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Persketchtivity: An Intelligent Pen-Based Online Education Platform for Sketching Instruction

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Design sketching is an important and versatile skill for engineering students to master. Through it, students translate their design thoughts effectively onto a visual medium, whether to produce hand-drawn sketches onto paper, seamlessly interact with intelligent sketch-based modeling interfaces, or reap the advantages of educational benefits associated with drawing in general. Traditional instructional approaches for teaching design sketching are frequently constrained by the availability of experienced human instructors or the lack of supervised learning from self-practice, while relevant intelligent educational applications for sketch instruction have focused more on assessing users' art drawings or cognitive developmental progress. In this paper, we introduce an intelligent pen-based computing educational application that not only teaches engineering students how to hone and practice their design sketching skills through stylus-and-touchscreen interaction, but also aide their motivation and self-regulated learning through real-time feedback.

Design sketching. Online platform. Engineering education. Visualisation. Creativity.

1. INTRODUCTION

Undergraduate engineering education and education as a whole in the 21st century is undergoing rapid change. For students to succeed, "ways of thinking and doing" would require students to think more broadly and attack problems from multiple viewpoints (SUES Committee 2012). The development of an undergraduate student's ability to incorporate diversity of thought and approaches will define innovation and creativity in the new millennium. From applying scientific methods and using formal reasoning, to performing aesthetic and social inquiry, the diverse application of multiple mental models has been shown to yield richer educational experiences, resulting in more diversely informed, and creative individuals (Glynn 1997).

Engineers need to be effective problem solvers and innovators. The difficulty is how to incorporate these critical skills into an already over-packed curriculum with limited resources. Innovation is generally only briefly addressed in engineering curricula. However, one's ability to innovate is not an inherent and fixed skill; it can be fostered (Torrance 1972, Mansfield 1978, Ma 2006). *The Engineer of 2020* recognises that creativity, invention, and innovation are indispensable qualities of engineering (Engineering 2002). Sketching is a critical part of this toolbox allowing engineers to visualise their ideas and to effectively communicate them to other engineers early in the design process.

The ability to visualise and draw combines multiple aspects of this educational paradigm. Leveraging learning modalities from the kinesthetic (muscle movement, muscle memory), and visual (spatial reasoning) aspects, drawing has the power to access multiple modalities of learning simultaneously in order to formalise and communicate ideas (Gardner 1983). Combined with current engineering education, drawing helps to access knowledge based in the applied sciences through aesthetic and social inquiry.

Creativity can be defined as the application of diverse inspirations to generate multiple new or novel ideas (Franken 1993), and drawing is a signifier or resultant by-product of the creative processes of the mind. Drawing and visual thinking has the power to unlock understanding of the sciences by serving as mental models and proxies. Used in combination with analysis and mathematical models, engineering drawing has the potential to enhance creative output. It is this cross-linking of modalities that leads to innovative concept solutions.

2. USER SCENARIO

To understand freehand sketch pedagogy and how the learning platform software is structured, it is best to describe a use case scenario on the learning progression or trajectory of an industrial design or engineering design student.

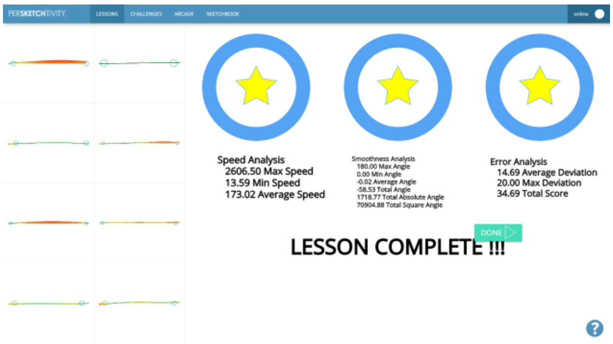

Figure 1: *A student receiving drawing feedback for Lines.*

2.1 2D Drawing Sheet Exercises: Lines, Circles and Squares

Barbara, a freshman mechanical engineering major, is taking an introduction to engineering visualisation and computer aided design course. The first topic of her class encourages learning visualisation through exercises and lessons in drawing basic shapes in perspective. The first assignment for this topic begins with a series of drawing exercises in the form of drawing "sheets". The first assignment sheet develops kinesthetic awareness and hand-eye coordination. Barbara is asked to connect dots using a digitising tablet and a new sketch recognition program, *Persketchtivity.* Students first develop their muscle memory by connecting the dots using freehand lines (see Figure 1). Upon completion, the software than analyzes the deviation from optimum and assesses a score.

