Everyone Can Sketch: Reviving Hand-drawn Sketching with an Intelligent Tutoring System

Abstract
Sketching is a powerful method for exploring ideas and communicating those ideas to others in disciplines like design, engineering, and education. Conventional pedagogy for teaching this skill has limitations in terms of instructor bandwidth, individualized feedback, and students who struggle with low motivation and self-efficacy. The skill itself has been abandoned in the curricula of many disciplines. An intelligent tutoring system can leverage sketching pedagogy to give students personalized feedback outside of classroom hours, which can potentially improve self-efficacy, motivation, and creativity in the students. Additionally, such a system can allow for curricula that have abandoned drafting and free-hand sketching to once again include it as a fundamental skill for students to learn.

We have built a system called SketchTivity which includes intelligent interactive lessons, challenges, and games that teach sketching fundamentals. We have deployed the software in design and engineering courses over the past two years and have found it to be an effective system that can improve students’ sketching ability in dimensions like accuracy, line quality, and speed. Ongoing work will be focused on developing more advanced lessons, creative challenges, and measuring more nuanced effects of the system on students.
Author Keywords
Human-Computer Interaction; Intelligent Tutoring System; Sketch Recognition; User Experience Design; Sketching; Creativity; Creative Self-efficacy

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
Drawing is a valuable skill that can improve visual communication ability and benefit internal thought processes [19], among many other benefits.

This research is largely focused on improving access to a form of drawing known as design sketching or conceptual sketching, which is often shortened to just sketching. Sketching is a tool for visual communication and idea generation. It has practical purposes in many disciplines including design, engineering, science, research, and education. Students are usually taught how to sketch free-hand, that is without the need for rulers or other tools, in an effort to encourage fluidity and rapid idea generation. Despite it’s inherent value, it is not often taught formally outside of design disciplines such as Industrial Design. Many other disciplines like Mechanical Engineering have largely abandoned it in favor of teaching CAD software skills.

Background and Motivation
Sketching is traditionally taught in studio environments by experienced instructors. However, valuable expert feedback from instructors can become less available as classroom size increases and less accessible beyond classroom and instructor office hours [6]. An additional constraint is that for studio environments that involve students sharing their work to the rest of the class, those students who have low self-efficacy tend to be less motivated to participate and share their work. Sketching as a skill requires extensive practice (Figure 1) and is significantly affected by self-efficacy [1] such that students with low self-efficacy are less confident in their ability, unmotivated to practice, and tend to be discouraged by their more skilled peers [10]. This problem affects people of all ages and may be rooted in childhood as many children seem to decline in spontaneous art from around age 7 [9]. This decline has been found to be caused by a decrease in self-efficacy as it relates to sketching and artistic pursuits in general [18].

SketchTivity improves upon traditional sketching pedagogy by providing real-time feedback to students via sketch recognition. Sketch recognition is the automated recognition of hand-drawn diagrams by a computer. It may be possible to greatly improve student sketching ability, motivation, and creative self-efficacy with this approach, while empowering human instructors to give more personalized feedback and instruction within their limited bandwidth. Additionally, this approach may allow for a more diverse and inclusive audience to learn sketching, not just those attending universities and enrolled in specific programs.

Related Work
Related work in this area has included other sketch-based intelligent tutoring systems for drawing [5, 4, 12, 2] and computer-assisted art applications [7, 15, 8]. However, this work is unique in that it focuses specifically on design sketching, and the system teaches it in a way more analogous to teaching a language of visual
communication, rather than teaching how to sketch only specific forms. Students can learn fundamental skills that can be used to sketch anything from their imagination. In this way, the system has a broader impact and focus on creativity than other tutoring systems.

**System Features**

SketchTivity is a web-based system built in HTML5. This allows for use on a wide variety of devices and operating systems, which is ideal for the long-term deployment and evaluation of the project.

**Interactive Lessons**

The interactive lessons are arranged in a mastery-based [3] approach. They cover sketching fundamentals like lines, circles, planes, ellipses, 2-point perspective, cubes (Figure 2), cylinders, etc. They utilize sketch recognition algorithms to give real-time feedback on the accuracy of forms as well as line quality (smoothness) and speed.

**Challenges**

Challenges allow for students to begin trying their sketching skills in creative exercises that test their ability to transfer knowledge (Figure 3). These open-ended tasks can be done in any number of ways, and are therefore interesting approaches to measuring creativity and idea generation.

**Profile**

The student and instructor profiles visualize data gained from the system on performance over time and lesson completion (Figure 4). This could potentially empower students to better self-regulate their learning [17] while also empowering instructors to personalize their instruction.

**Arcade**

A game called ZenSketch has been developed that allows students to practice their line work (Figure 5). More games will be developed to assist with fundamental sketching skills. These games are intended to increase self-efficacy and motivation to practice in the students.

