SKETCHING APP TO TEACH SPATIAL VISUALIZATION SKILLS SUITABLE FOR REMOTE AND IN-PERSON INSTRUCTION

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Abstract

In spring of 2020, institutions across the world transitioned with almost no preparation to remote instruction. This proved especially challenging for technical and pre-engineering classes that traditionally incorporated hands-on projects or use of computer and manufacturing labs. One challenge was that students did not have access to lab hardware or computers that could run specialized software such as Computer Aided Design (CAD) packages. Another challenge was the instructors could no longer provide feedback to students as easily as they used to when looking over a student's shoulder in the lab. To address these challenges, a number of middle schools, high schools and higher education schools adopted the use of an educational software app, Spatial Vis, for the first time. This app teaches how to freehand sketch isometric and orthographic sketches of 3D shapes. These spatial visualization skills are foundational for learning CAD, building physical devices, and have been shown to improve retention and grades in introductory Science, Technology, Engineering, and Math (STEM) courses. The Spatial Vis app also provides personalized feedback in the form of hints to a student if they make a mistake. These attributes were seen as a potential way to increase student engagement during remote instruction. In spring of 2020, the app was offered for free and over 180 instructors signed up to use it in the United States. However, considering the challenges of switching to remote instruction, only 64 courses ended up using the app. Through a post survey, this paper describes the instructor perspective including challenges encountered and why some instructors chose not to use the app. It also summarizes feedback from instructors who did use the app, including how they adapted its use and how they saw it fill the gaps created by remote instruction. Results indicate that the Spatial Vis app is suitable for not only in the classroom but also for remote instruction.

Keywords: Spatial visualization, CAD, pre-engineering, sketching, remote instruction, engagement, orthographic, isometric.

1 INTRODUCTION

In a response to the COVID-19 pandemic, educational institutions across the world had to pivot to online learning. Initially, teachers had to adapt quickly to emergency remote teaching and were overwhelmed with resources and the additional work required to develop their remote classes [1]. A survey to understand the successes and challenges that teachers faced as they moved to virtual instruction last spring indicated that teachers transitioned immediately to virtual instruction but did not feel they were properly trained or given enough time to effectively modify their pedagogy. They felt overwhelmed by how quickly they had to transition, as well as inundated with the wealth of information and resources that suddenly became available to help them with virtual instruction [2]. While there was a barrage of resources available, some schools seemed to have funding and support from their administration at their disposal to try new tools, but other schools lacked resources to support online instruction, especially in the area of career and technical education (CTE) or other science, technology, engineering, and mathematics courses that normally have hands-on or laboratory learning.

High-quality CTE can help boost in-demand employment opportunities for young people [3], but key features of some CTE programs, especially hands-on and work-based learning, are not simple to convert to a virtual environment. Common challenges that CTE sites face in the current environment are their need for access to high-end equipment or computing resources requiring high-speed internet, the loss of in-person, close-up demonstrations of proper technique, and the opportunity for teachers to gauge students' mastery in real time [4]. This has led to concerns that students might not be receiving quality CTE during school closures, which would negatively impact their college and career readiness upon graduation [5].

To address these challenges, when the pandemic hit eGrove Education, Inc. offered their Spatial Vis app to teachers for free. A number of middle schools, high schools and higher education schools immediately adopted the use of the Spatial Vis app for the first time. Spatial Vis teaches freehand sketching on smartphones, tablets, and Chromebooks to improve spatial skills which can increase grades in science, technology, engineering, and math (STEM), as well as computer aided design (CAD) and design skills. Since the app automatically grades students' sketches and provides immediate feedback, it had the potential to increase student engagement during remote instruction. Many CTE classes had to compensate for the technical constraints and reduced capabilities to teach their traditional hands-on curriculum. In fact, some teachers were trying to teach hand sketching remotely by requiring students to scan or take photographs of their sketches and submit them to the teacher for grading. Typically, it would take a few days to a week to get feedback to the students. Therefore, the use of the Spatial Vis app in many of these newly adopted courses in spring and fall 2020 resulted in an increased amount of spatial visualization instruction for the students.

