, confidence in math and science skills, professional and interpersonal skills, solving open-ended problems, and academic engagement/disengagement.

Skill-Specific Assessment Scale

Engineering skill-specific assessment scales found in the literature addressed engineering design, tinkering skills, 2D and 3D rotation, and spatial visualization skills. The Engineering Design Self-Efficacy scale [11] was developed to measure self-efficacy of engineering skill and general skills includes the following constructs: engineering design self-efficacy, motivation, outcome expectancy, and anxiety. Design in this scale refers to the iterative process used in engineering: 1) identifying a problem, 2) analyzing the data, 3) identifying possible solutions, 4) designing a prototype, 5) implementing a plan, and 6) assessing the plan. Within the studies reviewed, three utilized the Engineering Design Self-Efficacy Scale [27, 28, 29]. This scale does not address physical design through hand-drawing or CAD programs. Carberry et al. [11] found statistical differences in self-efficacy between high, intermediate, and low experience groups when comparing engineering or engineering education professors (12), engineers (26), engineering education graduate students (7), engineering graduate students (28), engineering undergraduate students (60), non-engineers with science backgrounds (32) and non-engineers without science backgrounds (37). Participants with high levels of experience in engineering also had high levels of Design Self-efficacy, such as engineering professors and engineers, those with intermediate levels of experience had lower levels of Design Self-efficacy, such as engineering graduate and undergraduate students, and those with the least experience had the lowest, indicating a need for additional support to learn the engineering design process. Motivation, outcome expectancy, and anxiety (negatively) were all found to be strongly correlated with self-efficacy. Another skill-specific scale, the Tinkering and Technical Self-Efficacy Scale by Baker [30] measures skills associated with engineering, such as assembling, disassembling, constructing, and modifying. The purpose of developing a Tinkering and Technical Self-efficacy Scale was to identify students with low self-efficacy in engineering skills and to develop interventions to retain those students. Students with low self-efficacy in engineering skills are at higher risk of leaving the discipline, especially female students [30]. Within the literature reviewed, other non-validated author-designed self-efficacy measures were described as measuring specific skills in 2D and 3D rotation and spatial visualization of line versus solid drawings [17, 18, 19. 20].

Ten different measures were used to assess spatial skills, including the Purdue Spatial Visualization Test (PSVT)(5) [31], Purdue Spatial Visualization Test: Rotations (PSVT:R)(9) [12], Mental cutting (2) [32], Mental Rotations (MRT)(4) [33], Lappan (1) [34], Paper Folding (1) [35], origami (1) [36], CAD assignments (1), a drawing quiz (1), and the MR subtest of Differential Aptitude Tests (1) [37]. The PSVT was developed by Guay in 1977, and it was revised by Bodner and Guay in 1997 to include Rotations (PSVT:R). Yoon [38] revised the PSVT:R for online use of the assessment, as there were figure errors in translation from paper-pencil to the online version. The PVST and its revision to the PVST:R compose the majority of the spatial-skills assessments identified in the engineering education literature.

Studies Implementing the Scales

This section presents the results from RQ2: What are the statistically significant relationships between engineering self-efficacy, spatial visualization, and student success (i.e. academic achievement and retention) in engineering programs?

Prior experiences have been shown to influence students' drawing self-efficacy, but the type of experience matters. Rafi et al. [39] found that students with prior drawing experience had higher drawing self-efficacy, and those with prior math success had lower drawing self-efficacy. Female students reported a higher perception of being able to learn engineering drawing, especially the female students with low prior experience.

TYPE of Instruction

Spatial visualization skills are often assessed pre- and post- to measure gains in ability before and after an intervention or experience. Three of the studies examined the effect of instruction on spatial skills, but did not examine self-efficacy (40, 41, 36]. The literature provides conflicting results as to whether hand-drawing or computer-based instruction is superior for learning and improving spatial skills. Computer-based instruction versus hand-drawing was found to be equally beneficial in one study. According to Connollu et al., [40], computer-based instructional tools were used, and on-line instruction and practice resulted in similar gains as compared with mixed computer/manual or entirely manual instruction. In contrast, when comparing a technical drawing course and an engineering design course, Snyder & Spenko [42] reported that hand drawing outperformed product design, 3D software, and prototyping on PSVT:R (with rotations) scores. In more recent research, Van Den Einde et al. [41] found students using an app for spatial visualization training increased their PSVT scores up to 33 percent in 67 to 85 percent of students across three semesters, although no comparison was made to a control group that included hand-drawing. Regardless which method is superior, hand-drawing or computer-based instruction, it is clear that spatial skills can be improved. Bairaktarova et al.[43] found that males scored an average of 2.5 points higher on the PSVT, but there was no significant difference for race, major, student classification, or experience. Van Den Einde et al. [41] suggest that students needing remediation, especially female students, would benefit from on-line instruction and practice with visualization skills because the instruction and practice is available to students all day every day to be used at their convenience.

