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EDGD Calendar of Events

Future ASEE Engineering Design Graphics Division Midyear Conferences

75th Midyear Conference – January, 2022, Raleigh, NC

Site Chair – Nolan Fahrer (nefahrer@ncsu.edu)

Program Chair – Kevin Sutton (kgsutton@ncsu.edu)

Future ASEE Annual Conferences

Year	Dates	Location	Program Chair
2021	July 26 - 29	Long Beach, California	Lulu Sun and Magesh Chandramouli
2022	June 26 - 29	Minneapolis, Minnesota	
2023	June 25 - 28	Baltimore, Maryland	

If you're interested in serving as the Division's program chair for any of the future ASEE annual conferences, please make your interest known.

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Elections

According to the Division by-laws (available at: https://www.asee.org/documents/member-resources/divisions/bylaws/EDGD-Bylaws-2019.pdf), the chair of the Nominating Committee shall transmit the slate of candidates to the Editor of the *Journal* for publication. The candidates for the election are as follows:

Vice-Chair

Dr. Steven Nozaki is an Assistant Teaching Professor in the Mechanical Engineering Technology department at Penn State Behrend. His teaching focus is on engineering graphics, production design, and mechanics. He earned a BS and MS in Civil Engineering along with a MA and PhD in STEM Education, all from The Ohio State University. His research interests include improvement of spatial visualization skills, assessment in education, and engineering graphics and design.

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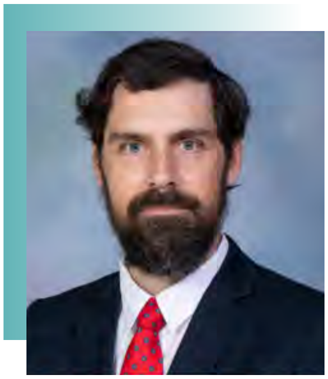

Dr. Matthew Wettergreen is an Associate Teaching Professor at the Oshman Engineering Design Kitchen (OEDK) and is Director of the Master of Bioengineering Global Medical Innovation (GMI) Program. While at the OEDK, Wettergreen has co-developed six of the seven engineering design courses in the design curriculum, including the flagship first-year engineering design, the Prototyping and Fabrication course, and the first engineering design minor in the US. Wettergreen has over ten years of experience teaching client-based engineering design courses, and a deep interest in engineering education, specifically curriculum that can be employed to build capacity for student development in makerspaces.

Dr. Wettergreen took his Ph.D. in Bioengineering at Rice University and his B.S. in Bioengineering from the University of Illinois at Chicago.

Director of Publications

Dr. Nancy E. Study is a faculty member of the School of Engineering at Penn State Behrend where she teaches courses in engineering graphics and rapid prototyping and is the coordinator of the rapid prototyping lab. Her research interests include visualization, standardization of CAD practices, and haptics. Nancy is a former chair of the ASEE Engineering Design Graphics Division and is currently the Circulation Manager and Treasurer of the Engineering Design Graphics Journal. She received her B.S. from Missouri State University, and M.S. and Ph.D. from Purdue University.

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Strategies for Teaching Computer-Aided Design Online: Lessons Learned from the COVID-19 Pandemic

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Syracuse University

Abstract

In spring 2020, the impact of the COVID-19 pandemic forced universities across the globe to move all teaching from in person to online. This pivot led to instructors needing to support students who became dispersed all over the world with little time to prepare. Whilst online teaching is not a new concept, there is relatively little literature devoted to how to teach computer-aided design (CAD) online effectively. This transition to online teaching midway through the semester offered a unique opportunity to compare the student experience of a fully in person class with a hybrid experience — the first half in person, and the second half online. To investigate this impact, research was conducted to assess whether this experience was affected by the transition to online learning for a course that is traditionally based in a physical computer lab. This paper discusses the challenges and positive insights from teaching CAD online to undergraduate students and provides recommendations for how delivery could be further improved.

Introduction

Instruction of CAD courses builds on foundational engineering concepts and is an applied approach to connecting geometry and mathematics through 3D visualization. Instructors typically guide students in building models in CAD through guided tutorials, case studies, and individual and team projects. Successful instruction relies on a range of teaching approaches, especially in a class where students have varying levels of experiences in CAD either developed through personal interest or exposure to different software packages in high school (Asperl, 2013). Varying the difficulty of the class assignments, structured group discussions, and model troubleshooting sessions creates a learning environment that encourages experimentation and collaboration. With a heavy focus on laboratory-style teaching, it is unsurprising that little research has been conducted on teaching university level CAD online. Indeed, there are video tutorials (Cozzens, 2012), MOOCs (Kang et al., 2016), and professional development courses online that teach the viewer how to operate software packages, but they typically lack the discourse needed when learners encounter problems in their own work. MOOCs, for example, rely heavily on a peer review system whereby learners evaluate each other's work rather than on individualized expert feedback from the instructor. This method of assessment has received mixed outcomes in effectiveness as students feel uncomfortable or unqualified to assess their peers work (Beasley et al., 2018).

In addition to the comfort level of assessing peer work, acknowledging that students have different learning styles is important. In their study which analyzed learning styles in CAD courses, Goodridge, Lawanto, and Santoso (2017) showed that while some learning styles excelled in online learning environments, others did not. Beyond the engagement with learning materials, there are also infrastructural challenges for students and instructors to overcome. Dosen et al.(2012) found challenges in teaching CAD online mostly related to lack of university resources in managing a large student cohort especially with expectations to meet with students outside of the regular timetable. Notably, students struggled to

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stay organized and meet submission deadlines without the in-person community and face-to-face engagement with the professor, therefore the need for teaching assistants to work with students on completing coursework was evident.

Online courses require significant effort on the part of the instructors to develop materials, keep students engaged, and maintain the same sense of community that is enjoyed in person. In a case study comparing an in-person and online CAD course offering, Bender, Wood, and Vredevoogd (2004) discovered that professors spent more time per student with online enrollees than in person students. If the courses were developed for future online course offerings, less time would be spent on preparing materials and delivering lectures, and more time could be spent engaging with students. Viewed another way, the benefit to well-developed content for the instructors is that the materials can be reused for repeat course offerings, and used to reinforce learning objectives within the same course or used in other areas of the curriculum (Onofrei & Ferry, 2020). Professors do however, need to be adequately supported by their institutions to develop successful online learning materials (Stros et al., 2017).

The advantages to teaching CAD courses online include broadening participation of non-traditional students, providing remote certification programs for subject matter experts (Wittenborn et al., 2009), and engaging learners from across the globe (Kang et al., 2016). The e-learning experience can be used to mirror the working environment of engineering agencies that work in global teams for product development. This means that students can develop a skill set for online communication that can be advantageous in the early stages of their career.

There have been some studies comparing the effectiveness of online CAD learning in comparison to an online experience. In a study of multiple CAD course offering online, Fadda and Rios (2019) maintained a similar course structure to that of the in-person class, but with extra milestones added to the group design project. They utilized an online learning management system (LMS) to track student engagement in posted course materials, including video content that was used in place of live in person instruction. The found that the two course modalities yielded comparable student performance. Similarly, Branhoff and Wiebe (2009) observed that the instructional method had no significant effect on final exam scores between a hybrid and in-person introductory engineering course.

The global pandemic offered a rare opportunity to compare the student experience of a fully in person class to the unique hybrid model that was taught with the first half of the semester in person, and second half online. To that end, this paper discusses whether the student experience was affected by the transition to online learning for a course after beginning in person, and what teaching approaches could be utilized to support students in various hybrid models or fully remote learning environments.

Methods

IT infrastructure for in-person learning

Fourteen students (senior standing) were enrolled in an Advanced CAD course in the 2020 spring semester. All students had taken an introductory CAD class using the same software in their junior year. The in-person course was taught in the Visualization Lab, where students worked on university owned Windows OS desktop computers.

IT infrastructure for online learning

The impact of the COVID-19 global pandemic required all educational efforts to transition to remote learning in March of 2020 at Syracuse University (Figure 1). During the transition, students were encouraged to work with their professors and campus IT services (ITS) to determine what they needed to do to run CAD software on their personal computers. The student population at

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the instructor's institution own Windows OS and Apple OS personal computers which posed a challenge as the CAD software used in the course does not operate on the Mac OS. In response, two approaches were initiated to prepare students for online learning: (1) The university set up virtual desktop access for students to access the computers in the Visualization Lab without additional software installation, and (2) students were instructed to install parallel operating system software so that they could operate the CAD software. All students had access to either a CAD license check-out system operated by campus ITS or could install their own temporary license that was provided free of charge by the university's CAD reseller for the duration of the semester.

Existing IT infrastructure was utilized to facilitate a functional online learning environment by using cloud storage services for sharing large files which typical for CAD, and an online learning management system with integrated video conferencing capabilities.

In person course content, teaching style, and assessment

The Advanced CAD course was designed to teach students skills in design for manufacture, and covered advanced modeling, assemblies, and engineering drawings, with the addition of tools such as sheet metal design, mold design, and design tables.

In-person class format for introducing students to new concepts or tools, teaching would take the following structure: (1) instructor demonstration, (2) model together and allow for questions and individual assistance when needed, (3) model alone on an assignment that was more challenging than the group model, and (4) homework to reinforce the learning that introduced alternative ways to solve the same modeling problem.

