Visualizing Sketch Data to Support Learning Sketching

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ABSTRACT

Visualizing data to support learning outcomes has been shown to have significant value in many domains, but skills such as sketching are still taught in traditional settings with little to no use of data. There is an opportunity to mine sketch data taken from students practicing sketching fundamentals on a stylus-based intelligent tutoring system, and visualize that data to support learning sketching. This paper discusses our approach in developing and evaluating a modular data visualization system to support both sketching instructors and students. In our evaluation we found that the system was well designed and supported many tasks such as tracking progress and personalizing instruction, but failed to support more open-ended and creative tasks like pairing students for peer-based learning. We learned five principles from which to further improve the system that have implications for similar systems that visualize education data.

ACM Classification Keywords
H.5.2. Information Interfaces and Presentation: User Interfaces Graphical user interfaces (GUI); K.3.1. Computers and Education: Computer Uses in Education Computer-assisted instruction (CAI)

INTRODUCTION

Data is transforming the way that technology can help people gain actionable insights across many different domains, but sketching education is one that remains untouched. Numerous tools have been developed to visualize educational data in an effort to empower both teachers and students and improve learning outcomes in various settings [11, 13, 22]. To date, there has been little to no development of similar data visualization tools for subject areas in the arts such as drawing or music.

This research is aimed at exploring data visualization for drawing - Specifically design sketching, also commonly called conceptual sketching or sketching for short. This type of drawing is taught primarily to improve visual communication skills in domains such as industrial design, architecture, transportation design, concept design, and mechanical engineering [18]. Consulting with sketching instructors in Industrial Design curricula at Georgia Tech has revealed common challenges associated with teaching design sketching. For example, several instructors at Georgia Tech we consulted with mentioned the struggle in motivating students to practice. Sketching is a skill that requires extensive practice for improvement, and it is not uncommon to assign students over 100 sketches of a basic primitive (like cubes) for homework (Figure 1). This is perceived by many students as a chore and they are not motivated to put in the necessary work [10]. Bandwidth is also a common issue in not just sketching instruction, but education in general [7]. Class time is limited, and it is difficult for instructors to give individualized feedback and support to every student while also continuing to teach techniques. In a studio environment, it is more common for instructors to give feedback all at once using successful student work and poor student work. This in turn can create a stratification of more motivated good students and discouraged bad students which can reduce the overall learning outcomes of a class [8].

Figure 1. A student practices sketching cubes in 2-pt perspective in a traditional sketching studio course.
There is an opportunity to improve the ability of sketching and drawing instructors to have a better sense of student engagement, give more personalized instruction to students, and have better learning outcomes in their courses. This is possible through an online web-based intelligent tutoring system for sketching called PerSketchTivity (Figure 2) that has already been built and deployed [24], along with an interactive visualization system that displays data on student performance and lesson completion. The latter component is what this paper introduces.

![Figure 2. PerSketchTivity allows users to practice sketching basic forms using a stylus-based device. Sketch data on forms such as these primitives is collected and can be visualized for further insights.](image)

**PRIOR WORK**

In 2010 there was a proposal from John Collins at Harvard university to form a new subdiscipline of education called education informatics which involves the discovery and communication of education information. He argues that data obtained in educational settings can be very useful in improving education as a whole [4]. There has also been a push towards more personalized and self-regulated learning in the Web 2.0 era [12] and education informatics can enable this.

Widely used online educational platforms such as Duolingo and Khan Academy are paving the way for effective use of education informatics in learning foreign language and general K-12 subjects respectively. A study concluded that an average of 34 hours of using Duolingo was just as effective as a university course in Spanish [23]. Another study explored how individual learning curves could be obtained from Duolingo data using mixture modeling, yielding surprising and useful insights about the learning process [22]. A study of low level education data of the Khan Academy platform found that higher level learning information could be inferred from it, helping teachers obtain new insights that were previously difficult or impossible to obtain [13].

An information visualization system for course management systems (CMS) called CourseVis has been shown to help instructors quickly and more accurately understand the behaviour of students, and was found to be very useful for managing successful distance courses [11].

While some work has explored creative ways of obtaining sketch data via sketch recognition, such as through human computation and games [7], this data was not being used to improve learning outcomes in a sketching course or sketching ability in general.

This work is novel in that although collecting this type of data has been possible for some time, it has primarily been used for building classifiers and recognition algorithms, and has not been used specifically to improve learning how to draw or sketch. To the best of our knowledge, there has never been a prior attempt at visualizing education informatics specific to sketching instruction. Traditional pedagogy has largely consisted of subjective interpretation and feedback on student work in studio environments with little to no quantitative data. This work is both an exploration and a first attempt at designing and building a viable information visualization system for use in real classroom environments by sketching instructors and students. The work will have implications for further development of the system itself, but could also influence the design of similar systems in artistic domains such as fine art and music. Ultimately, it could influence the design of any and all systems that visualize data to improve education.

