First-Year Civil Engineering Students' Knowledge and Confidence in the Use of Visualization and Representation Tools to Solve Engineering Problems

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This complete evidence-based practice will describe how first-year engineering students are encouraged to use sketching as a method of problem solving. First-Year Civil Engineering students come to their programs with a diverse array of skills and motivations. Previous research by the authors indicates that students often choose engineering as a major due to guidance counsellor and parental recommendations based on their performance in math and science courses in high school and the professional prospects afforded by an engineering degree. So, we might expect that students arrive in college relatively confident in their skills in mathematics, but perhaps less so when it comes to writing or the other skills necessary to succeed in engineering courses. Further, their knowledge of the engineering profession itself is often minimal.

The authors have noticed in particular a marked resistance to engagement at any level to use visualization or representation to solve engineering problems. This introductory study evaluates a group of first-year civil engineering students at Syracuse University with regard to their attitudes about their current skills, the skills they see as most important for success, and the specific tools of visualization with which they have familiarity. Based on the results of a survey given to the students at the beginning of the semester, skills that students are not familiar or comfortable with when they enter the program include making sketches, diagrams, graphs, etc. and using them as tools to learn, to investigate, and to document. This paper will describe the results of that survey and the introduction of four specific assignments into the first-year engineering design course that are designed to both improve these skills and foster appreciation for these skills. The authors will evaluate the impact on the students' perception of their abilities and their level of comfort in using these visualizations skills to solve engineering problems.

Literature Review and Background

In the 1950's when the United States was focused on the space race, engineering education in the U.S. was reformed. In 1955 the ASEE "Grinter report" on evaluation of engineering education emphasized the importance of graphical expression, including sketching, as a means for creative thinking, spatial visualization, and the ability to convey ideas [1]. However, with the advent of computer aided design (CAD) in the 1970's, free-hand sketching was eliminated from the curriculum in most undergraduate engineering programs in North America [2], [3].

Much of the current literature in representational competence is in science education rather than engineering education, especially in chemistry and physics. In the engineering education literature, studies that show improved ability in CAD oriented engineering design classes have received more attention. Recent studies of the connection between manual drawing and descriptive geometry instruction in CAD classes include studies by Utal et al.[4] and Bairaktarova [5] . The benefits of free-hand sketching on engineering problem solving ability have been quantified in previous studies [6], [7] yet very few engineering programs have returned to teaching free-hand sketching. In 2005 a survey of engineering and engineering technology programs was done while the engineering technology department at UNC Charlotte was developing a new four-year engineering technology program [8]. The broadly summarized reasons for including hand sketching in 40 out of the 77 responding institutions surveyed are:

- A necessary skill for communicating thoughts/ideas without access to a computer
- Effective method of teaching technical drawing concepts (views, dimensioning, etc.)
- Necessary prerequisite to drawing in CAD
- Isometric hand sketches provide great visual insight
- Helps students' visualization skills
- Necessary skill for field sketches and drawings created when no computer is available
- Effective vehicle for introducing geometric relationships
- Sketching is how engineers think through a problem
- Is a vital skill for the professional success of today's students

In a study of collaboration among practicing architects and engineers, and the preparedness of contemporary engineering students, Olsen and MacNamar interviewed engineers and architects involved in projects around the world. They identified drawing and representation skills as a critical skill for engineering students[9]. In interviewing highly successful structural engineers engaged in the design and construction of projects of architectural note, large and small across the globe, questions were posed about how well American engineering curricula are doing in positioning students for success in the profession. Those professionals identified students' skills and attitudes in visual representation as a significant concern.

> *It might surprise students to learn that the practicing engineers interviewed for this project replied with one voice to the questions "Do you draw? Is drawing an important tool for communication in your practice? Should engineering students be taught to draw?" "Yes, yes, and yes" was the almost universal response* [9].

In the series of interviews, the importance of both drawing and model making for communication about design and for design work, was repeatedly emphasized. Richard Garlock of Leslie E. Robertson and Associates observed that drawing is fundamental to the development of design ideas for engineers and expressed concern that not enough engineering students develop their freehand drawing skills, and further argued that the capacity to both sketch, and a willingness to use sketches to test out ideas and throw away nine out of ten of those ideas is critical if engineers want a seat at the table in the design process [10]. Hans Schober of the German-based firm Schlaich, Bergermann and Partner discussed his habit of making a rough 3D model in Rhino, which he then prints and sketches over when tackling a new conceptual problem [11]. Guy Nordenson (principal of New York engineering firm GNA and Professor at Princeton University) notes that the engineers at his firm use drawing *and* models to investigate and communicate design ideas amongst themselves and with their architecture collaborators [12]. Xavier De Kestelier talking about the in-house engineers at architecture firm Foster + Partners noted that they were quick to adopt the typical design tools such as 3D printers and the laser cutter [13].