Students were graded on their ability to keep sketches fully defined, design tree features renamed, and assigned material properties to ensure that their design process could be easily understood by others, plus easily editable for design specifications changes. All students took the CSWA Mechanical Design Associate exam as part of the course fulfillment criteria. The redesign of a smoke detector was selected as the end of semester project for students to demonstrate all the skills learned throughout the course. The assessment structure was as follows: class and homework assignments (40%), midterm exam (20%), final exam (20%) and a project (20%). Before transitioning to the online format, each had taken the CSWA Certification Exam (~80% first time pass rate) and the majority of class assignments were completed. The individual project and final exam were still required to complete the class.

Online course content, teaching style, and assessment

To complete the class and homework assignments, students were supported with both synchronous and asynchronous teaching approaches. Weekly videos were created by the instructor for students to watch (similar to a flipped classroom model), and then a follow-along tutorial

In-person teaching	Spring break	Online teaching
Week 1-8	Week 9	Week 10-15
Content: Skill building, mid-term exam		Content: Skill building, individual project, final exam

Figure 1. Course structure over 15 weeks. Spring break acted as a buffer between teaching in person and online learning. Spring break was the designated time to ensure students and faculty were technologically ready for the transition.

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was completed which mirrored the in-person approach detailed above. To capture evidence of the tutorial attempts, students submitted screenshots. During the synchronous class, students could ask questions, screenshare, and email problematic files to the instructor for discussion and support. The online conference call was used to mimic the interactions that the instructor would have with the in-person classroom. Breakout rooms were utilized for one-to-one discussions.

To support the final project, the first-class period of the week was asynchronous with tutorials to reinforce understanding of specific features and tools that were related to designing for injection molding. The second class of the week was synchronous for live discussion and project troubleshooting. Two weekly milestones submissions were required: one for tutorial completion, and one for project progress. These were both screenshots and short descriptions that detailed their success, struggles, and progress. One-to-one online meetings and email correspondence were encouraged. Due to the restrictions in place, no 3D printing of the final product could be facilitated, therefore only virtual prototypes were submitted for grading.

After the transition to online learning, new check-in assignments were added for 10% of the final grade. The final exam was reduced by 10% to accommodate for these new submissions. In lieu of a timed modeling final exam that would have been administered in class, the instructor used the CSWP Mechanical Design Professional practice exam on the SolidWorks Virtual Tester (Tangix Virtual Tester, 2021).

A university-wide grading option was offered to all students due to the disruption to in-person learning thus the students could elect to switch to Pass/Fail grading scheme or continue with the A-F scheme.

Data collection and data analysis

Assignment submission data was collected to gauge student engagement with assessment materials and was used to compare in-person teaching submission rates to online teaching submission rates within the 15-week course which was tracked in the LMS.

Student engagement data was collected though an anonymous university-administered survey with questions 5-point Likert scales (1-5, one being least satisfied and 5 being most satisfied) and open-ended questions about their experience throughout the course. Course evaluation were automatically distributed during the last 2 weeks of semester by a university-wide automated system, with email reminders sent daily to students who had not completed the survey. Survey completion was not mandatory, hence the number of completed surveys is lower than the number of students enrolled in the class. The full survey had 18 questions of which 6 were selected for comparison. This data was compared with previous course offering survey data. For the 2020 hybrid course offering, the response rate was 50% (n=7) and for the 2019 in-person offering used for comparison, the response rate was 62% (n=15). As the sample sizes were small, unequal, and not uniformly distributed, a Mann-Whitney U test was used to determine whether the teaching modality (hybrid versus in person) had a significant effect on the student experience, as collected from course evaluation survey.

Finally, the number of students who elected to transition to a Pass/Fail grading scheme was collected. This was made available to the instructors by the Office of Student Success after final grades were posted and was interpreted as a measure of confidence by the student that they would be able to maintain their grade through the transition.

Results and Discussion

Table 1 shows data from the 2020 hybrid course offering in comparison to the last time the course was delivered in person. In general, the 2020 students rated the course similarly to those from

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Table 1

Instructor evaluation data from the semester affected by COVID-19 (hybrid delivery) compared to data from the previous year's course offering (in person delivery) for Advanced CAD: mean score and p-value from the Mann-Whitney U test. Survey responses for each course: Hybrid n = 7, in-person n = 15.

Instructor evaluation question scored from 1 (strongly disagree) to 5 (strongly agree)	*Hybrid delivery mean*	*In person delivery mean*	*p-value U = 24*
I feel that I performed up to my potential in this class	4.14	4.47	0.67
Used class time well	4.57	4.60	0.81
Delivered clear and understandable presentations	4.43	4.87	0.24
Was willing to meet with students outside of class	4.86	4.27	0.18
Provided helpful feedback on my work	5.00	4.67	0.32
Instructional technology used in this course contributed to my learning	4.71	4.93	0.57

2019 with one exception: 'I feel that I performed up to my potential in this class' dropped from 4.47 to 4.14. Statistically, there was no significant difference observed between the two course offerings, as reported by the Mann-Whitney U test which used a 0.05 p-value, U=24. That there were no statistical significances reported for the questions analyzed suggests that the student learning experience was not disrupted by the transition to online teaching in the middle of the 2020 spring semester. This result was consistent with the findings of other published studies in teaching effectiveness across learning modalities (Branoff & Wiebe, 2009; Fadda & Rios, 2019).

In the open-ended questions where students were asked to comment on what they found most and least valuable about the course, students were generally positive about their experience with the course and transition to online learning. Key insights showed that some students initially struggled with the online format. Student comments for this course showed that working remotely without the physical presence of the professor was difficult at times when they needed answers to questions (Figure 2). Students acknowledged that there were online infrastructure difficulties, but that the professors were not at fault and that there was appreciation for the effort put forth by the instructor.

Using the assignment submission rate as a measure of student engagement is limiting. When comparing in-person and online submissions rates, an increase in failed assignment submissions was observed. Table 2 shows that this rate was observed in both percentage of non-submissions, and the number of students who had at least one non-submission. Most of the failed submissions for the online half of the class were attributed to the check-in assignments (screenshot and description of progress) that were implemented similarly to the approach of Fadda and Rios (2019). This could have been because the students simply forgotten to document their work-in-progress or did not feel that they needed to check-in beyond meeting with the instructor in the synchronous sessions. Perhaps the submission of this assignment was no aligned correctly with some student's individual project workflow.

For the student elected grading scheme, 50% opted for the Pass/Fail grading scheme when classes transitioned to online learning. As this data is anonymously submitted, the author cannot link the decision to grade standing at the course midpoint. This could be due to the fact that the advanced course was an elective and therefore not deemed as important as other courses to complete to the best of their ability. The course evalu-

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"The second half of the semester, Dr. Manfredi did a great job transitioning to online instruction, but it was a bit trickier to ask questions or have her explain when you're remote."

"My other issues with the class are more due to the limited access to the proper computers. However, I do not blame my professor or the university of the unforeseen circumstances we faced this semester. I do feel like it did limit my ability to perform up to the standards of the class."

"I thought the class was well structured. I think it was just difficult transitioning to online classes."

"I do think I missed some areas of the class/could have had less trouble if we were in class together more."

"With the transition to online classes, I struggled not having Professor Manfredi easily reachable in the moment like I did in the physical class so a lot of the time I would confuse myself. I find that this course was easier for me to learn and adjust to when we were in the classroom, but that is not the fault of the professor by any means."

"Dr. Manfredi is the most valuable part of the course and my learning experience! It shows in her teaching style, prompt email responses, quick grading/feedback, and willingness to help students anytime!'

"New ways of thinking about efficient and thorough 3D modeling techniques that will stay with me long into my career."

"I enjoyed that the professor was available during class to help people one to one when we were sent off to do class work."

Figure 2. Student feedback excerpts from the open question 'What aspects of the course were the least and most valuable to your overall learning experience?' posed to students about the Advanced CAD course from the hybrid 2020 course delivery.

ation showed a lower mean score in 'meeting my potential' in the course compared to the previous year. As stated by Goodridge et al.(2017) that not all learning style excel in an online environment, perhaps student were no confident in their ability to work remotely and as such opted for the grade scheme that had less risk. Alternatively, if the student's original motivation for taking the class was to complete the CSWA certificate, then this was already completed before the shift to online teaching and their personal goal has already been met.

Table 2

Summary of student engagement by tracking number of non-submissions for the hybrid course delivery of the Advanced CAD class. N=14.

	In person	*Online*
Total number of assignments	17	8
Number of students with at least one non-submission	6	9
Percentage of assignments not submitted (total across all students)	7.14%	17.86%

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The blend of synchronous and asynchronous content was well received by the students. The the scores were consistent in course evaluations for 'delivered clear and understandable presentations', 'willing to meet outside of class' and 'provided helpful feedback' indicating that CAD could be successfully taught as an online or hybrid course in the future. As stated by student feedback in Figure 2, it is "trickier to ask questions online". With more targeted use of interactive online whiteboarding tools that allow for annotating and collaborating in real-time, some student questions could have been addressed quicker. Additionally, peer advisors or a teaching assistant (as recommended by Dosen et al. (2012)) could have helped students with more trivial modeling issues, reserving the instructors time for more complicated errors. This could be managed through office hours and discussion board activity to encourage more collaborative problem-solving outside of the synchronous class periods but was not possible to arrange on such short teaching modality turnaround.

This expedited time frame to online teaching meant that use of the LMS was not optimized for content engagement tracking. With more time to prepare for online learning, embedding video content in the LMS, rather than links to videos, would allow the instructor to see how much of the video content, and how often the content, was watched. In knowing which video lectures are most frequently re-watched or tutorials revisited, the instructor would have the opportunity to evaluated where learning objectives need to be reinforced.