Because the move to remote instruction occurred quickly, the courses that adopted the Spatial Vis app were not part of a controlled study. However, through instructor feedback, qualitative information regarding learning outcomes was established and the impact that the Spatial Vis app had on learning outcomes and engagement during the COVID-19 pandemic can be ascertained. This paper demonstrates the Spatial Vis app's suitability not only for in the classroom but also for remote instruction through anecdotal instructor perspective from a post survey and interviews.

2 SPATIAL VIS SKETCHING APP

Spatial visualization is a fundamental skill for student success, but in a packed curriculum, it is challenging for many instructors to add this content to their course. A spatial visualization app was developed by eGrove Education, Inc. [6] to make use of the prevalence of touchscreen devices in education and to make spatial visualization training more engaging and easier to teach. Spatial Vis teaches freehand sketching to improve spatial skills for students in pre-engineering, manufacturing, and CAD courses. Motivated by Sorby's finding that the "importance of sketching in developing 3-D spatial skills cannot be understated" [7] the app enables students to freehand sketch assignments on a touchscreen. Sketching provides an added benefit beyond SV, and has been correlated to communication, teamwork, and creativity [8]. The app runs on iOS and Android phones and tablets, and Chromebooks (see Figure 1). Students sketch isometric and orthographic assignments and the app provides automatic grading and personalized feedback on student work making it especially well-suited for remote learning as well as in-class instruction. Studies with the Spatial Vis app have demonstrated its efficacy when used in class or as homework ([9] through [14]).

Figure 1. Spatial Vis™ App available on Apple and Android Phones and Tablets, and Chromebooks

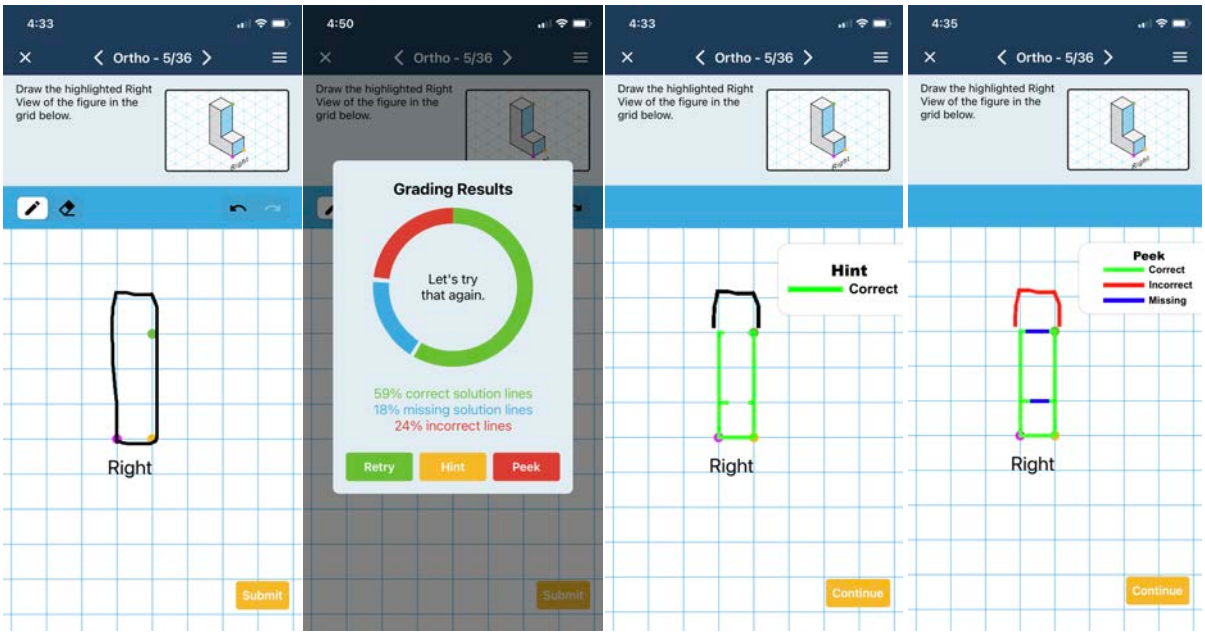
2.1 Features Suitable for Remote Instruction