In this manner, Persketchtivity analyses and continuously monitors Barbara's progress through several drawing exercises. These exercises include drawing Circles (see Figure 2), and Ellipses. These first drawing exercises are used to develop not only a "visual foundation" where students will build their skills, but also a kinesthetic one that gives students confidence to perform physical movements with consistency. Learning to perform these basic movements such as drawing accurate lines, circles, and ellipses are critical in subsequent lessons, where the students use these individual elements to visualise basic primitives in perspective.

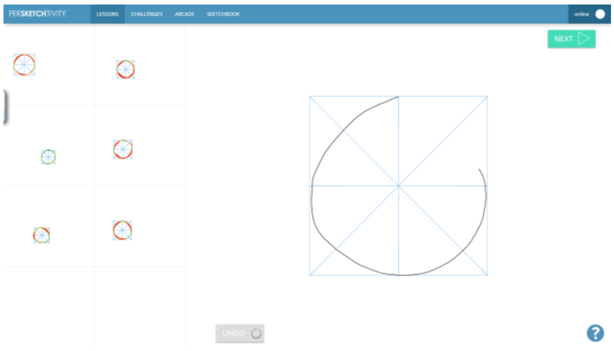

Figure 2: *A Circle Drawing Exercise.*

2.2 3D Visualisation Lessons: Cube and Basic Shapes in 2-Point Perspective

Barbara continues with subsequent lessons using Persketchtivity. The next drawing lesson involves understanding how to draw a unit cube in 2-point perspective. The benefit of learning this construction allows the student to visualise a single building "block" from which more complicated visualisations are built. Using perspective, optically and mathematically accurate representations of basic primitive forms can be taught. The next lesson (Figures 3 and 4) explains how to construct an accurate cube in 2-point perspective space, using simple, straight lines, which converge back to 2 points on a horizon line. Once this lesson is mastered, the next three lessons (Figure 5) all use the cube as scaffolding to help create accurate primitives (cylinder, cone, and sphere). The software determines the accuracy of the drawing by measuring deviation against construction lines (light blue), which the software provides.