Conclusion and Recommendations

The spring 2020 semester began with in-person teaching and ended with online instruction to protect the health and wellbeing of the university and local communities due to the COVID-19 pandemic. This presented a unique opportunity to evaluate whether the student learning experience in an advanced CAD course was impacted by the change in learning environment. Computer-aided design courses are traditionally taught in-person for various pedagogical and technological reasons. This research into hybrid CAD teaching did reveal that with effective use of technology and teaching tools, effective distance CAD learning can be achieved. From this limited research study, key insights where gathered that can be used by other instructors to create a hybrid or fully online CAD course.

1. Well-constructed short videos are vital for teaching students how to use certain tools and common modeling routines. A robust screen capture and video editing software is vital essential for enabling instructors to produce and publish their content with ease to their LMS. This was achieved piecemeal by the instructor and was time consuming. Seamless integration to the LMS plays a crucial role in delivering feature-rich, repeatable, and private video content.

2. Instructors can also reuse video content in future course offerings or in advanced classes to reinforce foundational learning objectives.

3. The use of LMS content engagement tracking is crucial to knowing if students are interacting with digital content. This data can be used by the instructor or teaching assistants to help students manage their deadlines and stay organized.

4. A file exchange system for interactive collaboration is vital, whether that is between peers or with the instructor. Many CAD software packages have this capability but are not always included in the education license.

5. Peer advisors would be an excellent addition to the teaching staff for an online CAD course. Their role would be to help students troubleshoot their work before a more complicated issue reaches the instructor. This is important to managing

students online, especially if class sizes are large.

6. Online teaching tools such as Miro, a platform for visual communication (Miro, 2021), can help peers and instructors synchronously mark-up engineering drawings or suggest design changes in collaboration with the student using screenshots of models and assemblies.

7. A laptop loaning program could alleviate software accessibility issues and ensure equitable access for students with older or incompatible machines.

8. Reinforcing learning with physical products in important for connecting virtual modeling and physical product form. Mailing parts and products or negotiating student use of local makers spaces should be considered to enhance the course and provide students with tangible learning experiences.

Recently, there has been a more concerted effort at Syracuse University to support instructors in developing online content since the beginning of the pandemic. Creating this content takes significant investment in time and resources (Stros et al., 2017), and as such, cannot be reactionary if the goal is to create longer-term use content which can broaden participation in typically in-person learning environments.

References

Asperl, A. (2013). How to teach CAD. *Computer-Aided Design and Applications*, 2(1–4), 459–468. https://doi.org/10.1080/16864360.2005.10738395

Beasley, Z. J., Piegl, L. A., & Rosen, P. (2018). Ten challenges in CAD cyber education. *Computer-Aided Design and Applications*, 15(3), 432–442. https://doi.org/10.1080/16864360.2017.1397893

Bender, D. M., Wood, B. J., & Vredevoogd, J. D. (2004). Teaching Time: Distance Education Versus Classroom Instruction. *International Journal of Phytoremediation,* 21(1), 103–114. https://doi.org/10.1207/s15389286ajde1802_4

Branoff, T., & Wiebe, E. (2009). Face-to-Face, Hybrid, or Online?: Issues Faculty Face Redesigning an Introductory Engineering Graphics Course. In T*he Engineering Design Graphics Journal* (Vol. 73, Issue 1). http://www.edgj.org/index.php/EDGJ/article/view/23

Cozzens, R. (2012). Youtube: An effective cad training resource. *ASEE Annual Conference and Exposition, Conference Proceedings*. https://doi.org/10.18260/1-2--22259

Dosen, A. S., Sher, W., Gajendran, T., & Gu, N. (2012). Teaching Cad: The Challenges Of Online Delivery To Distance Learning Students Circular Construction View project Developing a theoretical model for improving Waste Management View project. In researchgate.net. https://www.researchgate.net/publication/235906867

Fadda, D., & Rios, O. (2019). Online Computer-aided Design Class. *2019 American Society for Engineering Education Conference and Exposition*.

Goodridge, W. H., Lawanto, O., & Santoso, H. B. (2017). A Learning Style Comparison between Synchronous Online and Face-to-Face Engineering Graphics Instruction. *International Education Studies*, 10(2), 1–14.

Kang, S. C. J., Li, Y., & Tseng, C. M. (2016). The effect of soft classroom: A new learning environment integrating MOOCs into conventional classrooms for college students. *ASEE Annual Conference and Exposition, Conference Proceedings*, 2016-June. https://doi.org/10.18260/p.26138

Miro. (2021). O*nline Whiteboard | Collaborative Free Online Whiteboard | Miro.* https://miro.com/online-whiteboard/

 Copyright 2020
ISSN: 1949-9167

Onofrei, G., & Ferry, P. (2020). Reusable learning objects: a blended learning tool in teaching computer-aided design to engineering undergraduates. *International Journal of Educational Management*. https://doi.org/10.1108/IJEM-12-2019-0418

Stros, M., Kugler, G., Schibelbein, A., Feldmann, N., Bohmer, C., & Beck-Meuth, E. M. (2017). Lecturers' views on e-learning in an engineering study program for non-traditional students: An online survey. *IEEE Global Engineering Education Conference*, *EDUCON*, 453–457. https://doi.org/10.1109/EDUCON.2017.7942886

Tangix Virtual Tester. (2021). *VirtualTester :: Home*. https://www.virtualtester.com/web

Wittenborn, D., Richey, M., Paredes, J., Schrage, D., & Atkins, D. (2009). Using distance learning for CAD-based training and PLM education of incumbent engineers. *ASEE Annual Conference and Exposition, Conference Proceedings*. https://doi.org/10.18260/1-2--5518

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Dr. Louise Manfredi is an assistant professor of Industrial and Interaction Design and an adjunct associate professor of Engineering Management at Syracuse University, New York.

Dr. Manfredi's research focuses on (1) expanding sustainable product development strategies for undergraduate designers and engineers, and (2) developing methods to improve the working relationship between designers and STEM practitioners. She holds a Ph.D. in Mechanical Engineering and a BDes in Product Design from the University of Leeds, UK. Manfredi was the recipient of the Industrial Design Society of America's Young Educator of the Year Award in 2020.

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A Tale of Two Universities: Developing Spatial Skills of Engineering Students during a Global Pandemic

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Abstract

Studies show that spatial skills are essential to engineering success, and particularly in engineering graphics courses. Research also shows that sketching is important in developing spatial skills. Aimed at improving the spatial skills of engineering students, an intervention was developed consisting of a workbook and software (Sorby et al., 2002). Implementation of the intervention has been shown to improve: spatial skills, grades in introductory STEM courses, and retention/graduation rates for first-year engineering students.

In response to the global pandemic, course materials have been revised to facilitate remote learning. Resources for each module include video mini-lectures, online software, and Getting Started videos that show the basics in sketching and other topics. The original workbook included multiple-choice, matching, fill-in-the-blank questions, as well as sketching exercises. Partly in response to the pandemic, the fixed choice (multiple-choice, matching, and fill-in-the-blank) questions in the workbook were converted to Canvas quizzes. A new workbook was developed with only the sketching content from the original workbook. For modules that did not previously contain sketching problems, new sketching exercises were created, and practice problems were created for difficult topics. The practice problems included solutions and examples of common student mistakes. This paper presents the revised intervention and feedback from four universities that employed the original and revised intervention.

Background

Strong correlational evidence links spatial skills to success in STEM (Smith, 1964; Shea et al., 2001; Kozhevnikov et al., 2007; Yoon & Mann, 2017). Spatial skills have also been linked to creativity and technical innovation (Kell et al., 2013) and success in computer programming (Jones & Burnett, 2008; Cooper et al., 2015). In a 30-year longitudinal study, following adolescents from the 1960s (Wai et al., 2009), it was found that good spatial skills are better predictors of STEM degree attainment, especially for graduate degree attainment, than are mathematics skills. More recently, Duffy, Sorby and Bowe (2020) found a link between spatial skills and success in solving mathematics word problems among engineering students. In addition, Sorby, Duffy, and Loney (2020) found links between spatial skills and the ability to solve typical problems in chemical engineering.

For over a century, scientists have found significant gender differences in 3D spatial skills favoring males (e.g., Linn & Petersen, 1985; Voyer et al., 1995; Sorby et al., 2013; Duffy et al., 2017). Furthermore, research shows that students from low socioeconomic status (SES) groups also have comparatively weak spatial skills (Levine et al., 2005; Casey et al., 2011). In some cases, SES dif-

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ferences are significantly larger than gender differences. Since well-developed spatial skills are important to success in engineering, poor spatial skills could hinder our ability to diversify engineering specifically and STEM more broadly.

Improving Spatial Skills for Engineering Success

In the 1990s, a curriculum consisting of software and a workbook was developed to help first-year engineering students improve their 3D spatial skills. The curriculum has been deployed in several engineering programs and has been the focus of extensive research over the years. Longitudinal studies have shown the efficacy of the curriculum with the following key outcomes (Sorby & Baartmans, 2000; Gerson et al., 2001; Sorby, 2001, 2005, 2009; Sorby et al., 2013):

- Significant increase in the spatial skills of students who participated in the course.
- Increases were uniform for both male and female students.
- Students who participated in the course went on to earn higher grades in their introductory engineering, calculus, chemistry, computer science, and physics courses.
- More students with poor spatial skills, particularly women, who completed the course, graduated from engineering compared to students with comparable spatial skills who did not participate.
- Sketching and handling physical objects is important to developing 3D spatial skills.