2.1.1 Automatic Grading Algorithm with Hint and Peek Capabilities

The Spatial Vis app provides a sketching window and an assignment window, each with a reference dot so students know the position in the sketching window they need to draw their solution for the grading algorithm to correctly score their submission (Fig. 2a). When the user selects the submit button at the bottom of the screen, the grading algorithm is initiated. If the solution is correct, the student can move on to the next assignment. If incorrect, the grading algorithm produces a pop-up window that gives the student immediate feedback by providing them with a circular progress indicator showing them how much of their sketch is correct and how much is incorrect (Fig. 2b). If the student just uses the feedback from the progress indicator, they have the option to retry the assignment as many times as they would like without losing any credit. If the student would like more help, they can select the Hint button or take a Peek at the solution.

The Hint tells the user which parts of their drawing are correct by highlighting them in green (Fig. 2c). If a student uses a Hint and most of their submission is highlighted in green then the student is close to the solution. Alternatively, if the student uses a Hint and most of their submission does not show as green then they know they need to rethink the problem, ask for help, or possibly use a Peek.

The Peek highlights the correct parts of the drawing in green, incorrect parts in red, and missing lines in blue (Fig. 2d). Additionally, gamification was added to the app to encourage persistence. Students now receive three stars for each assignment they solve correctly without any assistance regardless of how many times they attempt the sketch. If a Hint is used, then they are awarded two stars for the problem and if a peek is used then students earn only one star when they successfully complete the sketch (Fig. 3).



a) As Drawn by Student *b) Initial feedback with progress indicator* *c) Hint showing correctly drawn portion in green* *d) Peek showing missing components in blue and incorrect in red*

Figure 2. Orthographic Sketch Assignment with Different Feedback Options

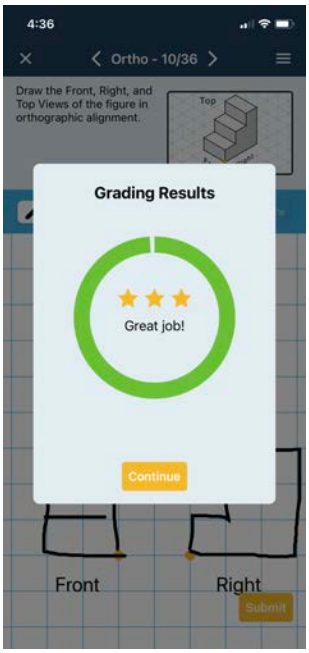


Figure 3. Star Reward System

2.1.2 Personalized Feedback (Mini Hints)

An expert teacher looking over the shoulder of a student struggling on an assignment will often give a small hint to the student, even before the student raises their hand for help. This small hint will keep the student productively working on the assignment while reducing frustration, but still elicits effective struggle to solve a difficult assignment. Accordingly, there is value for creating hints that provide only a small amount of help. To try to replicate a teacher looking over the students' shoulder, the Spatial Vis app provides Mini Hints to students as "free hints" without the loss of stars. The hints are based on specific errors that the grading algorithm identifies when students submit an incorrect sketch. If these free mini hints are not sufficient, a student will still have the option of looking at the original Hint and Peek options that were shown in Fig. 2, albeit with loss of stars. The challenge is to create mini hints that would help move a student forward, but still require them to actively engage and struggle to solve an assignment [15].

The most common mini hint is a progress indicator indicating the amount completed in different categories. When a student's sketch is graded there are three categories of lines: correct, incorrect, and missing. This was previously shown in Fig. 2b. The progress indicator hint can quantify to the student how much of the various categories of lines are present. By viewing the progress indicator, a student will get a sense of how close they are to finishing the sketch but will not be provided with specific graphical information as to what part of the sketch is correct or what the actual solution is. If a student sees that their initial lines are correct, then they will know that they are on the right track and feel encouraged to continue. Alternatively, a student may see early on that much of their approach is incorrect which may encourage them to start over.