The argument that the engineering student must engage in drawing and other modes of representation to achieve success in design is an old one. Writing in 1959 about his thoughts on engineering education Ove Arup, founder of the international engineering giant ARUP, declared

“The Author believes firmly that the civil engineers should learn more solid geometry, freehand sketching, and appreciation of architecture.” [14]

In this paper the authors focus specifically on developing the skills in first-year students to use sketching as a method of problem solving. Our experience is that skills emphasized in every engineering class, starting with the first year, receive more attention from the students. The students develop the habit of “always writing out the assumption” or “always graphing data when analyzing data”, or in this case “always drawing a freehand sketch”. As can be seen in our study, introducing sketching in the first-year class also improves student attitudes towards their own skills.

Context

The cohort of students in this study are first-year students at Syracuse University who are pursuing a civil engineering major and as such enrolled in ECS 101 M001 Introduction to Engineering (Civil). The group was made up of 62.2% male students and 37.8% female students. Only 5.4% were international students, and 37.8% of the students self-identify as belonging to an under-represented minority community (32.4% Hispanic students and 5.4% African-American students). The students were asked to participate in a pre- and post- survey to evaluate their attitudes about engineering skills generally and visualization in particular. 44 Students responded to the pre-survey and 24 to the post survey, 37 students completed the course.

The course, ECS 101 Introduction to Engineering (Civil), is a required course for civil engineering majors. The learning outcomes for the course are that students: get exposure to civil engineering, career opportunities, and the engineering education process; develop an understanding of the engineering code of ethics, professional licensing, and an engineer’s responsibility to society; get exposure to several of civil engineering’s supporting technologies, including infrastructure, soil mechanics, transportation, structures, and materials; develop the skills to “learn” course material through a combination of in-class and out-of-class activities; and learn about engineering from design challenges.

Pre-Survey

The purpose of the pre-survey was to establish some baseline information with regard to student attitudes towards their own skills and those skills they saw as important to the study of engineering. We also wanted to understand what if any software, tools, or apps to which the students had some exposure. The survey was administered by sending an email link to all students in the course in the first week of classes and 44 students completed the survey. The results of the pre-survey are presented in Figures 1-5. Naturally with a small sample sizes it is important not to parse the results too-finely, but a number of very broad conclusions may be drawn from the survey.

When asked about their confidence with regard to the skills they were bringing to the study of engineering (Figure 1), a majority of students were somewhat confident or very confident in their mathematical ability, skills in making a graphic presentation (such as PowerPoint), and their written work. In contrast a majority of students were somewhat unsure or very unsure of their ability to make a digital representation or visualization (defined as using any program or app to manipulate photos, or make drawings, diagrams, or graphs). Further, a plurality of students was not sure about their skills in graphic representation (defined as making sketches, diagrams, or graphs by hand).

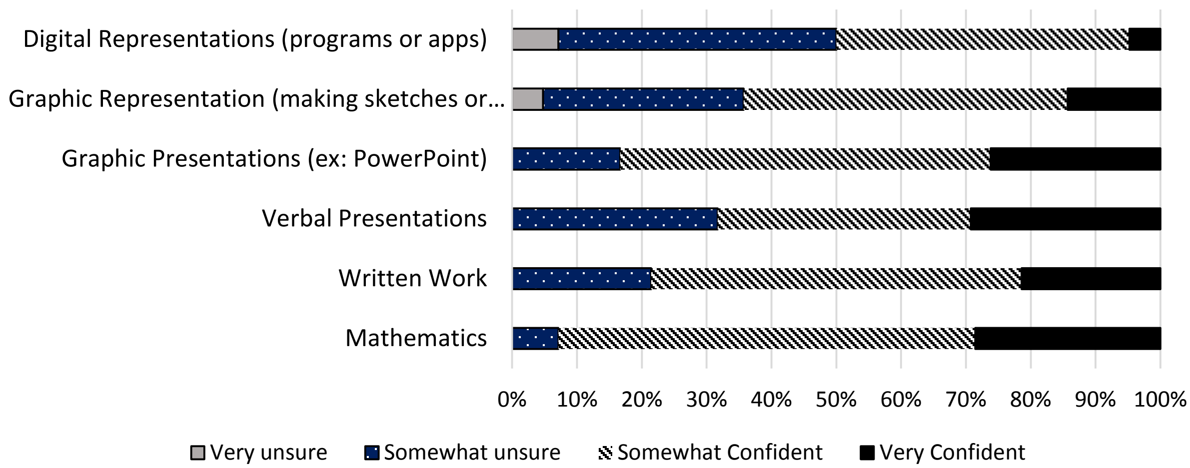

Figure 1
Pre-Survey Q1: As a new engineering student rate your confidence with regard to your skills in the following areas

When asked to rank the importance of the same set of skills for success in the study of engineering, students were remarkably clear in their opinions as seen in Figure 2. Over 85% of students ranked mathematics as a critical skill that a student could not succeed without, with the rest ranking it as important. For all the other skills listed above between 30 and 45% of students listed the skills as critical skills and the vast majority of the remaining students listed them as important. This result suggests that while students definitely rank mathematics as the single most critical skill for their success, the majority of students do see the importance of the other skills. This is a very encouraging result.