Adapting the Curriculum for Online Learning during the Pandemic

Initial development of the materials was completed around 1999, and the spatial skills curriculum consisted of two components: the software and the workbook. The software was written in Flash and was included on a CD affixed to the cover of the workbook. There were versions of the software suitable for use with either a PC or a Mac. With changes in Flash, around 2015 an online version of the software was developed. Students gained access through a code that led them to the website where the software was hosted. Short videos were developed in 2016 in support of the curriculum. There are two types of videos available: 1) short voice-over-PowerPoint mini-lectures presenting the topic and main points for each module, and 2) Getting Started videos showing step-by-step how to make simple sketches. The Getting Started videos were created using an overhead camera showing someone making the sketches with narration explaining the process. Both types of videos are close-captioned for ADA compliance. Although the videos have been available since 2016, they have not been in widespread use at the university level.

The original workbook consisted of multiple pages of problems per module. Most modules had problems in two broad categories: 1) open-ended sketching problems and 2) fixed choice questions, i.e., multiple-choice, fill in the blank, or matching questions. For three of the ten modules, there were no sketching problems available. In research conducted in 2005 (Sorby et al., 2005) it was found that the workbook contributed significantly to the development of 3D spatial skills, but the software alone did not. Based on those results, it was surmised that the sketching exercises, found only in the workbook, were important to developing spatial skills. This finding reinforced findings from a 1998 study (Sorby & Gorska, 1998) where sketching-based graphics courses improved spatial skills significantly more than did a computer-aided design-based graphics course.

As the reality of the pandemic took hold and as it became apparent that the Fall 2020 would feature a significant amount of online learning, further revisions to the curricular materials were contemplated. Based on the research, it seemed that keeping some kind of sketching component in the online version of the course was essential.

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In the end, a decision was made to convert the fixed-choice problems into a Learning Management System (LMS) based "quizzes," to develop open-ended problems for the modules that previously did not have them, and to compile a "sketching only" workbook suitable for use in the spatial skills course. The rationale behind this decision was as follows:

- As we moved to online, one significant criticism levied against universities was the increased cost that was an especially difficult burden for students from low SES groups. Since these are some of the students targeted for spatial skills instruction, a brief workbook would be less expensive than requiring them to have a printer and toner, or to have a touch-screen computer/tablet, or a stylus for sketching.
- There is evidence in studies conducted with K-12 students that spatial skills instruction using only an iPad improved spatial skills but not math skills. Spatial skills instruction with hand-held manipulatives improved both spatial and math skills. The current curriculum, which uses hand-held manipulatives and requires pencil-and-paper sketching, has been shown to improve both spatial and math scores.
- Numerous studies have shown the deleterious impact of too much screen time for young children. With the abrupt change to remote instruction due to the pandemic, data is beginning to emerge that too much screen time also negatively impacts ~20-year-olds. Giving students a break from their screens to engage in pencil and paper sketching should be a positive outcome and a welcome break for most students.
- Engineers need to know how to make sketches for communication and design ideation. There is scant evidence that sketching on a touch screen will translate to sketching on a piece of paper. Research conducted with writing assignments shows that writing using a word processor is not the same as writing with pencil and paper. It could be that the same holds true for sketching, meaning that it is important for students to experience sketching with pencil and paper.

Figures 1 and 2 show examples of the fixed choice problems from the original workbook that were converted to Canvas quizzes. Figure 1 illustrates a fixed problem from Module 2 (Combining Solids) where an operation on the objects on the left are to result in the object shown on the right.

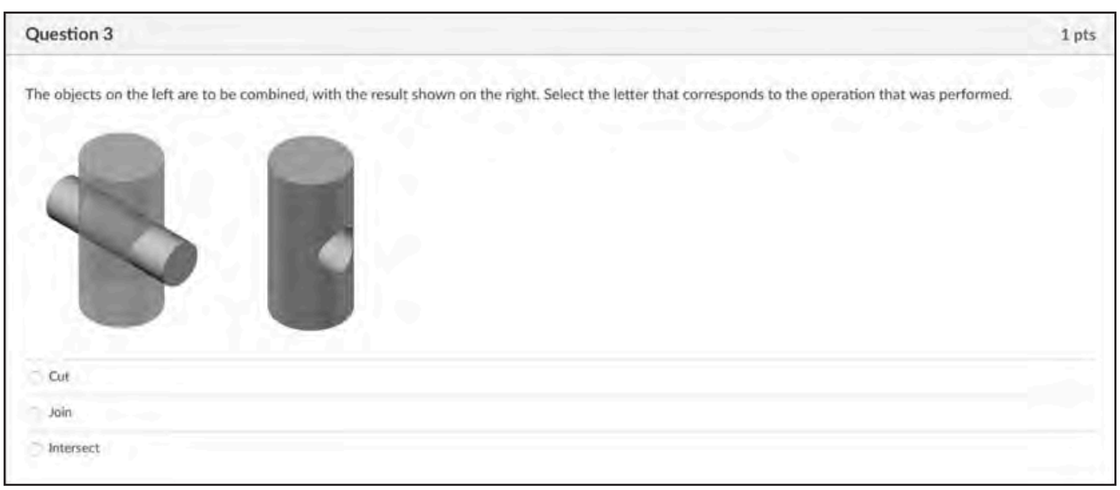

Figure 1. Multiple choice workbook problem in Canvas (Module 2-Combining Solids).

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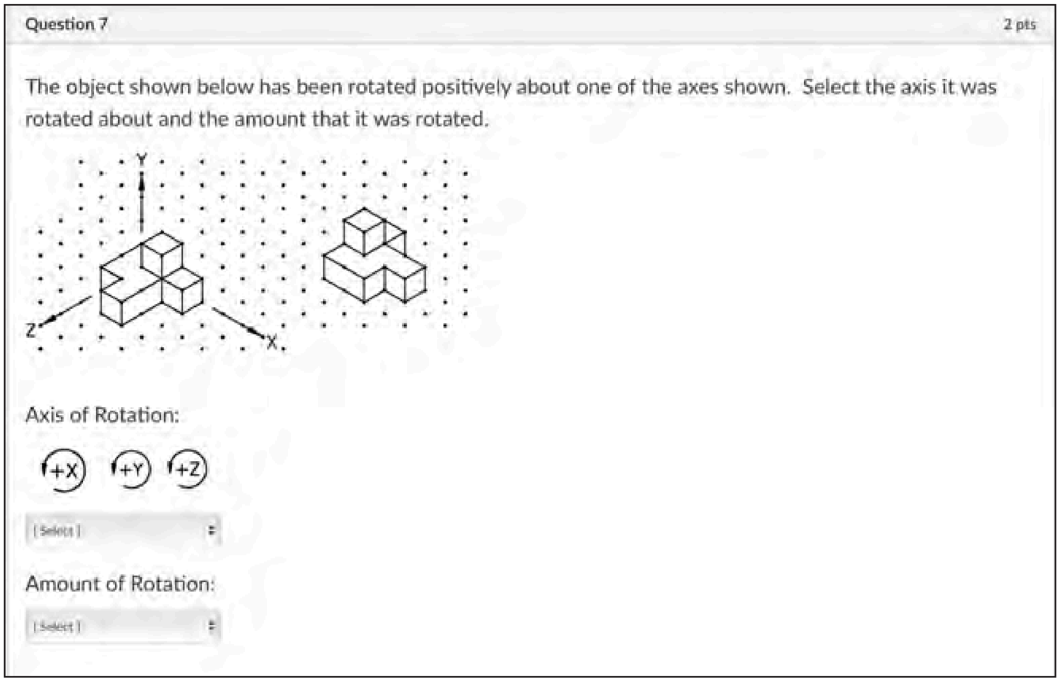

Figure 2. Two-part fixed choice workbook problem in Canvas (Module 7-Rotation of Objects About a Single Axis).

Figure 2 illustrates a two-part fixed problem from Module 7 (Rotation of Objects About a Single Axis).

The sketching only workbook includes paper and pencil open-ended problems for each of the ten modules in the curriculum. The length of the workbook was reduced from ~225 pages to ~80 pages. There were two modules in the original workbook that did not include open-ended problems. For the sketching only workbook, several pages of problems were created for each of these modules. Figures 3 and 4 show examples of the open-ended problems created in support

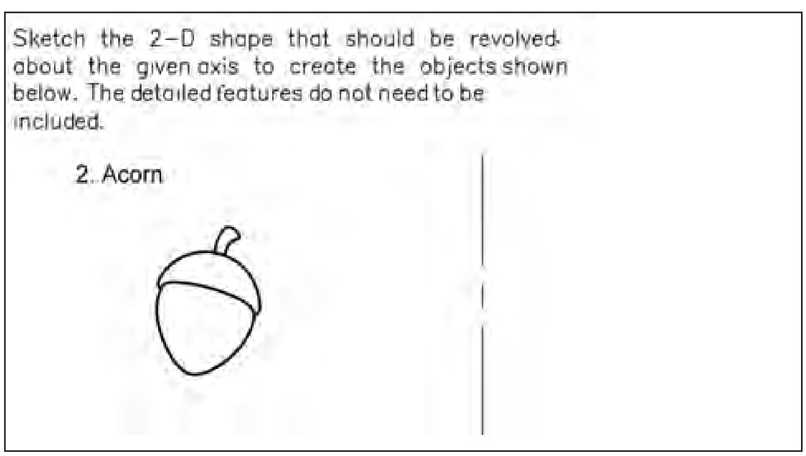

Figure 3. Example sketching problem added for Module 1 (Surfaces and Solids of Revolution).