**SCENARIOS**

In an effort to better communicate how a system such as this could be used, we have provided three scenarios which demonstrate why the system would be helpful to both students and instructors.

**Scenario 1: Student Motivation**

Caitlin is a student in a beginner design sketching course. She was made the example of poor work in class today in front of her peers which was humiliating for her. She has become very unmotivated and helpless because she feels like she is among the worst in the class and she is not improving.

When she uses the data visualization system she finds specific areas she needs to improve on and specific forms she should practice. She becomes much more motivated to get better as she begins to see she is actually making progress after all. When she compares her current sketches to sketches 3 weeks ago, there is a noticeable difference in quality.

**Scenario 2: Peer-based Learning**

Professor Nelson is seeing a large achievement gap in his sketching course. Some students excel while others are far behind. He’d like to try a peer learning [1] exercise today in class to mix things up and encourage collaboration.

He uses the data visualization system to pair up students in groups with complementary skills. Each group of two students must work together to sketch a series of concepts in class that day. It is very effective at reengaging students, as they learn from each other and feel less self-conscious of their own work when working together.

**Scenario 3: Distance Learning**

Natasha is from a low-income neighborhood and has had little opportunity to study the arts. She likes drawing but feels like she has a hit a plateau without any direction from mentors. While Youtube videos are a great source for learning, she does not get any feedback on her work from them.
She begins using the online platform PerSketchTivity on her tablet to improve her fundamentals and get real-time feedback on her progress without an instructor. She can also use the data visualization system to track her progress and plan what she will work on next. She sees significant improvement in her ability in a short time.

**SYSTEM DESIGN**

The design of our visualization system was in part driven by specific requests from a sketching instructor at Georgia Institute of Technology who has PerSketchTivity deployed in his introduction to sketching course. He requested being able to see progress of individual students in completing exercises, along with change in their sketching ability over time. He cited assistance with grading as his main purpose for using the system. In order to better explain how this information can be provided, it is important to explain how we extract the sketch data, and to provide a definition of ”mastery” of sketching ability.

**Sketch Data**

Our sketch data is gathered via sketch recognition in real-time. Sketch recognition is the automated recognition of hand-drawn diagrams. PerSketchTivity is web-based and relies on hardware input in the form of a stylus on a device such as a Wacom Cintiq drawing tablet or a Surface Pro. This hardware input is translated to X, Y, and Time values which can be analyzed and fed into sketch recognition algorithms.

By using template-matching algorithms like Hausdorff [14], we can determine accuracy of specific forms, and by using gestural features like change in angular rotation [16], we can determine the smoothness or line quality of sketches. Those metrics along with speed, form the basis for more high-level insights about sketching ability.

**Mastery of Sketching**

Mastery of sketching ability relies on many different physical and cognitive systems including perception [3], motor function [19], and spatial reasoning [20]. Using sketch recognition, we can determine metrics like accuracy, smoothness, and speed, which domain experts describe as the most important reflections of sketching ability: [9, 2, 15]. These metrics are the core metrics used for visualizing sketching ability and change in sketching ability over time (Figure 3).

**Design**

As previously mentioned, our system has two different versions, one for instructors (Figure 4) and one for students (Figure 5). Both feature overviews and, allow for further exploration into the information.

Because each sketch is saved, they can be reviewed (Figure 6), and even replayed if the student or instructor wants to view them to assess progress.

The system allows for details on demand [17] in the form of highlighted pieces of data and overlays (Figure 7). Due to the subjective nature of this domain, we believed visual structures would be more insightful than specific values, however having specific values available is useful for grading purposes.

**EVALUATION**

Our system was designed iteratively and relied on semi-structured interview research method [21], in which we
gained qualitative data from students and instructors progressively which helped to improve the system.

Participants
Both instructors and students were recruited for our study. We recruited three sketching instructors, two of which are from Georgia Tech and have PerSketchTivity deployed in their classrooms. The other was a drawing instructor at Stanford with over 30 years of experience teaching drawing and a long-term consultant on the project. All six students we recruited were in graduate school, ranged from novice to intermediate in sketching ability, and had some familiarity with the system.

Protocol
The students and instructors used separate versions of our prototype. While the students had access to data specific to them, the instructors had additional access to overall course data and specific visualizations depicting overall student performance.