The next set of questions presented in Figure 3 attempted to breakdown students' attitudes with regard to how they use their various skills and to what degree they see those skills as teachable or learnable as opposed to innate talents. Here again we see some differentiation between attitudes to mathematics versus representation or visualization skills of various kinds. All the students who answered the survey agreed that they can use math to find the answer to a problem and 65% of them do not agree that mathematics is an innate talent. When it comes to representational skills however, only 50% of students think they have good spatial reasoning and over 60% are not sure if spatial reasoning can be developed or sketching and drawing can be taught. This is a concerning result and aligns with the authors' experiences when trying to encourage students to create drawings and diagrams as tools to both help them solve problems and present solutions in sophomore and junior level courses.

Figure 2
Pre-Survey Q2: To succeed as an engineering student rank the relevance of the following skills

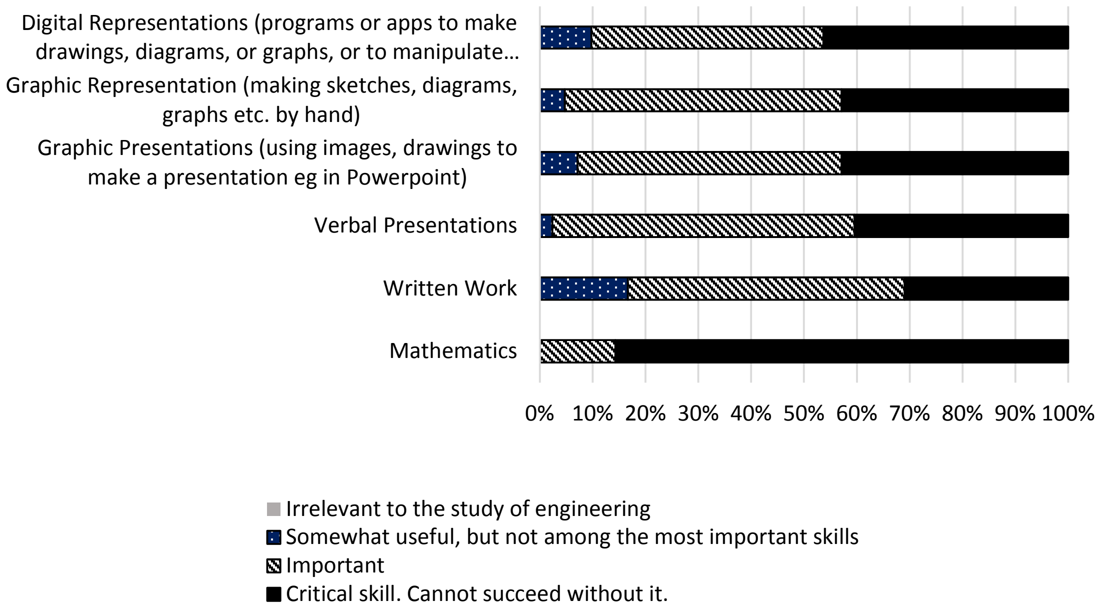

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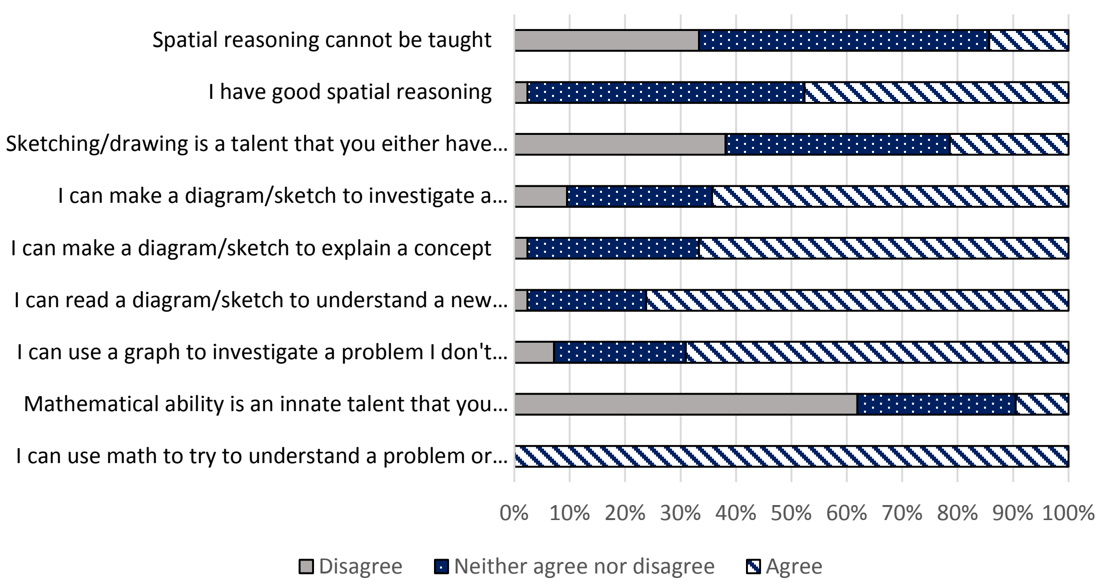
Figure 3
Pre-Survey Q3: Do you agree/disagree with the following statements



