Mini-Hints for Improved Spatial Visualization Training

Prof. Nathan Delson, University of California, San Diego

Nathan Delson's interests include mechatronics, biomedical devices, human-machine interfaces, and engineering education. He isCo-founder and Past President of Coactive Drive Corp., which develops novel actuators and control methods for use in force feedback human interfaces. Medical device projects include an instrumented mannequin and laryngoscope for expert skill acquisition and airway intubation training. He received his undergraduate degree in mechanical engineering from the University of California, San Diego, and then went on to get a doctorate in mechanical engineering from the Massachusetts Institute of Technology in 1994. He was a lecturer and Director of the Design Studio at Yale University for four years, and then returned to his alma mater, UC, San Diego, in 1999. He is now a tenured lecturer and Director of the Design Center in the Department of Mechanical and Aerospace Engineering. He teaches hands-on design courses, including an introductory design class, a mechatronics class, and a capstone design class. His interests in design education include increasing student motivation, teamwork, and integration of theory into design projects.

Dr. Lelli Van Den Einde, University of California, San Diego

Van Den Einde is a Teaching Professor in Structural Engineering at UC San Diego and the President of eGrove Education, Inc. She incorporates education innovations into courses (Peer Instruction, Project-based learning), prepares next generation faculty, advises student organizations, hears cases of academic misconduct, is responsible for ABET, and is committed to fostering a supportive environment for diverse students. Her research focuses on engagement strategies for large classrooms and developing K-16 curriculum in earthquake engineering and spatial visualization.

Elizabeth Rose Cowan, eGrove Education Inc.

Elizabeth Cowan is a User Experience Researcher and Designer for eGrove Education, Inc., which develops Spatial Visualization Training software. Her degree is in Cognitive Science and Human-Computer Interaction from the University of California San Diego.

Mr. Bob Mihelich, McHenry County College

Mr. Mihelich is a tenured faculty member teaching applied technology at McHenry County College, a suburb of Chicago, teaching within the areas of engineering technology, construction and manufacturing technology and management, and CAD/BIM technologies. Mr. Mihelich is also a licensed architect in the State of Illinois having worked on numerous building typologies including advanced manufacturing, mission critical, and data centers. His pedagogical emphasis is to bring real-world experiences to the classroom, and demonstrate best practices for his students to model to be successful.

Mini-Hints for Improved Spatial Visualization Training

Abstract

The pedagogical approach of Zone of Proximal Development (ZPD) is based on the belief that effective learning occurs when students are challenged just beyond the level they can do on their own. An expert teacher looking over the shoulder of a student would give just the right amount of help or hints; too much hinting gives away the solution which deprives the student of the productive struggle that is needed for learning new concepts. Alternatively, no hinting may leave the student frustrated to the point where they give up. A key challenge with developing software for independent learning is generating the proper level of hinting, similar to what an expert teacher would provide in the classroom. This paper describes the evolution of hints for spatial visualization training using a mobile app. Students sketch orthographic and isometric figures, which are automatically graded by the app. In an early version of the app, when a student draws an assignment incorrectly, they were provided with the option of taking a hint or peeking at the solution. In order to encourage persistence, gamification was added to the app which rewarded students to try solving the problem on their own before asking for a hint. This paper describes the unintended consequence of gamification, and how some students avoided using a hint even when simple guidance would be more effective. This behavior motivated the development of smaller hints, which we refer to as mini-hints that could be provided to the students without them asking for a hint. These, mini-hints are presented as free hints that do not cost gamification points and are meant to mimic an expert teacher standing over the shoulder of a student. This paper discusses the types of mini-hints that have been developed, and how their effectiveness will be assessed in an upcoming trial.

Background

Use of electronic tools for education, referred to as eLearning, presents unique challenges and opportunities. This paper presents work in progress for applying eLearning to Spatial Visualization (SV) training specifically in the area of providing feedback hints to students when performing freehand sketching exercises on touchscreen devices.