**Deployment**

The system has been deployed in two courses at Georgia Institute of Technology - An Introduction to Engineering CAD course, ME1770, intended for engineering students, and a beginning Sketching + Modeling course, ID1418, intended for first year industrial design students.

The first course, ME1770 Engineering Graphics and Visualization, is a mandatory course for engineering first year undergraduates. The traditional ME1770 sections, taught between aerospace and mechanical engineering, are taught in two parts. The first part focuses on isometric and orthographic sketching, with dimensioning and creating working drawings for manufacturing. The remainder of the course focuses on 3D Modeling software programs (e.g. SolidWorks). These traditional sections serve as the control group. It is primarily a software skills based course. The pilot “experimental” sections are aimed at mechanical engineers and focus primarily on product and mechanism design. Though addressing similar software skills, the pilot seeks to abstract deeper meaning in the pedagogy, concentrating more on the students ability to visualize concepts and translate them into effective visual communications rather than teaching only simple sketching and CAD software. A key differentiation is that the pilot sections teach with more focus on developing the students ability to draw realistic and detailed free-hand sketches while still teaching them the necessary CAD skills learned in the traditional sections.
The second course that utilized SketchTivity is a beginner sketching course for undergraduate Industrial Design students, ID1418 Beginning Sketching + Modeling, that sought to introduce first year industrial design students to the basics of freehand sketching and model making. As part of the curriculum, the students were all required to supplement their lectures and analog sketching practice with practice sessions using the SketchTivity platform.

**Evaluation Protocol**

The ME1770 pilot studies of SketchTivity typically included freshman (age 18-19). Class sizes were 40-45 per section in the ME1770 course and around 60 students in ID1418. By recruiting participants within the same classes, we effectively controlled for instructor differences as both groups had the same professor(s). Students were informed that they were participating in a study to evaluate a particular teaching technique. However, they did not receive information about the individual techniques. The recruited participants were randomly assigned to two conditions - with or without the software.

For the ID1418 course, students had logins to the system and were required to use the system weekly, with a recommended weekly practice session of about 40 minutes per week. Students were free to use a drawing tablet or laptop of their own, but a limited number (20) of Wacom Cintiq drawing tablets were also provided for students’ use as well through a drawing lab. Students in this course were evaluated using qualitative focus groups, and their usage of the system (attempts for each exercise, sketch data, etc.) was monitored and stored in a database.

**Findings**

The system has been formally evaluated over the past two years, and has resulted in several conference publications [20, 21, 11], demos at EVA 2016 [22], a book chapter [23], and an accepted journal paper upon revisions [14].

We found that the students using the software had increased sketching and visualization self-efficacy when compared with students who were using traditional pen and paper [20]. We also found that students sketching speed and accuracy improved significantly through the use of the system (p < 0.001) [13]. Statistical significance remained when we examined progress on each form independently (p < 0.05) and each student independently (p < 0.05). Motivation also seemed high as all students submitted more than the required number of sketches to complete the lessons.

Qualitative data in the form of feedback on the user experience design of the system has been very positive and has aided in continuous design improvements. From the initial results, all sections had a generally positive opinion on the sketching portion of the course. In addition, self-assessment of confidence in sketching, creativity, and visualization is greatly improved. The students feel that this method of learning will greatly benefit them in their future engineering career. In particular, the students seem to appreciate the real-time feedback as well as the provided scaffolding of the perspective grid and lines. These aids help them grasp perspective more easily and allow them to practice more forms in a shorter period of time than traditional practice methods.

**Ongoing Work**

Our findings to date have been promising in regards to the efficacy of the system to improve sketching ability, motivation, and self-efficacy in the students. Ongoing research questions relate to how improvements and knowledge gained via the system can truly transfer to
subsequent sketches. In order to test that we are building more advanced open-ended lessons and challenges in which students can begin really using their skills and flexing their creativity.

It has been found that exercises closer to real-world scenarios can better facilitate learning [16], so there will be an emphasis on realistic scenarios where creativity and visual communication is important, such as the design of products or communicating ideas visually that must be understood by others, such as sketching a map, or explaining an abstract concept.

**Trajectory of Research**

A comprehensive study is planned for the 2017-2018 school year at Georgia Tech where the system will be deployed in the same courses. In addition to measuring effects of the system on sketching ability in students, there will be a heavier focus on measuring creative self-efficacy and divergent thinking. Sketching ability data will be gained via sketch recognition features, and sketch data in the creative challenges will be acquired via the online platform and subsequently analyzed in terms of divergent thinking, and fluidity of ideas.

The study will also continue to include control groups who do not use the software in an effort to see the impact of the software in comparison to conventional methods for teaching sketching.

**Acknowledgments**

The authors would like to thank the National Science Foundation for funding this research through grant number 1441331, as well as all of our previous and current collaborators at Texas A&M and Georgia Tech. Special thanks to the many domain experts in design sketching that have been consulted on the project and continue to provide valuable input.

**References**