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The students also reported about their exposure to software for engineering specifically and representation more generally. The results (more detail in Figure 4) can be broadly summarized as showing that the students are largely unfamiliar with the representation tools of the discipline (AutoCAD, MicroStation, and Revit) and have some exposure to Microsoft Office applications (with most students describing themselves as at least a regular user of PowerPoint). In a separate question (Figure 5), students reported about their use of social media apps to generate visual content. Instagram, Snapchat, and YouTube were the most common tools, with 95%, 85%, and 75% of students respectively describing themselves as regular or expert users.

Figure 4

Pre-Survey Q4: What is your familiarity with the following software programs or tools to create content

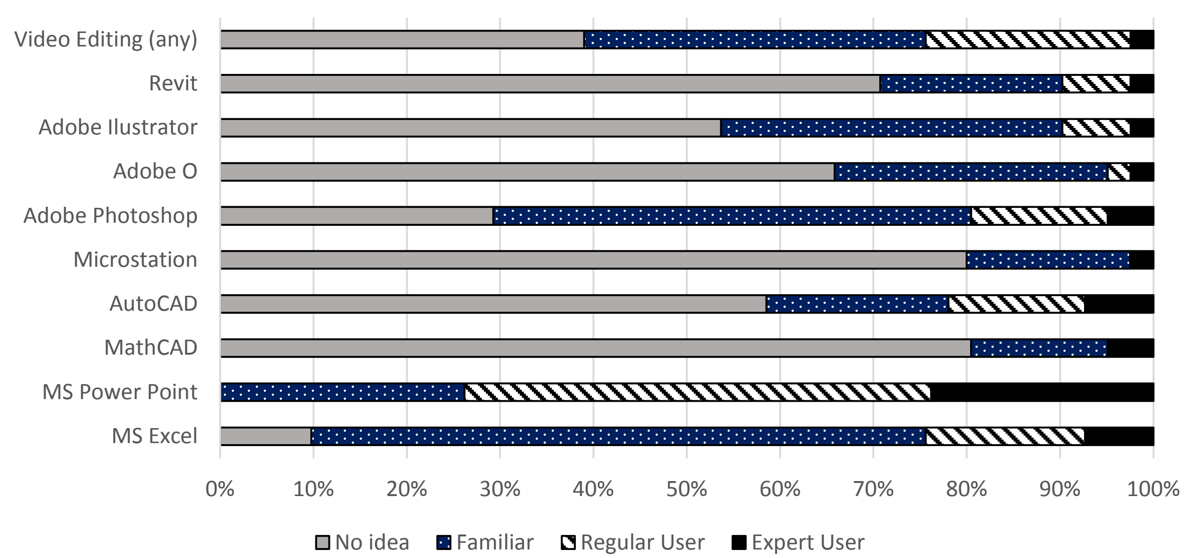
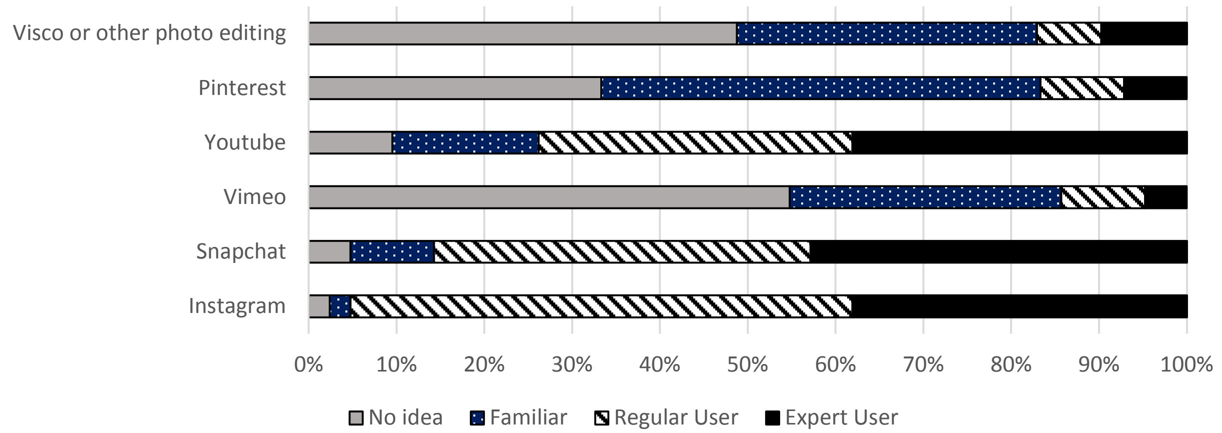