SV is the ability to visualize and manipulate 2D and 3D shapes in one's mind. This skill has been tied to success in many careers, yet this skill is undertaught or not typically taught in most K-12 and engineering curricula. A seminal study by Sorby [1] showed that SV skills can be taught and can result in a significant increase in GPAs and graduation rates. 7000 students were tracked for over 15 years showing similar results [2]. The increase in graduation rates is especially significant for women and other underrepresented minorities in STEM [3], who may have had less experience in playing with building toys as children.

An important part of SV training is freehand sketching of shapes such as orthographic and isometric views. As stated by Sorby [1], "The importance of sketching in developing 3-D spatial skills cannot be understated." A number of curricula have been developed to teach SV based on sketching on paper [4], and the NSF has funded an initiative to promote SV training

in Science Technology Engineering and Math (STEM) programs [5]. However, it is challenging to add additional material to an already full curriculum and there are a wide range of students' SV ability, with some students needing much more training time than others. Accordingly, there is a benefit to make SV training easier to teach and allow students to work independently on their own schedule. Furthermore, it is desirable to reduce the amount of time that students spend on SV training, as their curriculum is already very full.

To make it easier to incorporate SV training into educational curriculum, a number of software programs have been developed. The authors have developed a touchscreen sketching-based app with automatic grading for SV training [6]-[10]. Other software developed for SV training include a sketching-based tool [11] and an Augmented Reality (AR) tool [12].

The field of pedagogy has had numerous studies relating to learning effectiveness. One approach by Ermeling [13] advocates keeping students in a Zone of Proximal Development (ZPD). A good teacher will engage students in a productive struggle that challenges but does not frustrate them. Effective activities need to stretch students' thinking and performance just beyond the level they can do on their own, i.e. keep them in the ZPD. Effective learning occurs when students struggle to tackle novel problems—ones they have not seen before and are just beyond what they have already learned and mastered. Roll et. al [14] studied online problem-solving environments and concluded that students asking for help on challenging steps is associated with productive learning, and overusing help is associated with poorer learning. Designing challenging tasks that do not frustrate students but require just enough stretch takes refined and continuing teacher assessment and judgment. In designing an eLearning system, it is desirable for such a system to behave like an expert teacher and to keep students in the ZPD by providing small hints when necessary to avoid frustration, but not too much of a hint that would give away the solution and remove the meaningful struggle.

Prior Work

The authors have developed SV training software in which students sketch on touchscreens, and an algorithm automatically grades the student's sketches. In addition to removing the teacher's task of grading, this software allows students to work independently at their own pace. However, when a student makes a mistake on a sketching assignment, they need some type of assistance to move forward. In the first iteration of the software, students were provided with the option to peek at the solution if their sketch was incorrect. Some students avoided peeking at the solution and kept trying to solve the assignment on their own, while other students quickly peeked at the solution after their first attempt [6]. Pre and post testing showed that the students who were more persistent and tried assignments multiple times before peeking at the solution had significantly higher gains in SV skills.

In order to increase student persistence, two changes were made to the Spatial Vis™ app. An intermediate hint was added, which was made available for a student to look at before peeking at the solution. The hint showed the student the portion of their sketch that was correct, but not the complete sketch solution. With this approach, each student could receive a personalized hint based upon the work that they had completed up to that point. Figure 1 shows a simple 2D rotation assignment in which the students are asked to draw a rectangle rotated by 90 degrees counter-clockwise.
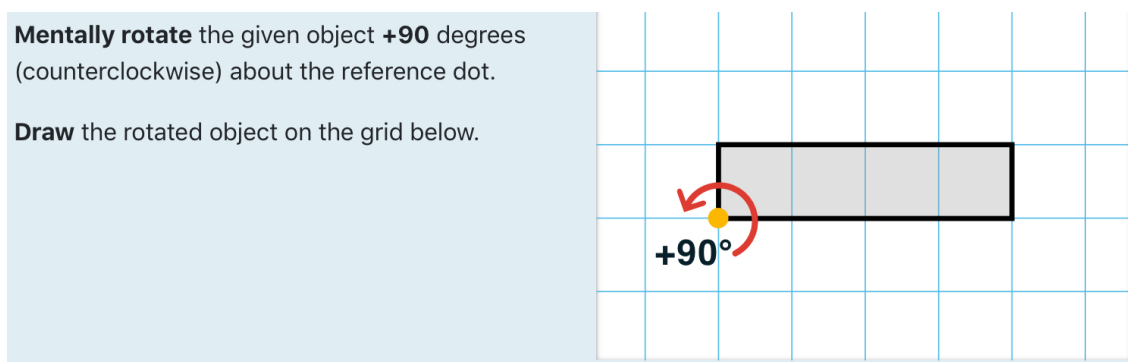
Figure 1. Simple 2D Rotation Assignment