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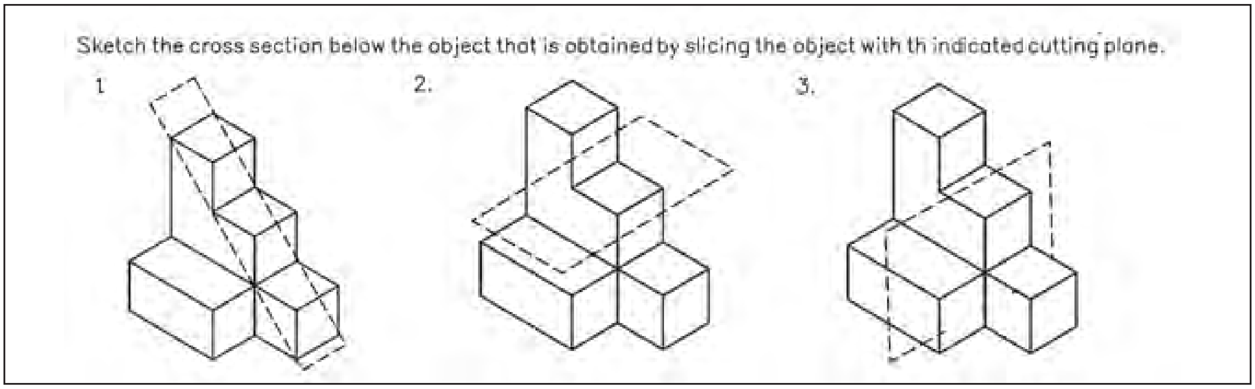

Figure 4. Example sketching problems added for Module 10 (Cutting Planes and Cross Sections).

of these two modules. Figure 3 illustrates a sketching problem from Module 1 (Surfaces and Solids of Revolution).

Figure 4 illustrates the new sketching problem from Module 10 (Cutting Planes and Cross Sections).

In addition to the inclusion of open-ended problems for all modules, several modules in the sketching only workbook now include a page of practice problems so that students can work through the easier problems before moving on to the more difficult problems found in the original workbook. The solutions for the practice problems are included in the workbook along with illustrations of common student errors for that particular type of problem. For example, Figure 5 shows the practice problems (with solutions) for the isometric sketching module in the sketching only workbook.

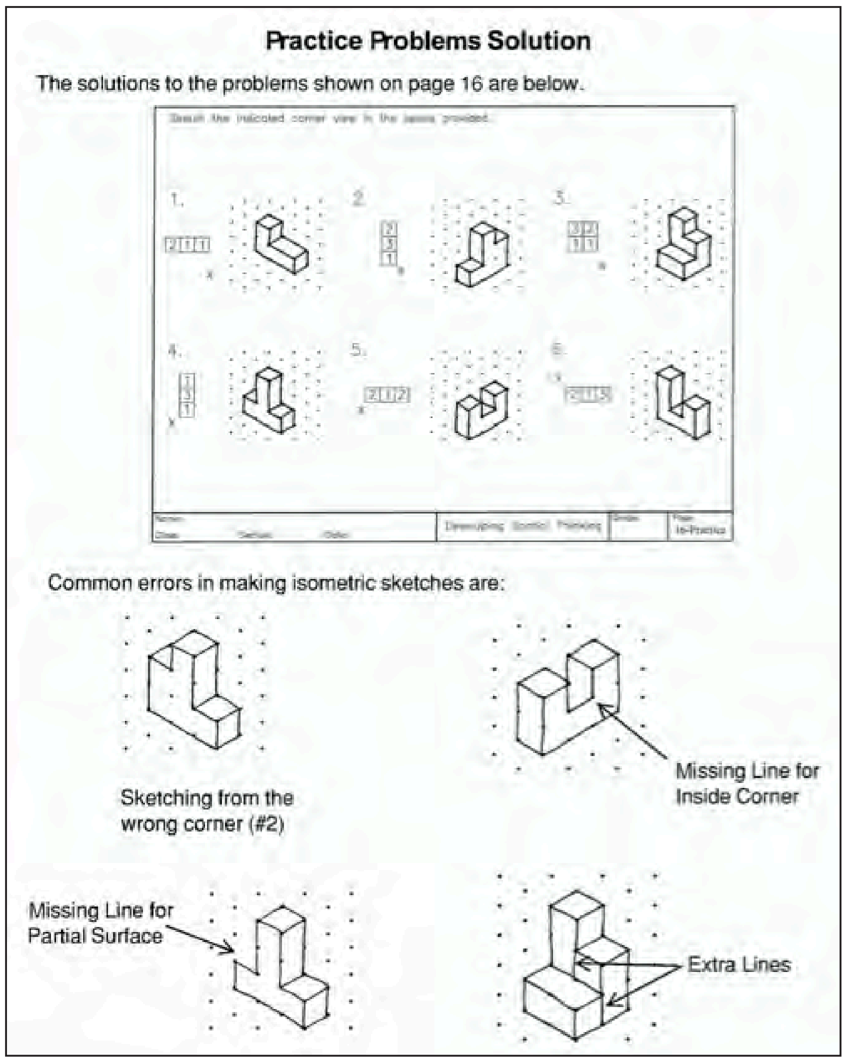

Figure 5. Sample solutions to practice problems and common student errors.

This paper primarily features the experience of students

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and instructors from Michigan Technological University and Clarkson University where the spatial skills course was taught entirely online in Fall 2020. The two primary authors of this paper (Veurink and Richards) worked independently on their "pandemic" spatial skills course design over the 2020 summer leading up to their fall implementations. The third author (Sorby), was aware of the individual plans and suggested that their experiences might be of interest to the broader Engineering Graphics community. Differences in individual planning meant that common measures were not always available for direct comparison of the two versions of the course. In this paper, we have attempted to make comparisons between the two courses where we could make comparisons to in-person non-pandemic courses where feasible, and describe unique findings of each course when comparisons were not practical. Although the research described in this paper was not a perfectly-designed study, the authors feel that graphics educators will find the results from this study of interest as they plan for expanded opportunities in online learning.

Pre-Pandemic Course Delivery

The spatial skills curriculum has been taught as a stand-alone course for several years at both Michigan Tech and Clarkson to improve the retention/graduation rates first-year for engineering students. Both universities ask all incoming first-year engineering students to complete the Purdue Spatial Visualization Tests: Visualization of Rotation (PSVT:R; Guay, 1976) before the beginning of the fall semester. Students who score below 18 out of 30 on the PSVT:R are enrolled in the spatial skills. Before the global pandemic, spatial skill courses were offered through in-person weekly or twice weekly class sessions. Each class session consisted of the following:

- A 15 - 20 minute lecture
  - The instructor introduced a learning module and completed example problems.
  - Students completed practice problems.
- Students worked through the course software module, although some students skipped this and went straight to working on the workbook exercises.
- Students worked together or individually on the module exercises from the course workbook.
  - Instructors provided students with hand-held manipulatives (e.g., when completing Module 3, 7, and 8).
  - The instructor and undergraduate teaching assistant (UTA) walked around the classroom and assisted students for the remainder of the class session.

Pandemic Course Delivery

In planning for the Fall 2020 online version of the course, the Michigan Tech instructor chose to teach the course synchronously while the Clarkson instructor chose an asynchronous delivery for the course. The following sections of the paper describe the experiences at each university.

Michigan Technological University

Student Placement in Spatial Skills Course
At Michigan Tech, engineering students are administered the PSVT:R during the week before classes begin, and those who score 18 or lower on the PSVT:R are required to complete the spatial skills course.

Pandemic Course Delivery
The spatial skills course was offered as a full-semester remote course with classes meeting for 80-minutes once per week through Zoom. Attendance was 10 percent of the overall grade in the course. With the exception of modules 1 and 2, students were to review the course software module and submit a screenshot of a particular problem in the software before the beginning of each class. At the beginning of each class session, the instructor briefly mentioned key concepts students should have grasped from the software module and then demonstrated sketching prob-

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lems with the use of a document camera. Students were to have printed a pdf (posted on the LMS) containing the demonstration problems and instructor-developed practice problems so they could follow along with the demonstrations. After the demonstrations, students were to sketch two or more practice problems from the pdf. For modules 1 and 2, which were the first two modules covered in the course and which have minor sketching applications, the course began with a more traditional lecture, and students were given time during the class session to work through the software modules.

After the practice sketching exercises, students were put in breakout rooms with three other students (same group the entire semester) where they were to complete fixed choice questions on the LMS and the sketching problems from the workbook. Students were encouraged to work together on these. The instructor and UTA visited the breakout rooms, answering questions and asking students to show at least one of their sketches. At the end of each class session, students were encouraged to meet with the instructor or UTA or email their sketches to the instructor or UTA for feedback on the homework exercises before they submitted them. Students scanned in the assigned workbook pages and uploaded the scans to the LMS. The fixed choice problems (from the original workbook) and sketching exercises were worth 40% of the overall course grade.

Assessments were administered through the LMS, with students completing fixed choice questions in the LMS. For sketching questions, students were instructed to print out a quiz template with isometric and/or square dot paper for use in completing the quiz sketching questions. The sketching questions were provided on the LMS. Students sketched the questions using pencil and paper and then scanned their completed sketches and uploaded them to the LMS in the same manner as they did the workbook pages. On assessment days, students joined the normal class Zoom session, but were required to have their cameras on while taking the quiz. These assessments accounted for 50% of the course grade.