Another type of mini-hint is specific textual messages such as "Hidden Line Incorrect", "You may be missing a line", "You may have an extra line", or "Close! Draw more carefully" (Fig. 4). Other hints that are anticipated in the future include "Shape is drawn correctly but in the wrong location", "The object is rotated incorrectly", "Error in right side (or top, front, etc.) view", etc. The purpose of a mini hint is to provide some guidance to the student without showing them the solution.

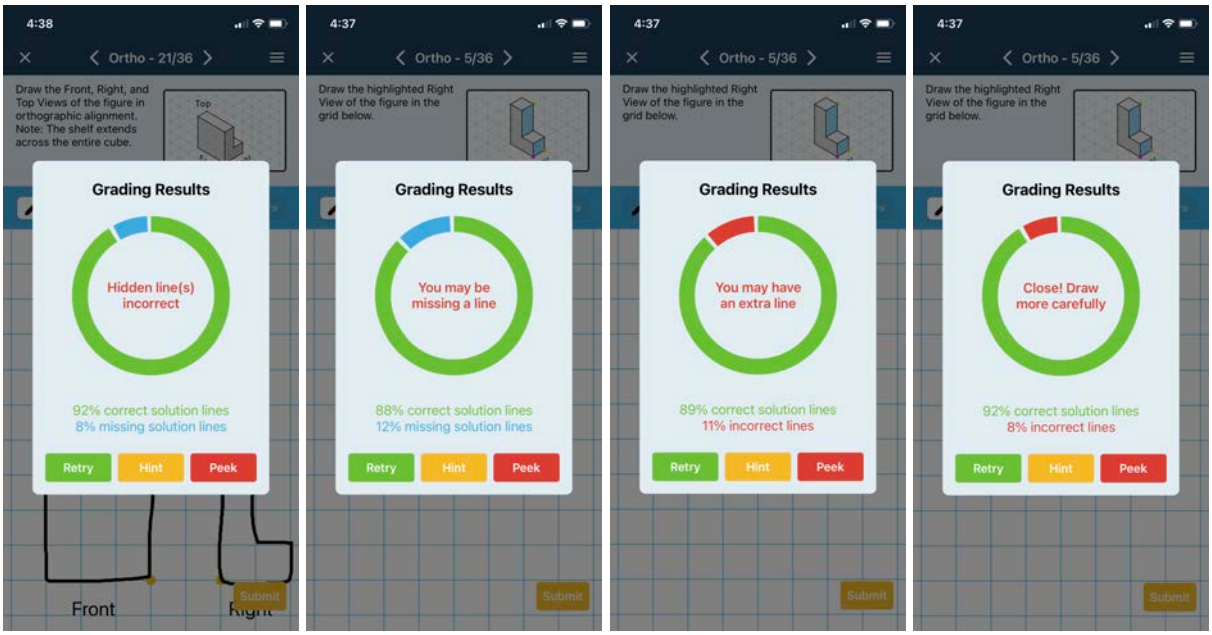


Figure 4. Textual Mini Hints Provided to Students Based on Errors in Submitted Sketch

2.1.3 Other Features Within the App

To facilitate instruction, eGrove Education also has created Lecture Slides and Videos that introduce the basic concepts necessary to solve the assignments in each lesson. These slides and videos are provided on the eGrove Education website [6] or can be directly accessed by the students within the app on the first page of each lesson.

Additionally, test questions are provided as the last three questions of each lesson. These assessments were chosen to be of moderate difficulty, and the Hint and Peek features are disabled. These test questions try to incentivize students to learn the material in each lesson rather than relying on the Hint and Peek features because students are aware that they will have to eventually complete three assignments without help features before they can move on to the next chapter.

Furthermore, a challenge with remote learning is ensuring all students have equitable access to the Internet. The Spatial Vis app can work in offline mode if access to the Internet is a problem. Essentially, grading of assignments can occur locally and progress in the app is saved until the app can connect with the internet and sync student progress with eGrove Education's servers.