Figure 2 shows the hint and peek feedback when a student makes a mistake on this assignment. Figure 2A shows a partially completed rectangle with the mistake of the line extending too far from the base of the rectangle. Figure 2B shows the hint, which presents in green to the students their portion of their sketch which is correct but does not show the missing portion of the solution or the incorrectly drawn portion. In the current version of the app, the hint feedback algorithm sometimes unintentionally and mistakenly shows short line segments that are incorrect, such as the small vertical stub on the top right of Figure 2B. However, future embodiments will reduce these artifacts to provide more clear graphical feedback to the student. Figure 2C shows the feedback provided to the student when they peek at the solution which shoes correctly drawn lines in green, incorrectly drawn lines in red, and missing portions of the solution in blue.

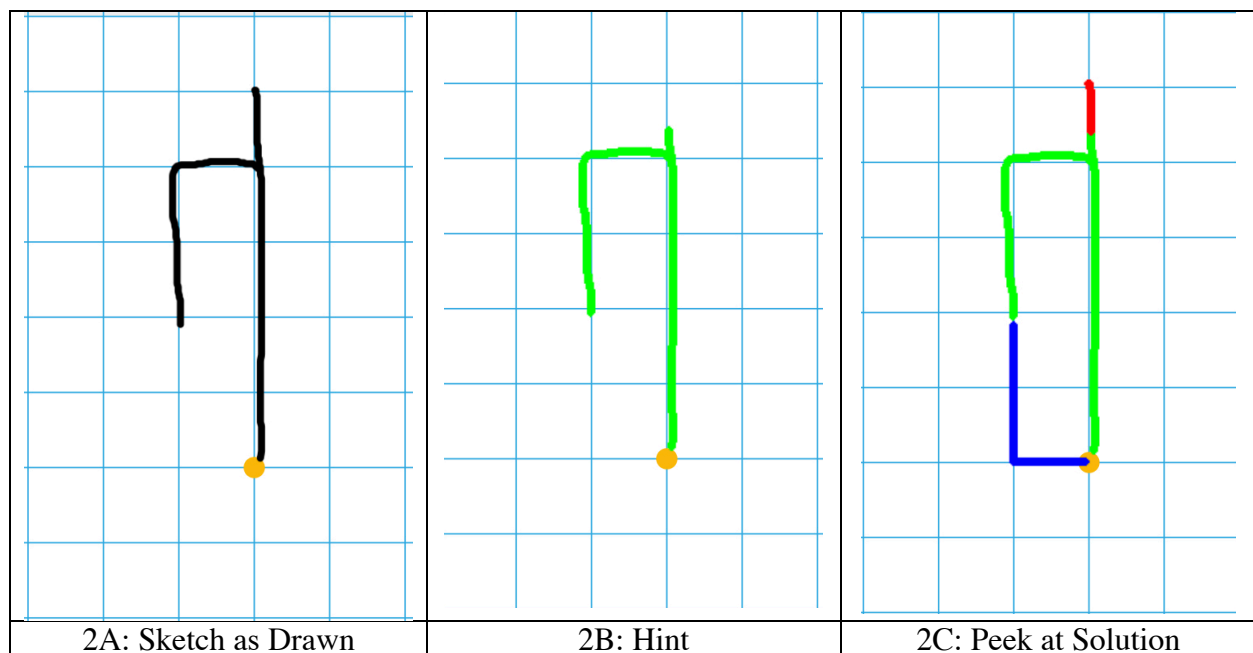| 2A: Sketch as Drawn | 2B: Hint | 2C: Peek at Solution |