Instructors
We asked the instructors to imagine as if they were using the system in their course, and had them perform specific tasks that ranged from straightforward to more open-ended and creative. Examples include:

Find which student has the lowest overall line quality.
Find which student has completed the fewest lessons. The most?

What is the weakest form that the class needs to practice the most?

You are trying to pair two students in an assignment today in class. You want a student with poor line quality to be paired with one with great line quality so that they can learn from each other. Which two students would you choose?

Students
Similarly, we asked the students to perform their own set of tasks.

What do you need to improve the most? Accuracy, speed, or line quality?

Which form do you need to practice the most? Choose 3 you’d like to work on today

How are you doing compared to the class average?

The instructors and students were additionally encouraged to think aloud and share their experience with us. We followed up the task with a semi-structured interview to gain more data about their individual needs and overall impression of the system.

We codified the results in to categories based on what needs were being filled and which ones were not, with a separate “wish-list” category for features and capabilities that should be added in the future that may be outside the scope of the current research agenda.

DISCUSSION
Our user study was rich in qualitative data that will help us continue to improve the design of the visualization system. We found that the straightforward tasks were completed easily with minimal error, however the system did not adequately support the more open-ended tasks. Instructors and students were either confused by those tasks or chose arbitrarily. Below are some of the themes and factors to consider that stood out from speaking to both instructors and students.

Scalability
Sketching courses can have quite a large range of sizes. One instructor said his course was over 60 students. For this reason, we have to consider how dense some visualizations such as scatter plots and bubble diagrams can get with information. This led to us abandoning donut charts to depict visual encodings that include individual students.

Worth noting is the fact that students should ideally be identifiable in the visualizations as this could help the instructor personalize their instruction.

Time
Our visualizations depict improvement in mastery over time. This was understood by the users, but several suggested taking it farther and allowing for time lapses and specific breakdowns of time periods (i.e. week 4 to week 8 and only Lines). It is important to show progress over time as it can be a motivating factor for many students.

Expected Learning Outcomes
One instructor described not knowing what an ideal learning outcome would be based on this data, in terms of thresholds. This instructor devoted a portion of her course to sketching but is not an expert herself.

"Where should the students be at Week 4, and week 8? I’m not as much of an expert so it would be nice to see where that threshold is and if it’s being met" - Instructor 2

Comparison Features
Our initial prototypes did not have comparison features, but this is something users requested in the semi-structured interviews. One instructor suggested being able to compare two students using the radar charts. (overlapping radar charts). One student wanted to be able to compare their performance between specific shapes / lessons. We believe this is what will empower instructors to instruct their courses more creatively.

Visual Design and Layout
Our visual design and overall modular layout / organization is effective and several users made positive comments about it.

"It's very clean, and I like how it's organized. I think that works well." - Instructor 1

"It's definitely readable, I like the color choices" - Student 3

"I really like the design of this. Really cool soothing design and I really like it." - Instructor 2

There was only once instance of confusion regarding the radial chart, as our initial version did not make it clear which was the student’s mastery and which was the average class mastery. Better use of colors and layering in our most recent version of the system helped considerably (Figure 8).

CONCLUSION
In this paper, we present an information visualization system that supports learning sketching. The system will utilize sketch data acquired via sketch recognition from an intelligent tutoring system. The system allows both students and instructors to view progress in specific lessons, mastery of sketching ability over time, and compare their progress and mastery to the class average. Our evaluation showed the system was designed well, and was successful in providing this information effectively, but more work must be done to empower instructors in more open-ended tasks like pairing students. We learned some principles that will assist us in further developing the system and could have implications for similar systems that visualize education data.

FUTURE WORK
We intend on developing more nuanced visual encodings which better empower instructors and students to find more detailed information about performance and mastery of sketching. The data being visualized currently could be described as low-level data, however it is the high-level insights that this data leads to that can be more powerful for influencing educational outcomes [13]. Better interlinking along with comparison tools could empower instructors to engage in creative new ways of instructing the students, such as a peer-based learning activities [1].

We also intend to explore gamification in the system and the data we are visualizing could translate very well to gaming elements such as levels, skills, and unlockable content. Gamification has been shown to increase student motivation and engagement when designed well [6, 5].

We will deploy the visualization system to our existing intelligent tutoring system PerSketchTivity for more extensive usability testing in real classroom settings. We believe real deployment with real data will drive more visualizations and changes to existing visualizations that will further improve the system.

ACKNOWLEDGMENTS
We thank Dr. Andruid Kerne and the whole teaching team of this course for guiding us to complete this project.

REFERENCES


