

Qualitative Assessment of CogSketch Worksheets in Introductory Geoscience Laboratory Courses: An Argument for Expanded Use

CogSketch in Geoscience Laboratory Courses

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Abstract

The use of computer-assisted instruction to tutor students in the geosciences is not common, in part because practical programs capable of assessing sketches relevant to introductory geoscience subjects are relatively new. One such program, CogSketch, is an open-domain sketch understanding system that is capable of tutoring students on sketch-based exercises and grading their work. This paper reports on the mixed-use of paper-based exercises and tablet PCs equipped with CogSketch worksheets in introductory geoscience laboratory courses. Potential benefits of using CogSketch worksheets include increased group focus and reduced barriers to starting laboratory exercises. Grading efficiency was not affected. However, increasing the proportion of CogSketch worksheets used during lab sessions will improve grading efficiency and amplify benefits in classroom social dynamics and teaching efficiency that may lead to learning gains.

1. Introduction

The use of sketches in teaching science, technology, engineering, and mathematics (STEM) courses is common practice and evidence for improved learning and the development of students' spatial skills from sketching diagrams is promising [Ainsworth et al., 2011; Gagnier et al., 2016]. It seems natural that sketching migrates to a digital format as portable touch-screen devices are now becoming ubiquitous in the daily lives of students and a number of sketch evaluation programs have been developed for the purposes of tutoring or coaching students in STEM subjects by having students create sketches [see Forbus et al., 2008 and Forbus et al., 2011 for examples].

CogSketch is an open-domain sketch understanding software that contains a tutoring system intended to be used in engineering and science disciplines. These disciplines commonly use sketching to communicate and to learn concepts that depend on evaluating spatial layout, visual conceptual relationships, and scaling [Forbus et al., 2017]. The program uses analogy mapping [Falkenhainer et al., 1989; Forbus et al., 2008] to compare solution sketches created by the worksheet designer with those of students and is able to make qualitative and quantitative assessments of their ink.

The use of sketch-tutoring software in the geosciences is not widely practiced at any educational level, but the educational benefits of rapid feedback in the classroom and computer grading for instructors are alluring. It is not, however, expected that the application of innovative and intuitively useful technology in the classroom will always be successful [e.g., Murphy, 2011]. If digital touch-based sketching is to be widely used in future geosciences courses, then some fundamental multi-faceted questions should be addressed: (1) What are the full range of effects generated by using computer-assisted instruction and sketching exercises? (2) How can benefits to learning outcomes be maintained or increased, while minimizing drawbacks? (3) When should such teaching strategies be implemented? These are not the only questions to be addressed and the observations and interpretations presented below are not sufficiently rigorous to answer these questions explicitly, but they can be used to generate research questions and to guide the classroom use of computer-assisted tutoring in the geosciences.

This paper reports on the deployment of CogSketch along with a number of introductory college-level physical geology worksheets that have been recently developed for the program and are now available at the Science Education Resource Center at Carleton College (SERC) website [SERC, 2017]. Exercises that were used in this study covered

the following subjects: topographic maps; geologic time; the principle of faunal succession; identification and kinematics of joints, faults, and folds; earthquake slip; flooding and flood recurrence; and glacial movement. The qualitative results focus on overall teaching efficiency and classroom social dynamics as compared to a traditional face-to-face physical geology laboratory course that uses paper-based exercises.

2. Previous Work

CogSketch combines concept sketching with the ability of the participant to receive immediate corrective feedback [Forbus et al., 2017]. Concept sketches are annotated cartoon diagrams that depict the spatial relationships among geologic features [Johnson and Reynolds, 2005]. Johnson and Reynolds [2005] developed the definition of a concept sketch and described how it could be successfully applied to a learning-cycle. Their work, as well as the work of others [e.g., Reusser et al., 2012] has produced useful methods for evaluating a student's understanding of concepts and documenting student learning progress.

Computer-assisted tutoring in the form of instant feedback has been shown to influence learning. Schofield et al. [1990] qualitatively noted higher levels of student engagement, higher levels of risk-taking in students, and that slower geometry students received more assistance from their instructor when an intelligent tutor was used in the classroom. Koedinger and Anderson [1993] demonstrated improvement in students' learning of geometry proofs when computer-assisted tutoring was combined with an instructor who knew the tutoring software and was actively engaging students during the learning process. Anderson et al. [1995] documented increased rates of learning and improved performance on a final assessment for students in a computer science minicourse.