Figure 2. Hint and Peek at Solution

The second change to the Spatial Vis app was to add gamification to encourage students to try to solve assignments on their own before asking for either the hint or peek. A star reward system

provides students with 3 stars if they solve the assignment on their own (regardless of the number of attempts), 2 stars if they use a hint, and 1 star if they peek at the solution. In all cases, students must correctly draw the sketch in order to get credit for it.

A metric was created to quantify persistence based upon the number of times a student retries an assignment on their own before selecting the option to peek at the solution. Prior studies [10] have shown that students with higher persistence achieved a higher gain in SV skills as measured by the PSVT:R test [15] administered at the beginning and end of the class.

Adding gamification had a significant impact on student behavior and performance. Among students who entered the class with low PSVT:R scores (less than or equal to 70%), the number of students who were able to increase their PSVT:R post-test scores to above the 70% threshold increased from 46% to 82% once gamification was added. The average score improvement in the PSVT:R rose from 18% to 39% [10]. Accordingly, gamification has a significant positive effect on student learning, but as described below, it resulted in other effects as well.

Mini-Hints for Improved Spatial Visualization Training

The purpose of a hint is to provide some guidance to the student without showing them the solution. For example, a very generic hint could be providing a link to tutorial material about the lesson. Indeed, tutorial content is provided at the beginning of each lesson in the Spatial Vis app. However, observations of an early version of the app that provided a link back to the tutorial material found these hints too general, often leaving students stuck. The challenge with developing hints is to provide guidance that allows students to solve the assignments, while also promoting the effective learning of new concepts while avoiding making repeated mistakes.

There was an unintended consequence of gamification in the Spatial Vis app that relates to the use of hints. Students became very aware of the number of stars they were earning, to the point where many refused to use the existing hint or peek features to avoid losing stars. While persistence is laudable, these students often remained stuck on an assignment. A small hint could have informed the students where to focus their efforts. But instead these students became frustrated and spent much more time on the app than needed.

Through data mining and observations, it was found that sometimes students had sloppily drawn lines that were causing errors in their sketches, while other times they had fundamental conceptual errors with the shape of their sketch. Sometimes a single line was missing in the sketch, while other times the sketch had a single additional line. Under such circumstances a student may spend a lot of time working in the wrong area. They may work on cleaning up their lines, when in fact the error was conceptual, or vice versa. When a student was either missing or had an additional single line, the student might be convinced that their sketch was correct, and the grading algorithm was in error. In essence, these students had moved out of the ZPD and away from effective learning.

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 in the ZPD by reducing frustration, but still eliciting effective struggle to solve a difficult assignment. Accordingly, there is value for creating hints that provide only a

small amount of help. Below is a discussion of the mini-hints that have been developed for the Spatial Vis app. These hints will be provided to students as "free hints" without the loss of stars whenever they submit a sketch for grading that has an error. 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 Figure 2, albeit with loss of stars. The challenge was to create mini-hints that would help move a student forward, but still require them to actively engage and struggle to solve an assignment. The following sections provide descriptions of the mini-hints that have been developed to improve the SV learning experience.

Progress Indicators Mini-Hints

The first mini-hint is a progress indicator such as a progress bar or percentage numbers indicating the amount completed in different categories. When a student's sketch is graded there are three categories of lines; correct, incorrect, and missing, as was previously shown in Figure 2. The progress indicator hint can quantify to the student how much of the various categories of lines are present. Figure 3 shows an example of a progress indicator.
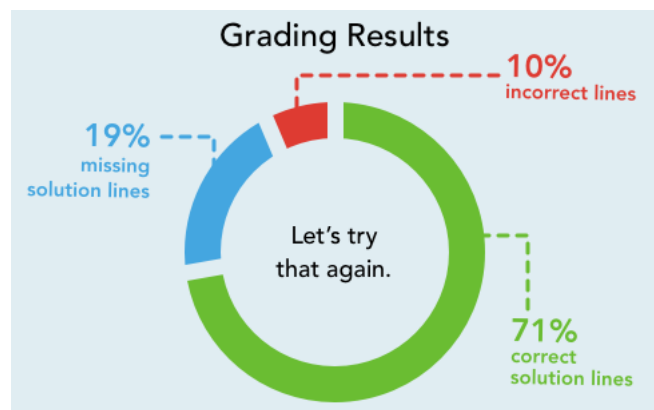