Seventeen of the studies assessed both spatial skills and self-efficacy of engineering students. There were no significant findings on spatial and self-efficacy measures based on race, type of engineering drawing instruction, at-risk status, major, student classification or experience. The type of instruction used to assist students in developing their engineering drawing skills is often examined, and students' perceptions of the skills they develop is often considered when measuring instructional outcomes. Hilton et al. [28], in a large study (N=694), found no significant differences between traditional sketching and perspective drawing groups on the PSVT and Mental Rotations Test (MRT), except for students who started in a low performance group whose scores increased significantly on both spatial measures and self-efficacy. Both traditional and perspective drawing resulted in the same increase in self-efficacy, as assessed by the Design self-efficacy scale [28]. Similarly, Ernst & Clark [44] found no statistically significant findings on the PSVT or the MSLQ (Motivated Strategies for Learning Questionnaire) between at-risk students and others in an engineering fundamentals graphics course.

Towle & Kinsey et al. [17, 18, 19, 20] created their own unvalidated self-efficacy scales to measure the self-efficacy of spatial skills specific to their studies. In their 2007 study, students had higher self-efficacy in line drawing versus solids, double rotations were rated lower and scored lower than single, and increased angle was lower as well. Instruction in line drawing versus solid object drawing did not result in a change in PSVT:R scores.

One study was very different from the rest, in that it used origami as a method of teaching spatial skills in a 12-week workshop conducted on-line. A work in progress paper by Zurn-Birkhimer et al. [36] compared two groups of females in a first year engineering program, one that completed online spatial assignments using CAD, and one that completed origami assignments that required hand-folding origami. Similar numbers of students maintained or increased their expertise in spatial skills between the two groups, but three of the students in the CAD control group decreased in their skills whereas none of the origami students demonstrated a decrease in self-perceived skill level.

Lasting effects of instruction

Although gains were found in both skill and self-efficacy in two studies by Miller and Halpern [22, 23], the gains were not sustained over time. Drawing abilities increased for gifted STEM students, as did their self-efficacy and spatial skills as measured by the Mental Cutting, Lappan test, mental rotations, paper folding, online surveys, STEM grades, physics learning outcomes, and self-efficacy of physics skills in a study [23], but the increases were not observed in the same students 8 months later when they were assessed again using the same measures. This is similar to Miller & Halpern's [22] study in which the training group demonstrated higher spatial skills initially but were not able to demonstrate the same gains after 8 months. After the 8 months, males outperformed the females on some spatial measures, had greater physics problem solving skills, self-efficacy, and achieved higher grades in electricity and magnetism. Although the men outperformed the women on mental rotation and mental cutting, they did not do better than the women on novel cross-sections or spatial working memory.

Major

In the following studies, students' major was considered as a comparison when considering spatial and self-efficacy measures. Major matters when it comes to undeclared versus declared students, students in engineering or STEM-related fields versus non-STEM majors, and even between majors in engineering. Onyanch & Kinsey[19] reported that students' scores on the PSVT increased most in mechanical and civil engineering from first year to senior, and self-efficacy scores pre to post differed in that the mechanical students increased while the civil students decreased on average from first year to senior. In another study by Towle & Kinsey et al. [20], a strong positive correlation was found between spatial skills (PSVT:R) and self-efficacy for all of the engineering majors but not for the undeclared students. Males (N=447) had higher PSVT and self-efficacy scores than females (N-50), and only males were considered on the comparison between first years and sophomores to juniors and seniors; juniors and seniors had higher PSVT and self-efficacy scores on solving single axis and double axis rotation problems. When considering retention, Kinsey et al. [18] found that males (N=447) scored significantly higher (70 percent) than females (N=50) who averaged 60 percent, and males reported higher self-efficacy. In a comparison of engineering students to those in a physical science major, there was a significant positive correlation for engineering students between self-efficacy and spatial ability, whereas the other disciplines did not demonstrate the same relationship. When considering major and spatial ability, Hilton et al. (45, 27] found that perspective sketching is just as effective as isometric sketching (traditional), and there were no significant differences in PSVT, self-efficacy, or MRT scores between groups. Taken together, these studies indicate that there is a positive relationship between self-efficacy and spatial abilities for declared-major engineering students.