Twenty-six geoscience worksheets were developed by Garnier et al. [2014] to be used with CogSketch. Worksheets are similar to concept sketches, but with some differences. Unlike concept sketches where the student or the instructor is required to generate most of the content, including the annotations, geoscience worksheets begin with a fairly sophisticated background and a curated selection of labels and annotations. Worksheets introduce a problem to students in the form of an uncompleted sketch and ask them to complete and annotate the drawing.

CogSketch geoscience worksheets have been used and tested in classroom pilot studies and in experiments. In pilot studies of geoscience worksheets, assignments were given to students as homework or extra credit in EARTH 201 courses at Northwestern University [Yin et al., 2010] as well as in in-class activities in an introductory geology course at Carleton College [Garnier et al., 2013]. Reports from the implementation of the program and the exercises indicate that students quickly learned how to use CogSketch worksheets and could complete multiple geoscience worksheets within an hour.

Experiments with CogSketch and worksheets have targeted cognitive research and educational topics. Jee et al. [2009] compared the sketches of experts (graduate and undergraduate geoscience students) and non-experts (undergraduate psychology students) and found that CogSketch could be used as tool to distinguish the degree of spatial understanding among users with different levels of expertise. In a large-scale study, Garnier et al. [2014] demonstrated that CogSketch could be used to conduct frequent sketching with minimal instruction and in some instances produced learning gains. Finally, Miller et al. [2014] identified learning strategies related to using feedback and connected them to the degree of learner gains.

This study is different from previous contributions in several ways. First, it considers how geoscience worksheets are integrated into the broader teaching process. Second, it compares the experience of using paper-based and digital worksheets as part of a single lab. Finally, it serves to document an independent and relatively large deployment of geoscience worksheets that was not directly influenced by the worksheet development process or experimental design.

3. Methodology

Qualitative observations were made in six different laboratory sections of an EARTH 201 Earth Systems Revealed course taught at Northwestern University between fall 2015 and fall 2016. All sections were taught by the same instructor, but the teaching assistants were different for each course. A majority of the students that participated in these courses were junior or senior undergraduates in the school of engineering.

Data used in this study consist of notes on the teaching experience that were collected by the author during the teaching process and notes that were made by the author after reviewing student worksheets. Observations were initially categorized as being related to teaching efficiency and broken out into subcategories. However, during this process, observations related to social interactions in the classroom also appeared to be prominent and were included as a separate category with a set of subcategories. Thematic content analysis [see Libarkin and Kurdziel, 2002 for a summary] was applied to the observations. Observations were interpreted, restated, and coded as potential benefits, neutral outcomes, and potential drawbacks with respect to activities and interactions experienced with paper-based exercises. Potential benefits are observed behaviors that improved teaching or learning efficiency by decreasing the time necessary to complete a task or which amplified collaborative interaction between participants in the classroom. Neutral influences did not have a detectable effect on the classroom experience as perceived by the instructor. Possible drawbacks are those effects which reduced teaching or learning efficiency, made tasks more complex or time-consuming relative to a traditional lab, or dampened the frequency of social interactions. Table 1 presents examples of categorized observations, their interpretation, and coded themes. The results of the analysis are presented in section 4.

Category	Observation	Interpretation and coding
In-class use	Rarely, if ever, did students request assistance with a blank worksheet or fail to use feedback.	Possible benefit: Fewer barriers to beginning worksheets.
Lab tear-down	Instructor never perceived clean-up time to be excessive given lab length.	Neutral: Tear-down time was not noticeably increased.
Lab preparation	At least once between quarters, a time was scheduled to clean desktops.	Potential drawback: Tablet desktops must be cleaned-up.

Table 1. An example of relationships among categories, observations, and coded themes.

3.1 Using CogSketch

Students used 10.5-inch Microsoft Surface Pro tablets to complete CogSketch worksheets which were pre-loaded onto the tablets. All six lab sections used the program and class sizes ranged from 9 to 22 students. Over the course of three quarters 492 exercises were assigned to 82 students.

Students used a stylus to create ink that was then designated as a glyph or they manipulated existing glyphs and moved them into the correct position. The glyphs were either conceptual (i.e., contour lines, glacial profiles) or annotations (i.e., arrows indicating relationship and kinematics). Glyph labels and annotation designations were assigned by the student as part of the exercise and were used by CogSketch, in addition to the ink, to evaluate the sketch against the designer's solution sketch and rubric.

Students received text and graphic feedback (Fig. 1). Text responses were predetermined and authored by the worksheet designer. The feedback tool measured the proportion of tasks that had been completed. The length of the feedback bar as well as its color indicated the degree of student progress. The color of the bar also indicated the degree of completion. A green bar indicated that the completed tasks were correct. A yellow bar indicated that some tasks were either not complete or were incorrect. The program provided a hierarchy of bars and text feedback. There were bars for "all glyph labels", "required glyphs", and "overall sketch" as well as feedback bars that measured the completeness of specific subtasks within a sketch.