Figure 5
Pre-Survey Q5: What is your familiarity with the following apps/platforms to create content



Intervention/Class Activities

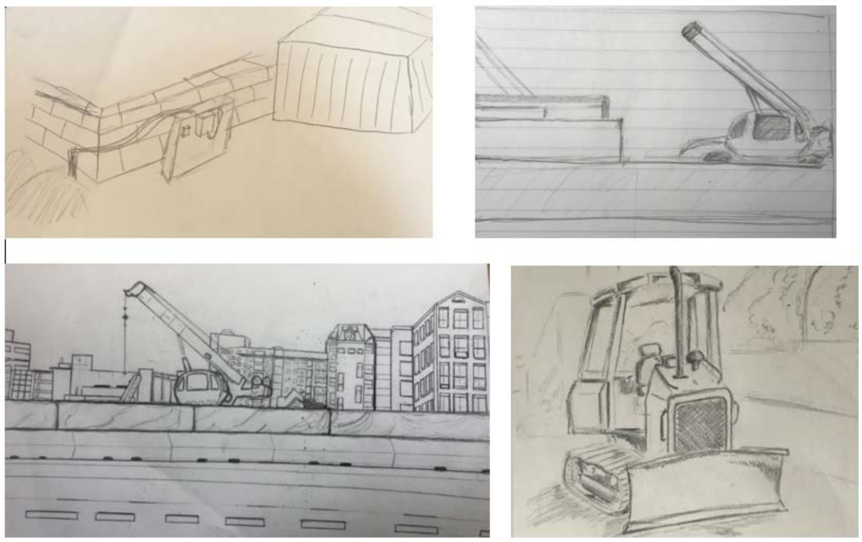
To address the authors' concern that students were not engaging in visualization (particularly hand sketching), a set of class activities was designed for ECS 101 in order to foster a culture of both drawing and engaging with representations (drawings, photographs, diagrams, etc.) of real world engineering artifacts. These activities encompassed using digital tools of the profession and hand sketching as graded portions of their course with the goal of improving their capacity to both solve the engineering problems at hand and to present their solutions. The authors used their combined skills in architecture and engineering to guide students to use pattern recognition and visualization.

Instruction in orthographic drawing by hand (three classes), AutoCad (three classes and a tutorial), and Excel graphing (two classes) were given during the semester. Additionally, the students were required to keep a portfolio of sketches and to use orthographic and hand drawings, AutoCad representations, Excel graphs, and PowerPoint slides with both images and text for the two major group projects in the course.

The first project was to design a shopping mall with a number of constraints and to present their design to a "client." The second project was to either design a bridge from a defined amount of material with specific criteria or to analyze an engineering failure and build a prototype that displayed some aspect of the failure. In each of these projects, the students were required to present hand sketches done in the early design phase when they were deciding what their final design would look like, a final AutoCad representation, and Excel graphs representing data used in their design. While these project briefs have been used in this introductory class for the past four years, the use of a "portfolio" of sketches and the requirement to include process diagrams and sketches in final presentations was new.

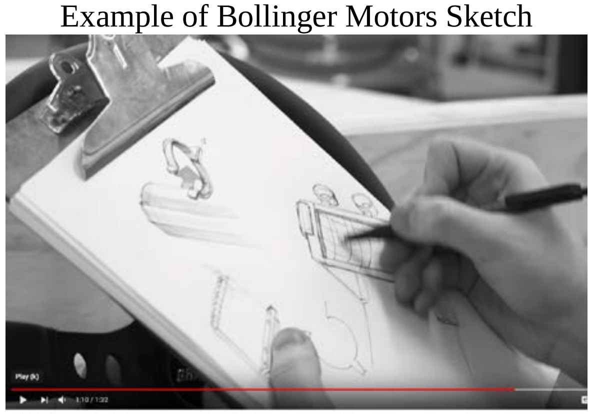
Over the course of the semester students were also instructed to use a sketchpad to do several smaller assignments. A picture of an engineering infrastructure was presented at the beginning of several classes (a truss bridge for example). Students were expected to "do their best" hand sketch and not to worry if their sketch wasn't "beautiful." Two volunteers showed their sketches after the five-minute sketching period. One homework assignment was to sketch any engineering artifact they liked on campus and another homework assignment was to sketch some portion of an active construction site on campus. The range of skills the students entered the class with varied greatly as can be seen in the student samples in Figure 6. The confidence of the students in their sketching ability, as measured from the pre-survey, is also indicative of this range.