2.1.4 Future Features

A prior study with the Spatial Vis app showed that students that took a Peek at the solution after an initial failure learned much less than those students who tried to solve a problem on their own with multiple attempts [10]. Based on this study a metric for student persistence was developed, but this metric is not shown to the teacher in the current version of the app. eGrove Education is currently working on an improved teacher interface that allows instructors to track student persistence (whether they are hinting and peeking too often) and intervene as necessary. Additionally, the experience of moving to remote instruction during the pandemic resulted in an increased interest by middle schools and a much wider range of classes that use the Spatial Vis app. Rather than developing a separate curriculum for the younger ages or for different types of courses, teachers will be provided with the capability to customize the assignments their students do within the app and take advantage of the scaffolding built into the system to assign problems of relevant difficulty and applicability to their courses. Students will be able to identify within the app which assignments are required by their teachers and which are optional, and grade reports for the teachers will correlate directly to the required assignments.

3 FREE COVID-19 OFFER

As soon as the pandemic hit in March 2020, eGrove Education, Inc. offered their Spatial Vis app for free to any teacher who wanted to try it as they quickly pivoted to remote learning. The offer spread

quickly through various sites where teachers shared resources and 184 signed up for a course to use the app. The schools included middle schools, high schools, and higher education institutions. Courses that signed up ranged from Computer Science, Design and Modeling, Drafting, Computer Aided Design, Fundamentals of Engineering, Woodworking, and Industrial Technology. Furthermore, some schools were customers who had already started using the Spatial Vis app prior to the pandemic so could comment on their change in experience with the app as they transitioned to online.

3.1 Data Collection

Because the move to online was immediate, a controlled study regarding the impact that Spatial Vis had on these institutions and students was not possible. However, to better understand how and why teachers incorporated the technology into their classroom, their overall engagement with the app, and the app's success in meeting learning outcomes, an online survey and several phone interviews with higher education and K-12 teachers were conducted. This included schools that both took advantage of the free COVID-19 offer and some that did not ultimately use the Spatial Vis app.

4 RESULTS

Out of the 184 courses that signed up for the initial free COVID-19 offer, only 64 actually used the app. A survey was sent to all instructors who initially signed up for the free COVID-19 offer. Only 6 people responded, but of these responses, half ended up using the free offer and the other half did not use it. Follow-up phone conversations with people who signed up for the free COVID-19 offer led to some interesting information about why they used or did not use the app.

4.1 Challenges

Through a survey and phone interviews many of the instructors indicated that they did not use the Spatial Vis app due to being inundated with resources and materials when they first transitioned to remote instruction and not having enough time to vet and incorporate the resources into their curriculum. However, the 184 courses that initially signed up to use the Spatial Vis app represented a diverse range of courses. For example, there was an increase in woodworking, CAD and other CTE manufacturing courses which were hard pressed to find material to teach since students did not have access to the normal equipment and laboratories for these courses.

Some reasons for not adopting the app included courses being canceled because they were considered electives and teachers were being diverted to instruct required common core courses, the spatial visualization and sketching material was already covered in the fall semester, or teachers were too busy with the move to remote and having to quickly redevelop multiple courses.

Several instructors had to make the app optional for students in the spring primarily because they could not immediately guarantee equitable access by all students to the appropriate technology requirements or everything was too overwhelming for them to implement the app properly. For example, one instructor made the app optional because she did not know it worked on touchscreen chromebooks which is what her school provides and she was not able to require materials that do not work on school issued devices.

4.2 Success and Adaptation

Due to the 64 classes that adopted Spatial Vis, almost 1500 new students used the Spatial Vis app due to the free COVID-19 offer. One instructor was very grateful that the app was offered for free. All students in his class except for one owned a cell phone despite being a low income school with 62% on free lunch. However, he indicated that the school did have funding for technology and materials to support their students in future years. Another instructor used the app with approximately 100 middle schoolers who loved it. He assigned all of the early assignments and hand-selected the harder assignments.