Student Perception of Pandemic Courses

At Michigan Tech, students were invited to anonymously complete mid- and end-of-semester surveys for each course offered at the university. For the mid-semester survey, the instructor added questions related to breakout rooms to the survey.

The mid-semester survey was given to students one-third of the way into the semester. Students were asked open response questions about what was helping them learn and what could be changed to improve their learning. They were also asked multiple choice type questions related to their experience in the breakout rooms during class sessions. Sixty-nine out of 130 students completed the survey. The comments that appeared most frequently regarding what was helping them learn were the instructor demonstrations (28%), working with others in the breakout rooms (16%), the hand-held manipulatives (snap-cubes) (12%), and the workbook sketching exercises and software (10% each). Most students did not have suggestions for what to change. The only suggestions that appeared more than once were to have more example problems (7%) and having the class be in-person (4%). Additionally, 49.3% reported they worked together well in the breakout rooms, and only 7% wished they would communicate more in the breakout rooms. Several students indicated there was not much talking in the breakout rooms, but they were comfortable asking questions and were able to get the help they needed in the breakout rooms. Only two students expressed an interest in changing breakout rooms midway through the semester. Because the surveys were anonymous, the instructor communicated to all students that if they wished to change breakout rooms for any reason to notify the instructor. Nonetheless, no students contacted the instructor to request a change.

Comments from the end of the semester course evaluations were overall positive. Representative

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comments about what aspects of the course effectively furthered their learning are below.

- The document camera was useful. Drawing things live in class was very useful.
- I really liked the format of the course as a whole. I am a very visual learner, so it was really nice to have you go through a few examples as a class and then transfer into smaller groups to work on the homework. It really helped me to talk through the content with other students and see where I was making mistakes. They really helped me to gain a better understanding of the material that I do not think I could've grasped on my own.
- I really enjoyed the breakout rooms. I think the ability to work on the quizzes with other people was really nice and allowed me to understand the material much more.
- Helping students with their workbook pages over email outside of class was huge for my learning in this class.
- I really liked using physical paper to complete workbook assignments. I previously thought this class would be mostly online but drawing objects on paper was helpful to understand what I was doing.

Few students had suggestions for things to change in the course in the future on the end of semester evaluations. The most common topic where changes were suggested related to breakout rooms. Examples of the comments are below:

- I would suggest maybe creating an incentive for people to have their cameras on in their breakout rooms. That may help increase collaboration/participation and create a more comfortable environment for students to reach out to their peers if they are confused or need help. I personally did not find the breakout rooms beneficial at all because we never talked to each other.
- I think if you are online again, you should make students turn their cameras on more often. I know you tried to do this, but maybe force it a little more. I honestly think it would make students focus more.
- The only thing I disliked was the breakout rooms as I had one that did not talk.

Instructor's Experience/Reflections

The instructor perspective of teaching remotely was overall positive. The class seemed well organized, and students seemed to follow along and do the practice sketching problems. As the semester progressed, a few students stated they never did print the packet with the practice sketching exercises, but no attempt was made to quantify how many students did not do this. Students seemed to utilize class time to complete the homework effectively. Students completed the fixed choice portion on the LMS and generally had a significant portion of the sketching problems completed before the end of class. When asked by the instructor to share one or two of their sketching problems, most students readily did so even though it was somewhat awkward to hold their workbook up to the laptop camera. There were however, some students who almost always stated some excuse to not share their work in this way.

The biggest drawback to the remote format was that students did not seem to work together as much as when the course was face-to-face. When visiting the breakout rooms, some groups were actively comparing answers to multiple choice questions while other groups were working in silence. Although the instructor encouraged students to have their cameras on and to actively talk to each other in the breakout rooms, even if the talking was mostly social, when the instructor visited the breakout rooms, less than half of them had their cameras on and the majority were not talking at the time the instructor joined.

Students were encouraged to seek help from the instructor or UTA in between class sessions or to

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simply email their sketches to the instructor or UTA for feedback before they submitted them to be graded. Because it was little extra effort to email the instructor/UTA their homework for review, some students did this. A couple also arranged Zoom meetings with the instructor. Overall, slightly more students reached out for help in the remote course than typically did in the face-to-face course. This difference was largely due to the ease of emailing homework to the instructor for feedback.

Clarkson University

Student Placement in Spatial Skills Course
Similar to Michigan Tech, Clarkson University engineering students are enrolled in the spatial skills course if they score 18 or below on the PSVT:R the summer prior to the start of the fall semester. However, on the first day of the course, students are provided with a second opportunity to take the PSVT:R. While students are encouraged to participate in the course, the spatial thinking course is not a requirement or pre-requisite at Clarkson. Therefore, some students decide not to participate in the spatial course, whether or not they score above 18 on the second test. For Fall 2020, about half of the students that were initially enrolled for the course completed it.

Pandemic Course Delivery
During the pandemic, the spatial skills course at Clarkson was delivered asynchronously using the pre-recorded content provided with the curriculum. Links to the module mini-lectures, Getting Started videos, the software, and additional pre-recordings of homework example problems developed by the instructor were posted on the LMS each week for review and completion of appropriate course assignments. As students did not have a designated class time, weekly reminder emails and announcements were sent to students via campus email and the LMS. Additionally, the instructor conducted regular drop-in office hours via Zoom three days a week. If students required further assistance outside of scheduled office hours, they were encouraged to sign up for appointments with the instructor.

Each week, students were assigned a selection of pages from the sketching workbook for homework, worth 40 percent of the overall course grade. Students were asked to complete assignments on workbook pages. Completed homework assignments were then scanned and uploaded to the LMS. Students were given one to two weeks to complete assignments, depending on the difficulty of the module. Homework assignments were graded based on attempt, legibility, and completeness. Students were provided with guidelines and a list of standard deductions for homework submission.

Clarkson students completed twelve graded quizzes, worth 40 percent of their grade. Two quizzes - the Purdue Spatial Visualization Tests: Visualization of Rotation (PSVT:R) pre- and post-course - were graded based on whether the quizzes were attempted. The other ten LMS quizzes covered the ten workbook modules and consisted of selected fixed choice problems from the original workbook and were graded on correctness. For these quizzes, students had on average 30 minutes and two attempts. The highest grade of the two attempts was recorded as the quiz grade. Quizzes were automatically graded within the LMS; therefore, it was at the student's discretion whether or not to make a second attempt. The majority of students completed the quizzes within 15 minutes and used only one attempt.

In the event of course interruptions due to quarantining, students were permitted to replace missed or lower scores on learning assessments by completing and submitting optional assignments and quizzes. Students were provided three optional assignments and three optional quizzes. There were no limits on how many of the three optional assignments or three quizzes they could submit. Furthermore, unlike the weekly homework and quizzes associated with the ten modules, all optional assignments and quizzes

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remained open until the last day of class. If the grade on the optional assignments or quizzes were lower than the weekly grades, the optional assignments grades were not used in calculating final course grades. Less than 1% of students took advantage of this opportunity.

In order to discourage cheating and engage students for the online asynchronous course, a final project was created. This project replaced the end of course cumulative fixed choice questions and sketching assessment. In the project, students were asked to design a table game (e.g., pinball machine, Rube Goldberg device) or community structure (e.g., playground) on isometric sketch paper and to provide a one-page reflective executive summary. In the summary, students were asked to reflect and discuss the motivation behind their design and describe each component of their sketches. A project rubric was used to evaluate students' spatial skills and their general understanding of spatial skills through evidence of their incorporation of the module components in the final project and their executive summaries. Figure 6 shows an example of a student sketch from the final project. Based on student feedback, it is anticipated that this project will be a component of the course post-pandemic.

Student Perception of Pandemic Course

This spatial skills course has been offered at Clarkson for several years; however, this was the first time it was offered in an all-virtual mode. To assess the virtual course offering, an end of semester questionnaire was developed. The survey was not anonymous, but students were encouraged to provide feedback to assist in the improvement of the course in the event virtual instruction was offered in subsequent years. This survey consisted of sixteen questions: fourteen agree/disagree, one fill in the blank, and one short answer. The survey results provided below are from all student responses.

For the agree/disagree portion of the questionnaire, when asked whether they believed their spatial thinking skills and ability to make isometric sketches improved, 94 - 98% of the students

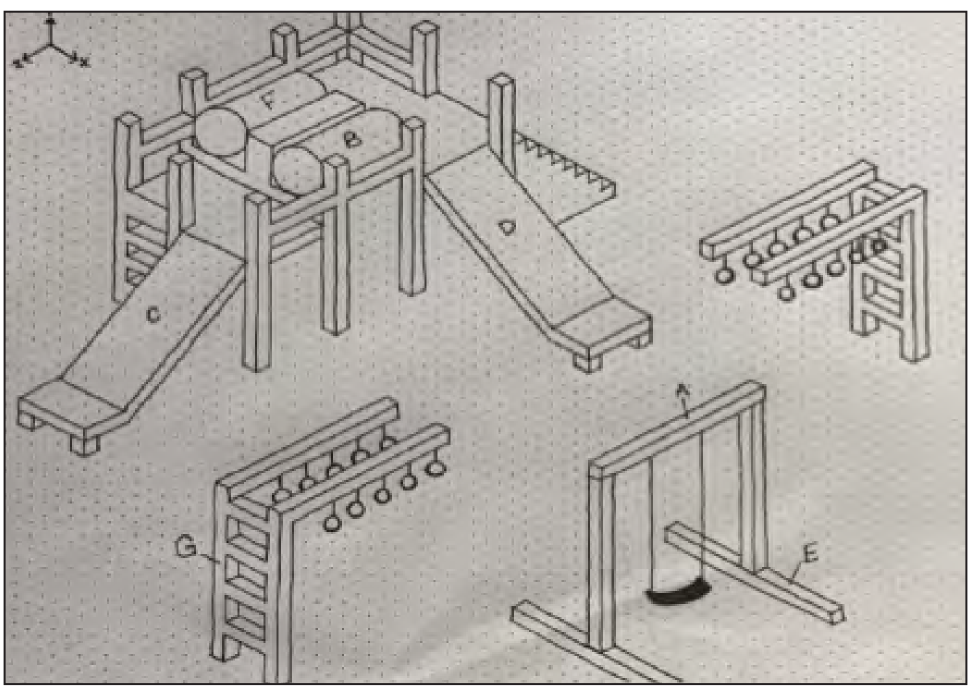

Figure 6. Sample isometric sketch of community play area.