Figure 6
A selection of student sketches from a campus construction site early in the semester.



Special attention was paid during instruction to making sure students knew that sketches used for problem solving did not need to be perfect, but must represent the ideas being presented. The concept that a sketch used in a presentation must be very neat and clearly presented was also emphasized. Examples of sketches from engineering company websites, such as Bollinger Motors, Figure 7 [15], along with examples of sketches needed in upper level civil engineering class work, were used during lectures, in class activities, and in homework assignments.

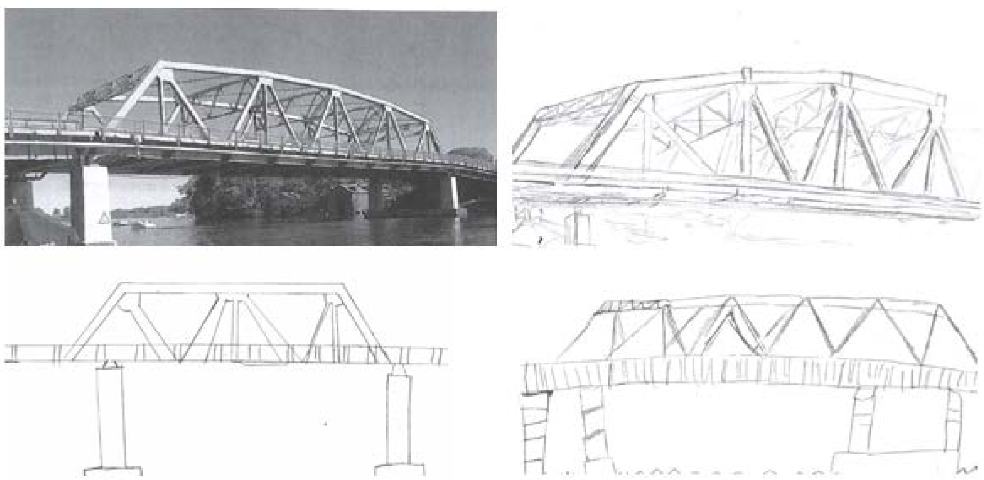
Figure 7
Example of Bollinger Motors Sketch



SEATING BUCK - Bollinger Motors

On the second exam, students were asked to draw a sketch of the bridge in Figure 8 and to "list three things that you notice about the picture that help you make a good sketch." The majority of the students responded with answers that included these terms: straight lines of the landscape/ bridge, size differences, comparison of the size of objects, parallel lines, perpendicular lines, analyzing details of objects, the fence/ rail/ support beams, and the truss. Three students, who had obviously had some prior instruction in drawing, used the terms perspective, vanishing point, lighting differences, and shadows. Three student samples in Figure 8 show the extremes in ability of the students.

Figure 8
Student sketches on Exam 2 of a truss bridge.



Showing students how professional and academic engineers use sketching as a problem-solving tool was done consistently throughout the semester. Examples used include truss analysis by method of joints and analysis of moisture content in soils. Thus, with these interventions, the increase in student confidence in their sketching ability in the post survey was encouraging.

Post-Survey

The purpose of the post-survey was to investigate students' self-perception about their own skills, the value of those skills, and any improvement in those skills over the semester. The survey was administered by sending an email link to all students in the course in the last week of classes and 24 students completed the post-survey. The results of the post-survey are presented in Figures 9-12. As with the pre-survey, the sample size means that only broad conclusions should be inferred.

In terms of improvements to their skills over the course of their first semester in college (see Figure 9), the students were more likely to report improvement in their confidence in their skills in graphic representation, graphic presentation and digital representation (almost 80% of students said all three had improved), than they were to report improvement in their mathematics (58%), their verbal presentations (54%), and written work (33%). In terms of the value that students place on their various skills as facets of their success in engineering educations (Figure 10) more students in the post survey considered digital representation (74% vs 42% in the pre-survey) and graphic representation (65% vs 42%) to be critical skills for success in the field. Reported attitudes as to the value of other skills were largely similar to those in the pre-survey.