The teachers who used the Spatial Vis app had very positive feedback. One teacher said, "During this in and out virtual year, I am glad we chose to use this app. It really teaches students how to hand sketch single-view, orthographic, isometric, and 3D visualizations without advanced verbal instruction." Another teacher said that it was an "Excellent tool for remote learning or in-person learning. The app helps students develop important skills for CAD and Technical Sketching." Most of the teachers felt

that the app filled a need since many were all virtual and they were grateful for the ability to have students draw by hand without being in the classroom.

One CTE teacher from Arizona, Melissa Wendell, appreciated that the students had access to the narrated videos. This allowed for high performing students to move ahead on their own without needing her to lecture on the material and gave her more time to work with students who were struggling. She noted that many of her students did not want to look at a Hint since they did not want to lose any stars. Wendell's solution for the students that needed a little more guidance was to have these students send a screenshot of their assignment to get some help directly from the teacher. Furthermore, Wendell had a set of Legos at home and would video chat with students one on one to show the rotations using the Legos, "It was a life saver for me this quarter because I was able to implement the app on top of what I was normally doing for the course and it made things different from the limited things we could do virtually."

Another CTE teacher from Tennessee said, "This semester was the first semester where we were both in the class and out of the class. Spatial Vis helped provide more assignments when we were not in class." In fact, this teacher was hoping for a more advanced version so that he could use the app again the following semester with the same students. The option of allowing teachers to customize their assignment sets and have the required assignments reflected directly with the app is currently being addressed.

Some institutions were already using the Spatial Vis app when the pandemic hit such as San Diego State University. Instructor Tammy Parsons said, "When we went online, students couldn't access the engineering graphics software that we used for the course without access to our computer labs. But, Spatial Vis worked as well online as in person. I didn't have to change anything and was able to seamlessly transition with Spatial Vis."

Parsons, like other instructors who were already using the app before the pandemic hit, indicated that her implementation was not that different when her course transitioned to online, "It was nice to have something that students already had access to remotely. The only thing I did was make Spatial Vis a larger amount of their grade since I was unsure about how to do online testing of CAD software".

5 CONCLUSIONS & NEXT STEPS

Spatial visualization training and specifically freehand sketching isometric and orthographic shapes has been shown to increase graduation rates in engineering for students with low spatial visualization skills. However, the ability to teach hand sketching during the pandemic and remote instruction can be difficult. Accordingly, the potential for spatial visualization training in which students can work independently is attractive. The Spatial Vis app was designed to meet this need as it allows for freehand sketches to be graded automatically and for hints to be provided when needed.

The rapid adoption of technology during COVID-19 provided an opportunity for people to use the Spatial Vis app because it filled a gap for remote instruction even though the app is equally good for use in person. This is especially true for hands-on and laboratory computer courses where the necessary computer software could not operate on school issued devices such as Chromebooks and iPads. The pandemic accelerated the adoption of the product during a time when teachers and school districts were struggling to adapt.

Of the 64 courses that used the Spatial Vis app in Spring 2020, 7 ended up paying for the app as repeat customers in Fall 2020. Additionally, 4 instructors who originally signed up for the free COVID-19 offer but did not use the app in Spring 2020 also paid for and adopted the app in their Fall 2020 courses. This was after teachers had more time to prepare for the continuation of remote instruction as well as vet the Spatial Vis app and its alignment with their curriculum.

While the pandemic required the entire education system to adapt quickly to new modes of delivery, the potential for this crisis to result in lasting positive changes to education should not be disregarded [1]. The Spatial Vis app provides a resource that is not only effective in the classroom but works seamlessly outside of the classroom providing flexibility to teachers.

The digital nature of the app allows for the quantification of data such as how many assignments the students completed in each module as well their performance on test questions. Future work will use this quantifiable data to establish the impact that the Spatial Vis app had on learning outcomes and engagement during the COVID-19 pandemic. With positive results, it is hoped to scale up the use of the Spatial Vis app so that all students will have a resource to help them develop their spatial abilities.