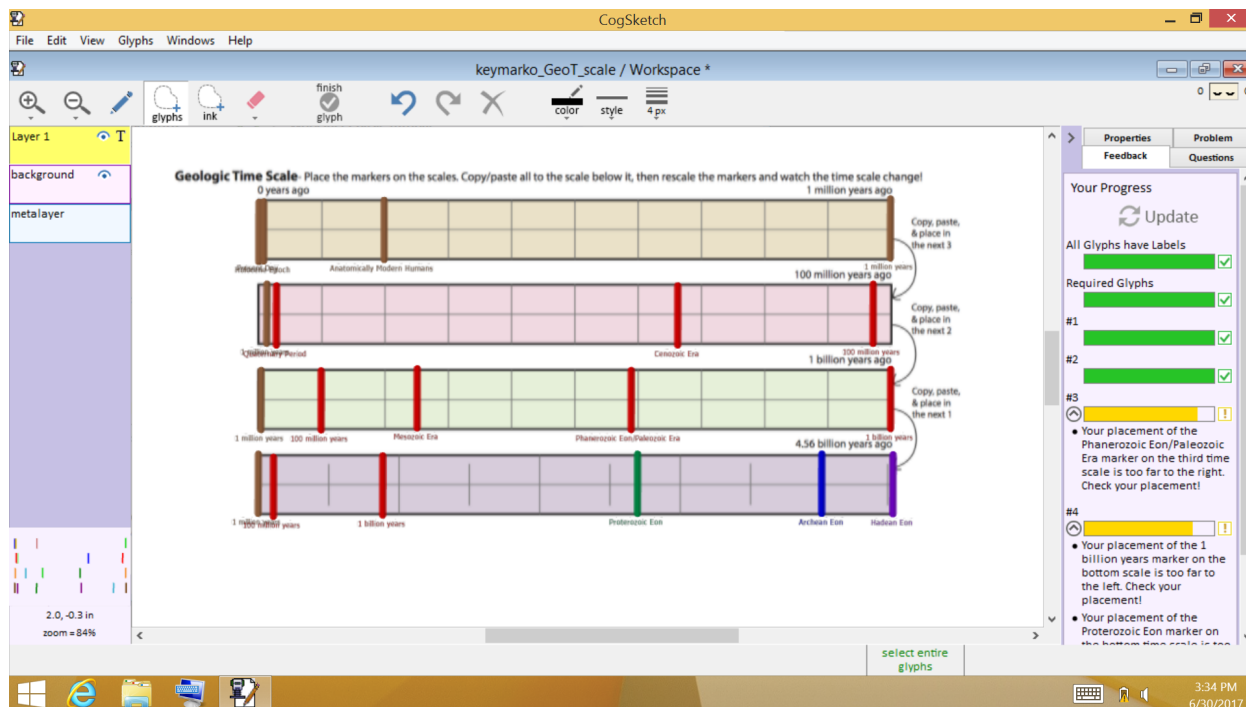


Figure 1. Image of workspace with feedback meters shown on right-side. Feedback text is shown below the related bar.

3.2 Course Design

CogSketch was used in the laboratory because there were enough tablets to outfit one lab section and because the sketch exercise content fit well with typical introductory laboratory assignments. Laboratory sessions lasted 110 minutes. Fifteen to thirty minutes of time was dedicated to an introductory lecture that provided an overview of the lab exercises, delivered conceptual background, and demonstrated worked example problems. None of this time was specifically dedicated to discussing CogSketch worksheets. Students used the basic worksheet tutorial to learn how to use CogSketch and practiced submitting their work digitally.

Laboratory problems consisted of paper-based exercises designed or compiled by the instructor and one or two CogSketch worksheets. Ideally, lab content was designed to be completed and submitted by the end of each laboratory session, but some students finished their exercises outside of lab. Students typically worked in groups of two or three.

Tablets were used in six of the nine laboratory meetings. Specific worksheets were chosen based on their topical relevance and the ability of the instructor to apply the exercise to the course learning outcomes. At least 20 minutes was budgeted for each exercise.