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agreed or strongly agreed. Eighty-six percent of the students agreed or strongly agreed that the "Getting Started' videos helped increase their knowledge and skill level. Furthermore, 90% of the students stated that the fixed-choice problems LMS-based "quizzes" helped them understand the course material better.

For the fill in the blank questions, students were asked on average how much time they spent on the learning activities and assessments combined for each module. In response to this question, 58% of the students stated they spent two hours or less, while 42% spent more than two hours. Of the 42% that spent more than two hours, 81% spent between two to three hours on each module.

For the short answer question, students were asked, "What are one to three specific things about the course that could be improved to better support student learning?" The top suggestions can be summed up from these student responses:

- I think more interaction on a one-to-one basis would be helpful, either between students or students-instructor.
- The book should contain extra sheets of isometric paper to practice with.
- Everything was online, which made it hard to remember that the homework was due. There should be one Zoom meeting per week where it is on your schedule so that you remember to do it.
- This course helped me with visualizing shapes and objects in my head. It also helped me improve my isometric sketches.
- "I believe more homework help videos would be beneficial. But other than that, this course was overall a great course, especially for being asynchronous.

Overall, the majority of students believed the course was important and would recommend it to other students.

Instructor's Experience/Reflections

The instructor's overall perspective of the asynchronous online course was also positive. The instructor and students benefited from the revised intervention and the overall structure of the virtual course. Eighty-four percent of the students agreed or strongly agreed that the course was organized in a manner that helped them understand the underlying concepts, while the remaining 16% were neutral.

Pre-pandemic, the instructor moved throughout the in-person classroom to gauge students' understanding of the content as they worked through sketching problems. During the pandemic, the instructor missed this weekly in-person interaction with the entire class. While the instructor provided students opportunities to interact virtually and encouraged students to attend Zoom office hours as groups, the instructor did not observe a difference in pre- and during-pandemic attendance of office hours.

Overall for the first eight weeks of the course, the instructor felt disconnected from most students. At week 8, however, when the students received the introduction and instructions for their final project, the student interaction changed dramatically. The project was developed to permit enough freedom in their design selections and sufficient ambiguity that more students sought guidance from the instructor. The instructor felt that the final project provided students with the opportunity to apply the content in a deeper manner as they needed to design, sketch, and provide a reflective summary of their sketches. Therefore, a final sketching project will be incorporated in the future.

Comparison of Student Success

To determine if offering the course in a remote format was detrimental to student learning, course metrics from the Fall 2019 and 2020 courses were compared.

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At Michigan Tech, the PSVT:R was given during orientation (pre-test score) and the last session of the spatial skills course (post-test). Homework assignments were nearly identical in the pre- and during-pandemic course offerings and attendance at each class session was recorded. The assessment quizzes varied substantially between the two years. Because homework accounts for 40% of the overall course grade and attendance 10%, all students who attend most classes and complete most of the homework earn a C or higher in the course. Those who earn a course grade below a C are students who simply stop attending but do not withdraw from the course or students who put little effort into the course (e.g., submit little homework or do not attend class on assessment quiz days). Table 1 below compares course metrics for Michigan Tech students who successfully completed the course with a C or better.

As shown in Table 1, the difference in pre- and post-test PSVT:R scores for the two groups was not significant, but it is concerning that the Fall 2020 group had higher PSVT:R pre-test, but slightly lower post-test scores, than the 2019 group. This means the students taking the remote version of the course on average had lower gains on the spatial test, although the difference in gains was not significant. There was no statistically significant difference in homework grades for the two groups. The students in the remote version of the course had a lower class attendance than the pre-pandemic students. This could indicate the remote version of the course was less engaging than the in-person class. Assessment quizzes accounted for 50% of the overall course grade, but they differed between the two versions of the course so were not used as a direct comparison of student success. Despite the difference in assessment quizzes, overall course GPA for the two versions of the course were not significantly different.

Table 2 shows a comparison of student success for the Clarkson students who scored 18 or below on the pre-PSVT:R and successfully completed the course with a C or better. For Clarkson, pre-pandemic, the PSVT:R pre- and post-tests were completed using paper-and-pencil, while during the pandemic, they were administered online within the LMS. Students were given 30 minutes to complete the test (longer than the recommended 20 minutes). The mean pre-test score shown in Table 2 is the mean of the PSVT:R taken on the first day of the course for those students who scored 18 or lower. Thus, the number of students presented in the PSVT:R comparisons does not represent the entire course enrollment for Clarkson as some students chose to stay in the course even though they had a higher score.

Table 1
Comparison of course metrics for Michigan Tech.

Year	Mean PSVT:R Pre-test Score	Mean PSVT:R Post-test Score	Homework*	Class Attendance	Course GPA (max = 4.0)
2019 (n = 156)	15.0	21.2	91.2%	99.6%	3.63
2020 (n = 121)	15.2	20.9	91.3%	97.6%	3.62
p value	N.S.	N.S.	N.S.	p = 0.001	N.S.

* Only homework assignments that were identical for both years are included. Portions of homework for Modules 7 and 9 that were slightly different between the two years are not included.

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Table 2
Comparison of course metrics at Clarkson.

Year	Mean PSVT:R Pre-test Score	Mean PSVT:R Post-test Score	Homework	Class Attendance	Course GPA (max = 4.0)
2019 (n = 26)	15.8	21.3	86.4%	94.6%	3.31
2020 (n = 18)	14.7	16.6	82.8%	n/a	3.57
2020 (modified) (n = 13)	15.1	19.5	80.9%	n/a	3.51
p value (2019 vs 2020)	N.S.	p = 0.0028	N.S.		N.S.
p value (2019 vs modified 2020)	N.S.	N.S.	N.S.		N.S.

At Clarkson, during the pandemic, PSVT:R tests were graded based on whether or not they were taken and not on the actual number of questions correctly answered. Therefore, the scores obtained may not be a true representation of student capabilities. Furthermore, as two quiz grades were dropped, some students chose not to complete the post-test, thus reducing the total number of student data available for analysis. Upon further examination of post-test data, it was determined that some students spent little time on the post-test, which resulted in negative gains for those students. For example, one student spent only three minutes on the entire post-test and scored eight out of 30, a little better than chance. This student scored a 17 on the pre-test, resulting in a gain score of negative nine. When the students who spent little time on the post-test were eliminated from the analysis, results in Table 2, labeled as 2020 (modified), were obtained with post-test scores similar to those obtained in 2019. The gains for the unmodified 2020 cohort were not statistically significant; however, the gains from the modified 2020 cohort were highly significant (p=0.001).

As it can be seen from the data presented in Table 2, when including all students in the analysis, there was a significant difference in post-test scores between 2019 and 2020; however, when the students who appeared to put little effort into the post-test were eliminated from consideration, post-test scores between 2019 and 2020 were not significantly different. Homework grades in the pandemic cohort were lower than those pre-pandemic; however, overall course GPA were up (neither of these by a significant amount). The inclusion of the final project and other changes in grading policies were likely the reason for these differences.

The percentage of students who did not successfully complete the course (earned a grade below a C or withdrew from the course after the second or third week in the semester) was also compared. Historically, the majority of the stu-

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dents that drop the course after the third week are not earning a passing grade at the time they withdraw from the course. Table 3 shows the difference in successful course completion rates for the pre- and during- pandemic courses were significantly different at both Michigan Tech and Clarkson. Thus, it appears the remote format was a significant barrier to successful course completion for both the synchronous and asynchronous versions of the course.

Table 3

Comparison of successful course completion rates.

Year	% of DFWs Michigan Tech	% of DFWs Clarkson
2019	6.0% (10/166)	0% (0/26)
2020	9.0% (12/133)	10% (2/20)
p value	N.S.	N.S.

Discussion

Based on the results from this work, we note that similar gains on spatial test scores were achieved. Similar pass rates and grades earned for the course were obtained pre-/during-pandemic. However, DFWs were up slightly (although not significantly), likely signifying that students had a harder time staying engaged during the pandemic. The instructors who have taught the course both pre- and during-pandemic reflected that what they were doing seemed to "work." Therefore, the good news is that, if needed, the course can be taught virtually with similar short-term outcomes. However, further research will be required to determine whether the long-term outcomes from teaching the spatial skills course are maintained when the course is taught virtually.