Figure 9
Post-Survey Q1: This semester how has your confidence CHANGED with regard to your skills in the following areas

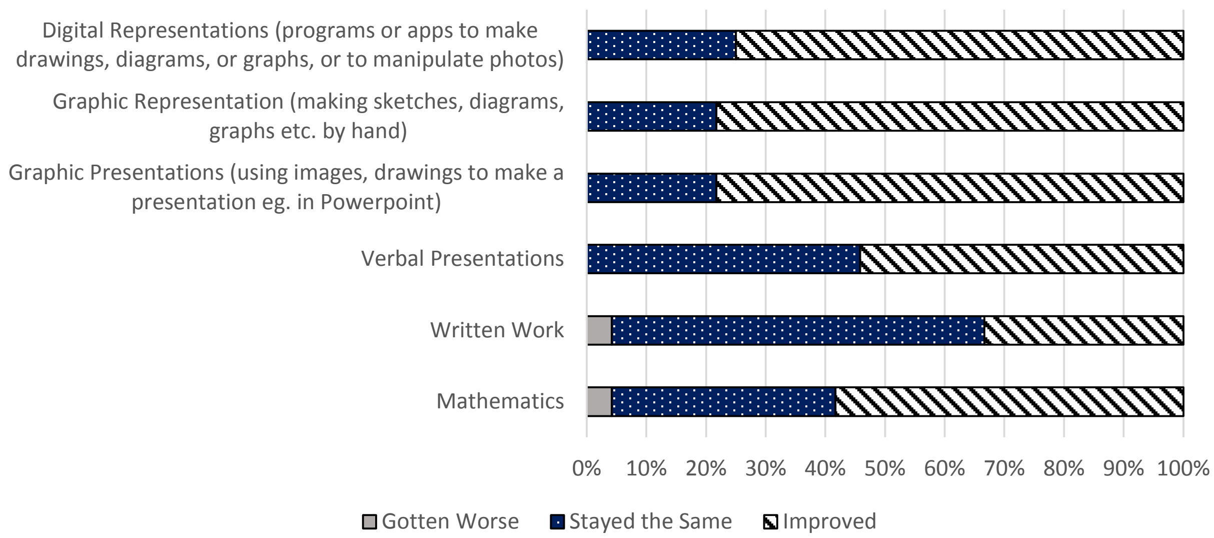


Figure 10
Pre-Survey Q2: To succeed as an engineering student rank the relevance of the following skills