3.2.1 Grading

Exercises were graded using pass/fail criteria that included two parts. (1) All elements or steps in a problem must be attempted. (2) Most (ideally 70%) of the exercise must be correct. Students used the feedback tool to measure their progress and estimated whether these criteria had been met. They were not provided with the numeric rubric that is part of each exercise. Exercises were submitted in two ways. (1) Images of the final sketch were exported as "JPEG" files which were then electronically uploaded to the Canvas educational support program. (2) CogSketch files with the ".skw" file extension were transferred to memory sticks at the end of each lab session by students. Exercises were manually loaded into the gradebook tool that is part of the CogSketch software.

Grading of exercises was done through Canvas using the SpeedGrader tool. This tool allowed the instructor to survey the entire sketch or zoom in to examine sketch details. It also allowed the instructor to sort through a collection of images quickly, provide comments, and enter a score. Because CogSketch provided feedback to each user, no additional comments were given during the grading process.

4. Results

Deploying CogSketch on tablet PCs in the laboratory environment impacted teaching and learning efficiency as well as the social dynamics in the classroom. A summary of potential drawbacks, neutral outcomes, and benefits pertaining to lab preparation, in-class use, tear-down, and grading are summarized in Table 2.

Areas of Teaching	Possible Benefit	Neutral	Possible Drawback
Lab preparation			Tablet desktops must be cleaned-up.
In-class use		Transition from paper to tablet use was smooth.	It can be more difficult to quickly diagnose worksheet problems on a tablet PC.
	Fewer barriers to beginning worksheets.	There was minimal off-task use of tablets.	The program did not always recognize changes made to a worksheet.
Lab tear-down		Tear-down time was not noticeably increased.	
Grading and reporting	Worksheets removed the need to decipher handwriting.	No perceptible changes in grading time.	Incorrect submissions must be opened and graded.
	No need to handle and track hardcopies.		

Table 2. Summary of effects on teaching efficiency.

Beneficial effects were observed in the areas of in-class use, lab tear-down, and grading and reporting. During class, few if any students were unable to start an exercise. This observation was common to all three quarters of teaching. Using CogSketch worksheets also limited the need to decipher cryptic handwriting because labels and annotations are added as typed text. Finally, the digital submission process produced less paperwork to collect, sort, carry, staple, identify, and return to students.

Areas of teaching where drawbacks were felt included lab preparation, in-class use, and grading and reporting. The combined influence of CogSketch worksheets and tablets made it more time-consuming to track problems with student work. One issue is that the tablet screens are relatively small compared to traditional paper-based exercises. Another issue is that the feedback presented by CogSketch is detailed (Fig. 1). Taken together, it was more time-consuming to evaluate the feedback and to link feedback to a problem in a student's sketch. This experience was common with the exercise that concerned the scaling of geologic time and was noted every quarter. Another drawback is that in some cases, CogSketch failed to recognize corrected glyphs and/or labels that were added and updated by the student. Typically, between zero and two students, per lab session, had a problem completing a sketch. However, most students had figured out the correct answer. Typically, saving, closing, reopening, and requesting feedback from CogSketch updated the worksheet. Restarting the worksheet from the beginning also solved the problem and redrawing a sketch only took a few minutes. Lastly, between 1% and 12% of the students submitted their work in the incorrect file format. This slowed the online grading process because the files had to be downloaded and opened in CogSketch before they were graded. The largest number of worksheets submitted in the wrong file format occurred during the first quarter of teaching.

Using CogSketch on tablets produced no effect in some areas of teaching. In class, the transition from paper to digital exercises was smooth because there were enough tablets for each student in the class and students appeared to remain focused on finishing the lab assignment. Packing up tablets and styluses was not different from packing up other types of teaching supplies such as maps. Most notably, the author's approach to grading did not allow for any perceptible gains in efficiency.

The use of CogSketch exercises on tablet PCs also influenced group, instructor–student, and student–student classroom social dynamics. A summary of these observations is presented in Table 3. A potential benefit was an observed increase in group focus. Possible drawbacks were experienced by all participants. Most notable was the nature and frequency of student questions. The overall perception is that the frequency of questions from students

decreased. This observed behavior is consistent with the findings of Garnier et al. [2014] who noted that students did not need much help with worksheets, but the interpretation that this behavior is a drawback is at odds with their findings for learning gains. This inconsistency is discussed below. Other observations indicate that the nature of the questions shifted toward solving both perceived and real technology-related problems with tablets and with CogSketch. However, questions varied with exercises. With topographic maps, there were almost no questions from students during any of the quarters. Questions regarding the scaling of geologic time were focused on precisely positioning glyphs on the worksheet and those regrading structural outcrops were both technology-related and related to the exercise content. Such questions occurred during every quarter of teaching. Finally, students interacted with each other less-frequently when using the tablets.