Overall, course instructors prefer teaching the spatial skills course in a face-to-face mode primarily because of the perceived decline in student interactions when taught virtually. In the asynchronous mode, there was little to no interaction between students, and in fact, there was little interaction between the instructor and students. If the Clarkson asynchronous course were modified to include one hour per week of scheduled course meeting time, the lack of interaction could be mitigated somewhat; however, in the Michigan Tech synchronous course featured here, the instructor noted that having breakout rooms in Zoom did not necessarily translate into student-to-student interactions. If the course is to be delivered virtually in the future, instructors should take care to put systems in place that encourage peer interactions, i.e., making this part of a participation grade, or part of an assignment grade.

In the course of preparing this paper, the authors had a conversation with faculty at two additional universities who taught the spatial skills course both before and during the pandemic to see if their experiences were similar to what the authors found. Both instructors felt their students were less engaged in the pandemic version of the course. Deirdre, from Rice University, who taught a hybrid course with social distancing protocols in place, felt there was much more interaction within larger in-person groups than in the much smaller in-person groups during the pandemic. Deirdre also sorely missed being able to give students manipulatives to use when they struggled with course topics (handing out manipulatives would have been a violation of pandemic teaching protocols). In the past, the manipulatives sparked discussion and reasoning out loud among the large groups of students. David, from Cal State Long Beach, who taught the course 100% online, felt students did not work together as much in the breakout rooms as they did in-person and missed being able to walk around, observe students' work, and listen to their discussions. On the positive side, David felt the students could talk through the thought process in creating the sketches in the breakout rooms in a way that was much more in-depth than what occurred in previous face-to-face classes. Both David and Deirdre believe they will

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continue asking students to watch the course videos and complete at least some of the fixed-choice problems in their LMS before attending class going forward; however, both plan to return to face-to-face instruction in Fall 2021.

Although teaching the spatial skills course virtually was not anyone's first choice, it is likely that this experience will bring about permanent changes in course delivery for most instructors. For many, future course iterations will likely include a hybrid structure, with students watching videos or working with the software prior to class time and class time itself devoted to problem-solving and completing sketching exercises. In some cases, this shift to a hybrid structure was already in progress and the pandemic merely moved it along more rapidly than before. The ability to have fixed choice problems from the workbook automatically graded with immediate feedback was viewed positively by instructors; however, because instructors feel that solving those problems together elicits student interactions and rich discussions, they may keep a portion of those as in-class exercises or set aside time for students to discuss the problems.

Conclusions

In conclusion, teaching the spatial course during the pandemic will likely have a lasting impact on course delivery in the future. Aspects of the course that can be effectively offered online will likely remain online so in-person class sessions can focus on improving sketching skills, a skill that has been found to be key in developing spatial skills. After seeing a marked reduction in student interaction during the pandemic delivery of the course, the instructors who shared their experiences all expressed a desire to increase their efforts to foster and emphasize those interactions in a return to face-to-face instruction.

If the class is to be delivered entirely or mostly online in the future, it is recommended that, similar to a flipped classroom model, the course be organized such that content delivery is available to the students through the LMS. Students could watch lecture and/or demonstration videos and complete the course software exercises and/or some of the fixed-choice exercises before attending a synchronous class session. During the synchronous sessions, instruction and activities could focus on sketching. Instructors should develop a plan to foster and reward student interaction during the synchronous sessions as well as a way to gauge student understanding. Use of slide decks in Jamboard and/or having students show their work using their laptop cameras are plausible methods. It is important to schedule regular meetings with the instructor and/or classmates so students feel less isolated and more engaged with the course material when teaching online. The good news is, even if the course is delivered totally online, spatial skills can be developed in a way that students find enjoyable. In fact, in the Michigan Tech remote version of the course, a few students stated on course evaluations that the spatial class was their favorite or the best taught class they were taking during Fall 2020. While online instruction is not typically the preferred mode of delivery for students or faculty, effective learning is achievable with careful attention to fostering an engaging and interactive experience for students.

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References

Casey, B. M., Dearing, E., Vasilyeva, M., Ganley, C., & Tine, M. (2011). Spatial and Numerical Predictors of Measurement Performance: The Moderating Effects of Community Income and Gender. *Journal of Educational Psychology*, 103(2), 296–311.

Cooper, S., Wang, K., Israni, M., & Sorby, S. A. (2015). Spatial Skills Training in Introductory Computing. *Proceedings of the Eleventh Annual International Conference on International Computing Education Research*, 13–20. https://doi.org/10.1145/2787622.2787728

Duffy, G., Sorby, S. A., & Bowe, B. (2020). Spatial ability is a key cognitive factor in the representation of word problems in mathematics among engineering students. *Journal of Engineering Education*, 1–19.

Duffy, G., Sorby, S. A., Mack, A., & Bowe, B. (2017, June 26). Performance by Gender on University Placement Tests in Mathematics and Spatial Skills. *ASEE Annual Conference 2017*. https://peer.asee.org/28737.pdf

Gerson, H. B. P., Sorby, S. A., Wysocki, A., & Baartmans, B. J. (2001). The Development and Assessment of Multimedia Software for Improving 3-D Spatial Visualization Skills. *Computer Applications in Engineering Education*, 9(2), 105–113.

Guay, R. (1976). *Purdue spatial vizualization test*. Educational testing service.

Jones, S., & Burnett, G. (2008). Spatial Ability and Learning to Program. *Human Technology: An Interdisciplinary Journal on Humans in ICT Environments*, 4(1), 47–61. https://doi.org/10.17011/ht/urn.200804151352

Kell, H. J., Lubinski, D., Benbow, C. P., & Steiger, J. H. (2013). Creativity and Technical Innovation: Spatial Ability's Unique Role. *Psychological Science,* 24(9), 1831–1836. https://doi.org/10.1177/0956797613478615

Kozhevnikov, M., Motes, M. A., & Hegarty, M. (2007). Spatial Visualization in Physics Problem Solving. *Cognitive Science*, 31(4), 549–579. https://doi.org/10.1080/15326900701399897

Levine, S. C., Vasilyeva, M., Lourenco, S. F., Newcombe, N. S., & Huttenlocher, J. (2005). Socioeconomic Status Modifies the Sex Difference in Spatial Skill. *Psychological Science. American Psychological Society*, 16(11), 841–845.

Linn, M. C., & Petersen, A. C. (1985). Emergence and characterization of sex differences in spatial ability: A meta-analysis. *Child Development,* 56, 1479–1498.

Shea, D. L., Lubinski, D., & Benbow, C. P. (2001). Importance of assessing spatial ability in intellectually talented young adolescents: A 20-year longitudinal study. *Journal of Educational Psychology*, 93(3), 604–614.

Smith, I. M. (1964). Spatial ability: Its educational and social significance. R.R. Knapp.

Sorby, S. A. (2001). A Course in Spatial Visualization and its Impact on the Retention of Women Engineering Students. *Journal of Women and Minorities in Science and Engineering*, 7(2), 153–172.

Sorby, S. A. (2005). Impact of Changes in Course Methodologies on Improving Spatial Skills. *International Journal for Geometry and Graphics*, 9(1), 99–105.

Sorby, S. A. (2009). Educational Research in Developing 3-D Spatial Skills for Engineering Students. *International Journal of Science Education*, 31(3), 459–480.

Sorby, S. A., & Baartmans, B. J. (2000). The Development and Assessment of a Course for Enhancing the 3-D Spatial Visualization Skills of First Year Engineering Students. J*ournal of Engineering Education*, 89(3), 301–307. https://doi.org/10.1002/j.2168-9830.2000.tb00529.x

Sorby, S. A., Casey, B., Veurink, N., & Dulaney, A. (2013). The role of spatial training in improving spatial and calculus performance in engineering students. *Learning and Individual Differences*, 26, 20–29.

Sorby, S. A., Drummer, T., Hungwe, K., & Charlesworth, P. (2005). Developing 3-D Spatial Visualization Skills For Non-Engineering Students. *Proceedings of the 2005*

ISSN: 1949-9167

American Society for Engineering Education Annual Conference & Exposition, 10.18260/1-2–15370.

Sorby, S. A., Duffy, G., & Loney, N. (2020). An examination of the role of spatial ability in the process of problem solving in chemical engineering. *Australasian Journal of Engineering Education*, 25(1), 55–65. https://doi.org/10.1080/22054952.2020.1785653

Sorby, S. A., & Gorska, R. A. (1998). The Effect of Various Courses and Teaching Methods on the Improvement of Spatial Ability. *8th International Conference on Engineering Design Graphics and Descriptive Geometry*, 252–256.

Sorby, S. A., Wysocki, A. F., & Baartmans, B. J. (2002). *Introduction to 3D spatial visualization: An active approach* (Book & CD) (Paperback/CD-ROM). Thomson/Delmar Learning.

Voyer, D., Voyer, S., & Bryden, M. (1995). Magnitude of sex differences in spatial abilities: A meta-analysis and consideration of critical variables. *Psychological Bulletin*, 117(2), 250–270.

Wai, J., Lubinski, D., & Benbow, C. P. (2009). Spatial ability for STEM domains: Aligning over 50 years of cumulative psychological knowledge solidifies its importance. *Journal of Educational Psychology*, 101(4), 817.

Yoon, S. Y., & Mann, E. L. (2017). Exploring the Spatial Ability of Undergraduate Students: Association With Gender, STEM Majors, and Gifted Program Membership. *Gifted Child Quarterly,* 61(4), 313–327. https://doi.org/10.1177/0016986217722614

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