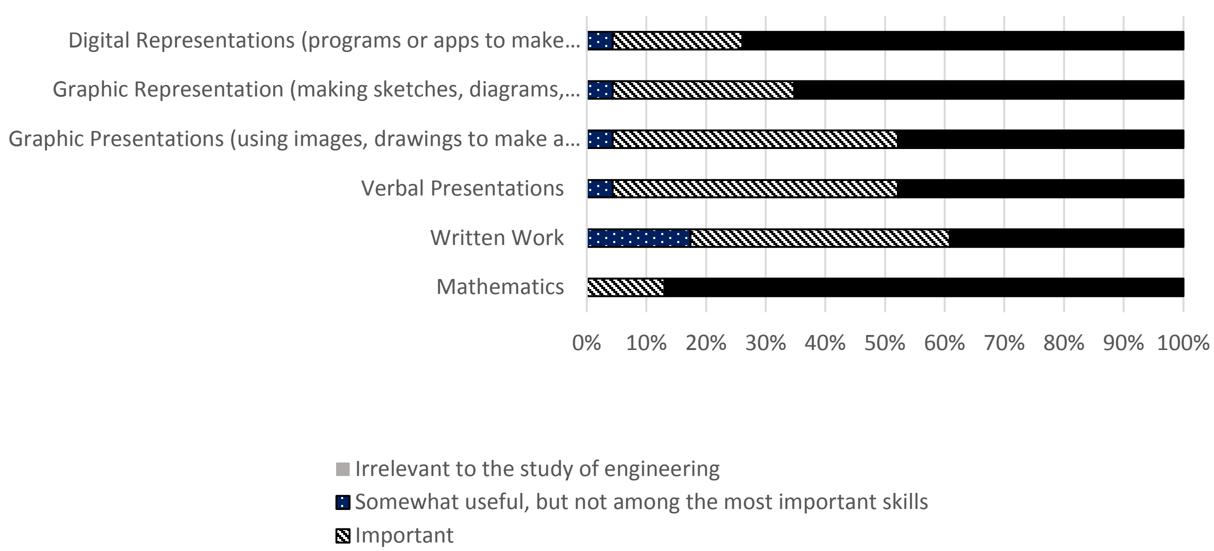
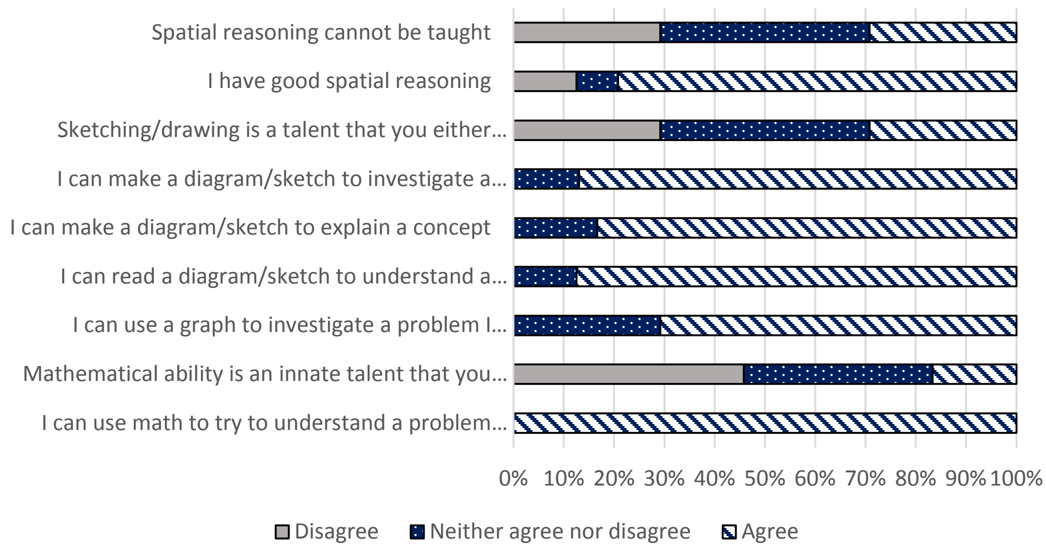
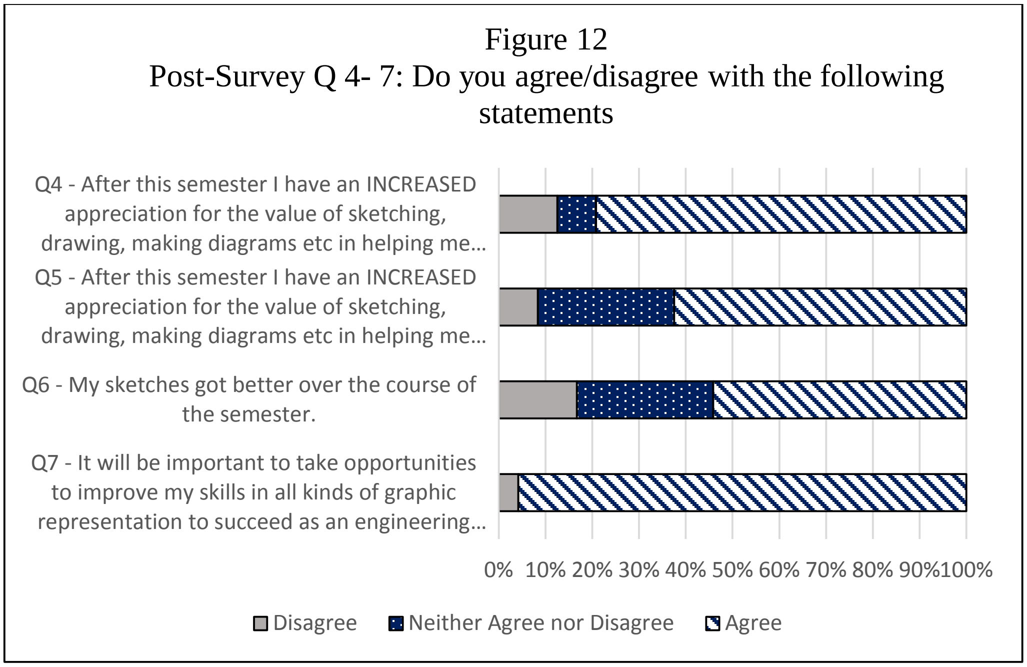


Figure 11 presents the post survey results of the same set of questions from the pre-survey presented in Figure 3. The only significant difference in attitudes that can be extracted from a comparison of the two are that students in the post survey were more likely (80% vs 50%) to say that they had good spatial reasoning, and marginally more likely to say that they could use a diagram, graph or sketch to understand a problem, solve a problem, or explain a concept.

Figure 11
Post-Survey Q3: Do you agree/disagree with the following statements



The final set of questions, presented in Figure 12, concern students' self-reported changes in attitude to the value of graphic representation. Encouragingly, the majority of students agree that they have an increased appreciation for the value of sketches and drawing to both do their work (~60%) and explain or present (over 80%) their work, and a slim majority (54%) of students reported that their sketches got better over the course of the semester. Very encouragingly, 95% of students reported that it will be important for them as they go through their engineering education to take advantage of any opportunity to improve their representation skills.



Conclusion and future work

This preliminary study shows that placing emphasis on the tools of visualization early in the engineering curriculum can yield positive results. Students self-reported an improvement in their skills and increased appreciation for the importance of those skills in their engineering education. Presenting hand drawing as a skill significantly increased the use of sketches in the students' work on exams, homework assignments, and projects. Future work, with this same cohort of students, to sustain the progress made during the introductory course will be done in two courses that follow, engineering statics and mechanics of solids.

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