Figure 3: Mini-Hint Progress Indicator with Three Line Categories

The length of the correct line indicator correlates to the length of the correct lines drawn relative to the total length of the solution lines. The length of the missing line indicator is also relative to the total length of the solution. Accordingly, when the solution is correct, the correct line indicator will be full, and the missing line indicator will shrink towards zero. However, there is not a limit on the amount of incorrect lines that a sketch can contain. Accordingly, the length of the incorrect progress bar can be defined in a number of ways. Here, we define the length of the incorrect lines relative to the length of solution but limit its maximum length.

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 encouraged them to start over. In the middle of a sketch when a student is stuck, they may select an approach of drawing one line at a time and receiving an additional free hint. But even with this approach the student will be forced to make decisions about the sketch and attempt to draw correct lines in order to get meaningful hint feedback. The fact that it takes a bit of time to

submit a sketch and wait a few seconds for grading results, is further incentive for students to attempt more of a solution on their own.

These mini-hint progress indicators can provide even smaller hints by displaying progress for only a portion of the line categories. Figure 4 shows a single progress bar, in this case for just the correctly drawn lines. Drawing an incorrect line would not change the progress bar one way or the other. This more limited hint would provide less information to the student and thus require that they solve more of the challenge on their own. If a student becomes over reliant on the free hints, then the hint could be adjusted in this fashion to provide less information. In the assessment section in this paper, determining the appropriate level of hints will discussed.
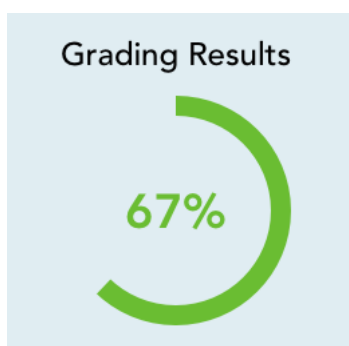

Figure 4: Mini-Hint Progress Indicator with 1 Line Category

Text Mini-Hints

Another type of mini-hint are specific textual messages. Students have been using the Spatial Vis training app for four years, and through data mining of student sketches it was possible to identify areas of repeated student mistakes. For example, it was observed that students often had difficulty noticing when a single line was missing. Figure 5A shows an example sketch of a single line missing. A single 30-degree line is missing near the left inner corner of the sketch, but many students miss this error. This has led to student frustration were they repeatedly resubmit the same sketch or redraw the same exact lines but trying to draw them straighter. Students ultimately would realize what their error was or resort to a peek at the solution. We believe that a simple text message such as that shown in the center of the progress ring in Figure 5B would not only be more time efficient but would result in the same amount of learning.