First year and sophomores vs. upper class students

Class standing also matters when considering both spatial skills and self-efficacy of spatial skills. Towle and Kinsey et al. [20] found that juniors and seniors had higher self-efficacy in solving single-axis and double-axis rotation problems. In 2006 [18], these authors found that juniors and seniors scored higher on the PSVT on an unvalidated self-efficacy assessment than first year and sophomore students, males scored higher than females on both, and students in a 3D CAD course scored higher on both compared to those in a 2D course. Similarly, Watson et al. [29] found that Design Self-efficacy increased with years in school, which is expected based on the purpose of the scale. They found that Design self-efficacy was positively correlated with motivation and outcome expectation. The design process was the focus of this research, and upper class students had higher self-efficacy for communicating a design versus constructing a prototype. In contrast, one study conducted by Minear et al.[46] looked at individual and gender differences using three forms of engineering self-efficacy, Tinkering, Math, and Design, between inexperienced (less than 24 credits, or first year students) and experienced (more than 24 credits, or sophomore standing) students, finding a strong positive correlation between spatial skills and Design self-efficacy only in the first year engineering students.

DISCUSSION

In the studies included in this review, there were many different measures of engineering self-efficacy relating to academic, skill-specific, and general self-efficacy, from reliable and validated scales to those created by the authors for the purpose of their study - making comparisons of studies are difficult across these domains. Regarding skill specific self-efficacy, research shows that experience and instruction in a specific skill is predictive of increased self-efficacy in that skill [22, 23, 39]. Also, high self-efficacy in academic and skill-specific areas have been found to be short-lived as shown in follow up studies up to 8 months later, but some researchers believe this is due to an increase in domain knowledge and less of a focus on foundational skill ability [47] . Self-efficacy in a field such as engineering is related to continual pursual of and increased skill in that area of study [48].

Spatial visualization was measured by the PSVT or PSVT:R in more than 50 percent of the studies. Thus, for the purpose of comparison, future work should use these measures. Overall, it can be concluded that remedial instruction in spatial skills, regardless of the instructional approach or medium, can increase spatial skills and engineering self-efficacy, which are both important for the success of all students and their retention in an engineering program [17, 18, 19, 20, 49, 43, 29]. Male students historically outperform female students on spatial visualization skills, but spatial skills can be learned with experience and instruction. Several studies noted the discrepancy between numbers of male and female students in engineering, along with the discrepancy between the numbers of majority (white) versus minority students. Our diverse world with its myriad issues needs a diverse engineering workforce to solve them, and ABET agrees. According to a Dear Colleague letter to ABET, the Accreditation Board of Engineering and Technology, from the Big 10+ Deans of Engineering, “We believe that diversity, equity, and inclusion (DEI) are core values for all engineers, and are essential considerations for generating creative and effective solutions to the most important challenges facing our society and our planet” [50]. Therefore, instruction is important for those students who enter engineering with lower skills and confidence in the skills needed to persist and succeed in an engineering program regardless of where they live in the world [51], such as engineering graphics and spatial visualization skills.

FUTURE RESEARCH

Miller and Halpern [23] assert that a theoretical framework is needed for the mechanisms at work mentally to improve spatial abilities. Future research on the cognitive processes used in spatial perception and thinking are needed to inform interventions and instructional practices in general. Future research is also needed to inform a more universal approach for assessing engineering self-efficacy, possibly a set of easily administered scales that includes general, academic, and skill-specific self-efficacy in engineering drawing. Constructs that are related to self-efficacy should also be considered, such as motivation to persist in an engineering program and anxiety toward meeting all of the requirements of earning an engineering degree, coping with demands, and fitting in socially with other engineering students. A longitudinal study of students’ engineering self-efficacy may help to determine if impacts are long-lasting from skill-specific engineering graphics instruction.

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