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REFERENCES

[1] E. Nordmann, C. Horlin, J. Hutchison, J.A. Murray, L. Robson, M.K. Seery, J. MacKay, "Ten simple rules for supporting a temporary online pivot in higher education*", PLOS Computational Biology*, October 1, 2020, Retrieved from https://doi.org/10.1371/journal.pcbi.1008242.

[2] D. Schaffhauser, "Educators Feeling Stressed, Anxious, Overwhelmed and Capable"*, The Journal: Transforming Education,* June 6, 2020, Retrieved from https://thejournal.com/articles/2020/06/02/survey-teachers-feeling-stressed-anxious-overwhelmed-and-capable.aspx.

[3] C. Cahill, S. Jackson, N. Summerall, K. Harruna, "Helping Career and Technical Education Programs Meet this Moment", *JFF,* September 1, 2020, Retrieved from: https://www.jff.org/what-we-do/impact-stories/pathways-to-prosperity-network/helping-cte-programs-meet-moment/

[4] E. Richmond, *"*Shop Class, Over Zoom: How one career and technical high school is going remote", *The Atlantic*, Retrieved from: https://www.theatlantic.com/education/archive/2020/05/remote-career-technical-school-covid-19-pandemic/611047/

[5] S. Blackburn, "How schools can improve CTE during COVID-19Online learning could have increased the equity gap for students enrolled in career technical education courses", *District Administration*, Retrieved from: https://districtadministration.com/how-schools-navigate-cte-online-cte-access-during-covid-19/

[6] N. Delson, L. Van Den Einde, E. Cowan, J. Tara "eGrove Education." [Online] Available www.egrove.education.

[7] S. Sorby, "Educational research in developing 3-D spatial skills for engineering students". *International Journal of Science Education*. Vol 31(3), pp 459-80, Feb. 2009.

[8] J. Power, J. Buckley, and N. Seery. "Visualizing Success: Investigating the Relationship between Ability and Self-Efficacy in the Domain of Visual Processing". *70th ASEE Engineering Design Graphics Division Midyear Conference*, Embry-Riddle Aeronautical University, FL, January, 2016.

[9] G. Hoople, E. Cowan, L. Van Den Einde, J. Tara, and N. Delson. "Teaching Spatial Visualization: A Controlled Trial of a Touchscreen App Implemented as Homework", *Conference proceedings for Frontiers in Education: Fostering Education through Diversity,* October 3-6. San Jose, CA. 2018.

[10] N. Delson and L. Van Den Einde, "Tracking student engagement with a touchscreen app for Spatial Visualization Training and freehand sketching," 1*22nd ASEE Annual Conference & Exposition proceedings*, Seattle, WA, 2015.

[11] E. Cowan, N. Delson, R. Mihelich, and L. Van Den Einde, "Improvement in Freehand Sketching Application for Spatial Visualization Training," in *Conference on Pen and Touch Technology in Education*, Illinois, 2017.

[12] L. Van Den Einde, N. Delson, E. Cowan, and D. Yang, "Increasing Student Persistence In A Sketching App For Spatial Visualization Training," *ICERI2017 Proceedings,* pp. 5373–5381, October 2017.

[13] N. Delson, and L. Van Den Einde, "Sketching, Assessment, and Persistence in Spatial Visualization Training on a Touchscreen", in *124th ASEE Annual Conference & Exposition proceedings*, Salt Lake City, UT, 2018. 10.18260/1-2--30968.

[14] L. Van Den Einde, N. Delson, E. Cowan, "Freehand Sketching on Smartphones for Teaching Spatial Visualization", in *126th ASEE Annual Conference & Exposition proceedings*, Tampa, FL, 2019. 10.18260/1-2--32859

[15] N. Delson, L. Van Den Einde, E. Cowan, B. Mihelich, “Mini-Hints for Improved Spatial Visualization Training”, in *126th ASEE Annual Conference & Exposition proceedings*, Tampa, FL, 2019, 10.18260/1-2--33112.