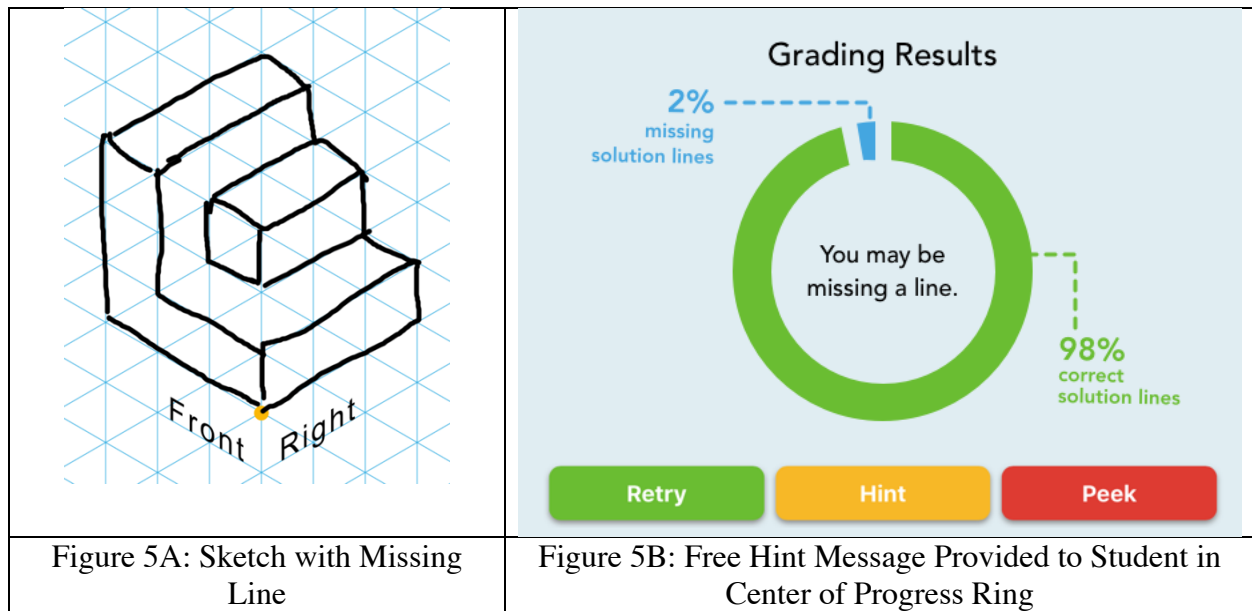|	
Figure 5A: Sketch with Missing Line	Figure 5B: Free Hint Message Provided to Student in Center of Progress Ring

Figure 5: Text Mini-Hint for Missing a Line

In other cases, students draw an additional line but have difficulty seeing their error. Figure 6A shows an example where an additional line is drawn in the middle of the sketch on the face between the two towers. Figure 6B shows the corresponding text mini-hint. Note, in both Figures 5 and 6, students are provided with buttons of Retry, Hint, or Peek. These buttons lead to the previously available "larger hints" that are used in the gamification of the app. Use of the hint or peek buttons result in a loss of stars. In order for the student to receive any credit for the assignment, they must draw the sketch 100% correct (within the grading tolerance of line accuracy). Accordingly, even a small percentage of error as shown in Figures 5 and 6 will prevent the student from getting credit for the assignment. These small errors can be especially frustrating to a student because they may feel that their answer is correct, and then begin to lose faith in the grading algorithm. The mini-hints provide the push to show the student that they need to focus on a few missing details, which is often all they need to do to find their error.

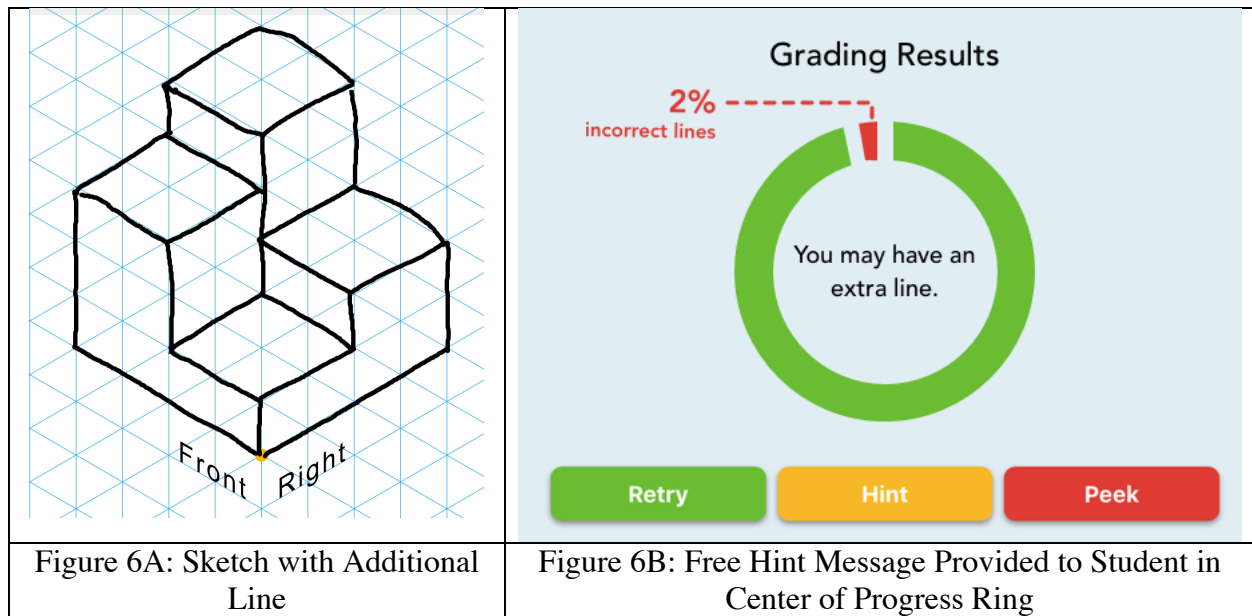| Figure 6A: Sketch with Additional Line	Figure 6B: Free Hint Message Provided to Student in Center of Progress Ring