Participants	Possible Benefit	Neutral	Possible Drawback
Group[students]	Increased focus when using tablets.		
Instructor–student interaction			Frequency of student questions decreased.
			Instructor role shifted toward technology support as students used tablets.
Student–student interaction			Decrease in student interaction.

Table 3. Summary of effects on social dynamics.

5. Discussion

Integrating tablet-based exercises into the lab was fairly straightforward because the program is easy to learn how to use and the available exercises have learning outcomes that could be combined with traditional paper-based laboratory assignments. Exercises are also relatively short and can be inserted into a traditional laboratory design which allows exercises to be added or deleted as time allows. The section below considers how alternative techniques and methods of deployment could improve on the application of CogSketch in laboratory courses.

Examining student work in class may be best managed by using additional technology. For example, it may be possible to use software, such as SynchronEyes, to allow the instructor to view student work on their own tablet or laptop and remove the need to look over the shoulders of students in the classroom. Other drawbacks such as managing tablet desktops, maintaining clean worksheet files, and fielding questions about technology will need to be absorbed into the teaching process and can potentially be offset by efficiency gains made in areas such as grading.

The instructor used the pass/fail rubric and grading method described above to manually grade CogSketch exercises. This style of grading allowed students to finish and submit their work before the end of the lab period with fewer technical issues. As it turned out, the instructor could grade worksheets as fast as CogSketch. This was because additional comments were not made, scores were not tallied, and some of the common minor mistakes, such as mislabeled glyphs, were ignored. As such, using the automated grading tool in a mixed-format course with a quantitative rubric should yield a modest increase in grading efficiency.

One approach to significantly improving efficiency would be to remove traditional paper-based exercises altogether. All exercises could then be graded automatically by CogSketch and students would not need to submit JPEG files. There are other potentially important benefits that may be amplified by this approach. For example, using more worksheets will require students to seek automated feedback more frequently and may move students through lab assignments more quickly, it may also influence which students receive assistance from the instructor. For example, the instructor may be able to focus their attention on students who are struggling with fundamental concepts and thus are making limited progress on their lab assignment as a whole. Finally, more frequent use of CogSketch and tablets could motivate some students to become more self-sufficient when solving basic technical problems.

Teaching geoscience labs using only CogSketch worksheets will require the development and testing of new exercises to target the multiple learning objectives that are commonly covered by a typical laboratory assignment. This is a significant drawback to only using CogSketch worksheets. One approach to this daunting problem is to take on laboratory topics individually and create batches of exercises for a specific topic. These exercises could be deployed

as a single “digital-format” lab among paper-based labs, but the entire set of exercises could be graded by CogSketch. This will change the work flow for grading lab assignments and result in perceivable time-savings for the instructor.

The reduced frequency of content-related questions and the reduction in student–student interaction may be amplified by increasing the number of worksheets used per lab. However, it is also possible that such behaviors will not dampen potential learning gains [e.g., Garnier et al., 2014] generated by using more worksheets. Other positive effects like increased focus and the benefits of instant feedback [see Miller et al., 2014] may simply compensate for working in a less collaborative environment.

6. Future Work

The qualitative summary of observations presented above highlights several interesting elements of social dynamics and teaching efficiency that may influence learning. Lines of future investigation should focus on accurate and quantitative characterization of increased student focus and the ability of students to begin exercises. The causes of these behaviors may not be simple. For example, improved focus could be related to receiving immediate feedback, using the tablet, worksheet content, or some combination of these elements. Similarly, there are also several explanations for the apparent lowering of barriers to getting started on exercises. These include receiving automated feedback, the content of the exercises, the ability of students to tackle spatial problems, or some combination of these reasons. Until CogSketch’s influences on classroom social dynamics and teaching efficiency are better understood, it will be difficult to predict if and how increasing the number of worksheets per lab will influence learning among the different student populations taking introductory geoscience courses.

7. Conclusions

CogSketch worksheets and tablet PCs were deployed in traditional face-to-face physical geology lab sections and used along with paper-based worksheets with minimal adjustment to the instructional dynamics of the course. Worksheets were easily integrated into a traditional geoscience laboratory design and content, and produced a mixture of potential benefits and drawbacks with regard to teaching efficiency and classroom social dynamics. Potential benefits include increased group focus and reduced barriers to starting laboratory exercises. The mixed-use course design and rubric used here did not allow for noticeable gains in grading efficiency. However, significant improvements in grading efficiency may be achieved by modifying the course design to increase the proportion of CogSketch worksheets used in class. This approach also has the potential to improve learning by making it possible for students to move through exercises more quickly and by allowing instructors to focus their attention on students who need it most.

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