Figure 6: Text Mini-Hint for Additional Line

Other types of free hint textual messages are:

- Try drawing your lines more carefully
- Shape is drawn correctly but in the wrong location
- The object is rotated incorrectly
- Error in side (or top, front, etc.) view
- Specific hints that are based on repeated mistakes student make, such as "Object is mirror image of solution"

The algorithm for generating these text hints is based on the grading algorithm and on data mining the database of repeated student mistakes.

Image Region Mini-Hints

The "larger hints" that were originally shown in Figure 2 present specific graphical information about the correctness and errors of the sketch submitted. In order to reduce the size of the hint, the prior two approaches for providing mini-hints did not provide graphical information to the user, relying instead on progress indicators and text messages. However, it is possible to provide a graphical hint without revealing the exact location of the error. A highlighted region could indicate the general location of an error, without revealing exactly where it is. To prevent students from always looking at the center of the region for the error, the location of the region could be centered in a random location as long as the actual error remains within the hint region. Figure 7 shows a mini-hint region highlighted in yellow (the error is a missing rectangle in the Right view).
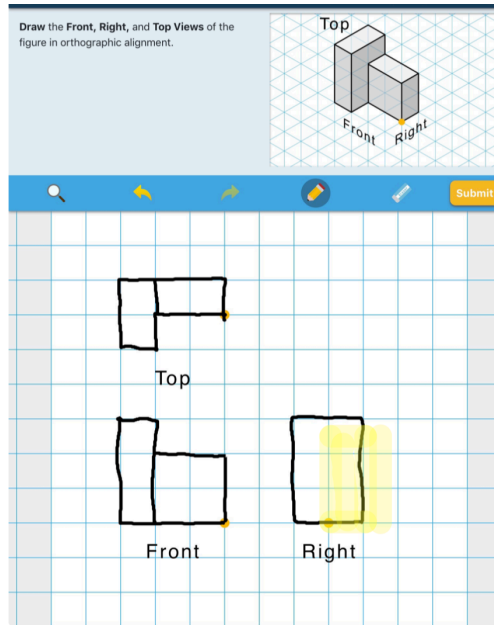
Figure 7. Highlighted Mini-Hint Region Showing Approximate Location of Error

Proposed Assessment Methods

The effectiveness of the proposed mini-hints will be assessed in future classes. A primary assessment method will be pre and post testing with the PSVT:R. Our hope is that the SV gains will be at least as high as a previous year that the class was taught without mini-hints. Key objectives of the mini-hints are that they will save student time and reduce frustration. Accordingly, we will track the time spent on each assignment as well as the overall time. We will measure frustration through a survey and add questions about the impact of the regular vs mini-hints. In addition, we will track how many extra credit assignments are done, with the hypothesis that reduced frustration will lead to students completing more extra credit assignments.

We would like to determine the appropriate amount of information that a hint should provide, and if a given hint is too large or too small. We will compare the number of overall hints used for each assignment. If students use a single hint and then immediately get the sketch right, it could indicate that the hint is too large and gives away the solution. If students use a large number of mini-hints, but then still need a large hint, it could indicate that the mini-hints are not helping enough.

A key goal with the use of hints is that students will truly learn, not just complete the assignments. Accordingly, we will look at assignments that follow those where hints are used. If the students repeat the same mistakes, then this will indicate that learning the concept is not complete. But if the student is able to tackle similar tasks without the use of hints, then this will indicate effective learning. For example, we will look at repeated errors, such as those that were shown in Figures 5 and 6.

Another option we may explore is adding a setting in the app that would turn on or off the mini-hints. If some students elect to turn these hints off, it would be an indication that the mini-hints are seen as an unwelcome intrusion on the learning process of persistent students.

Summary

Expert teachers will never be completely replaced by software algorithms. However, eLearning environments can be created that include some of the capabilities of expert teachers and allow students to work independently with a virtual teacher looking over their shoulder. Feedback to a student in an educational software program can have significant and sometimes unintended consequences that impact learning effectiveness and persistence. The proposed mini-hints presented here are an attempt to improve the learning environment in the Spatial Vis training app, and have been developed using guidance from pedagogical theory. This is a Work in Progress, and the actual effectiveness of the mini-hints will have to be assessed through educational trials.

References

[1] 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.

[2] S. Sorby, "Spatial Skills Training to Improve Student Success in Engineering," *2012 Specialist Meeting—Spatial Thinking Across the College Curriculum*, pp. 1– 4, 2012.

[3] C. Hill, C. Corbett, A. St Rose. *Why so few? Women in science, technology, engineering, and mathematics*. American Association of University Women. 1111 Sixteenth Street NW, Washington, DC 20036; 2010.

[4] S.A. Sorby, Developing Spatial Thinking Workbook. Cengage Learning. Boston, MA, 2011.

[5] S.S. Metz, C.D. Matt, P. Campbell, J. Langeman, and R. Ribe, "Engage Engineering." [Online]. Available: https://www.engageengineering.org/.

[6] N. Delson and L. Van Den Einde, "Tracking student engagement with a touchscreen app for Spatial Visualization Training and freehand sketching," *122nd ASEE Annual Conference & Exposition proceedings*, Seattle, WA, 2015.

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

[8] 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.

[9] 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.

[10] N. Delson, and L. Van Den Einde, "Sketching, Assessment, and Persistence in Spatial Visualization Training on a Touchscreen", 124th ASEE Annual Conference & Exposition proceedings, Columbus, OH, 2017.

[11] E. Hilton, M. Paige, B. Williford, W. Li, T. Hammond, and J. Linsey, "Engineering Drawing for the Next Generation: Students Gaining Additional Skills in the Same Timeframe," in *Proceedings for the 124th ASEE Annual Conference & Exposition*. Columbus, OH, 2017.

[12] J.E. Bell, et al. "Board# 32: Work in Progress: A Study of Augmented Reality for the Development of Spatial Reasoning Ability," in *Proceedings for the 124th ASEE Annual Conference & Exposition*. Columbus, OH, 2017.

[13] B. Ermeling, J. Hiebert, R. Gallimore. "Beyond Growth Mindset: Creating Classroom Opportunities for Meaningful Struggle". *Education Week Teacher*. http://www. edweek. org/tm/articles/2015/12/07/beyondgrowth-mindset-creating-classroomopportunities-for. html. 2015.

[14] Roll, I., Baker, R.S.D., Aleven, V. and Koedinger, K.R., 2014. On the benefits of seeking (and avoiding) help in online problem-solving environments. *Journal of the Learning Sciences*, *23*(4), pp.537-560.

[15] R. B. Guay, *Purdue spatial visualization test: Rotations*. West Lafayette, IN: Purdue Research Foundation, 1977.