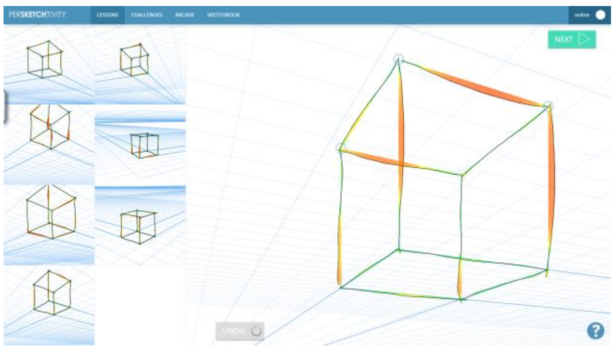

Figure 3: *Cube Construction in 2 pt. perspective.*

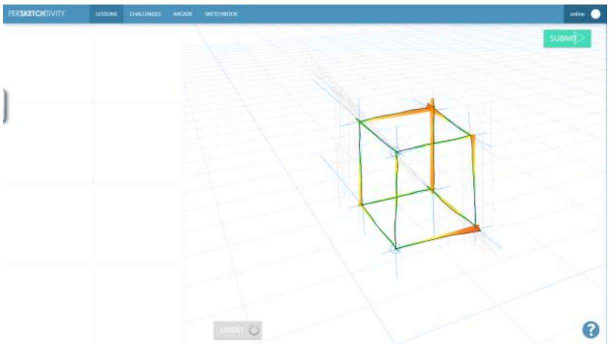

Figure 4: *A Cube Exercise & Analysis.*

2.3 Future Work: 3D Visualisation Lessons: Complex Basic Shape Combination in 2-Point Perspective

Armed with the confidence that Barbara can create basic primitives, accurate in scale and projected rotation, Barbara can now draw more complicated forms in any orientation. Using her imagination and strengthened visualisation skills, Barbara can now draw combinations of basic shapes that comprise more complex objects (see Figure 6). The role of the software is to help analyze the accuracy of the shape combination, and provide further help through rotations of the complex forms in accurate scale and representation.

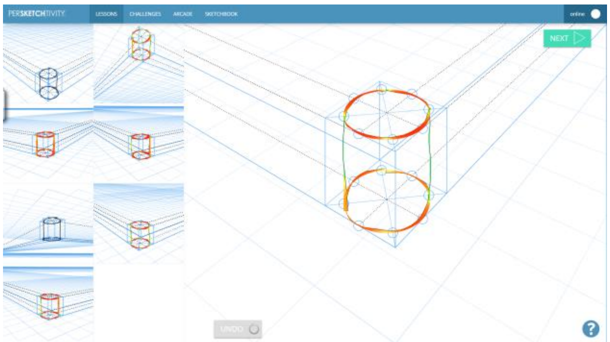

Figure 5: *Basic Shape Construction – Cylinder.*

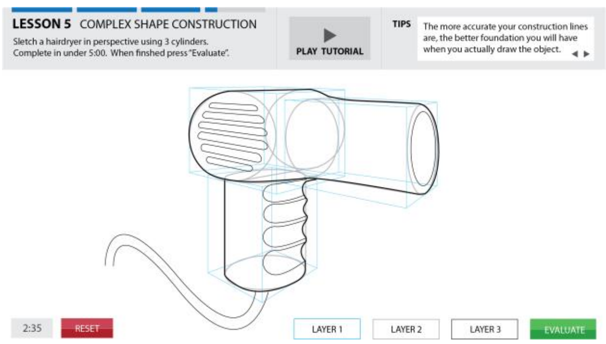

Figure 6: *Shape Combination – Complex Object.*

3. BACKGROUND

Visual representations such as CAD models and sketches possess several advantages over representations of the same object in text form. One of the main advantages of a visual representation is its ability to group useful information together (Larkin and Simon 1987). These groupings allow for further processing and eases the use of gathering the information needed to make inferences and allows a problem-solver to make connections between two representations in a way that would be difficult or impossible using only text. This may be a reason visual representations are more commonly used to represent engineering ideas (Atilola 2014).

The use of free-hand sketching and drafting has long been utilised in the early stages of idea generation and conceptualisation. However, as CAD technology and photography have become more advanced and easily accessible, these methods are increasing in use. As CAD modelling has become a more widely taught skill in engineering curriculum, sketching has begun to be used less, especially by students, and is often left out of early-stage design altogether (Schmidt et al. 2012, Ullman et al. 1990, Grenier 2008). Studies on Capstone Design courses have found an increasing preference for CAD renderings and photographs over sketches in these early stages of design by students unless specifically prompted to use hand-drawn sketches (Westmoreland et al. 2011). These were results of availability and familiarity of CAD programs and digital cameras.

The advantages of sketching are numerous and have been observed in numerous studies. Sketching:

- Promotes creative thought (Goldschmidt 1994, Goel 1995)
- Is economical, simple, and easily revised (Jonson 2002).
- Allows immediate visual and kinaesthetic feedback (Contero *et al.* 2009).

Sketching also has the major advantageous of being inherently ambiguous (Goel 1995, Stacey *et al.* 1999, Jonson 2002, Contero *et al.* 2009). Any one sketch can be interpreted a number of different ways, allowing for the sketch to be a source of creativity through the re-interpretations of the representations by the same person/group (Tversky *et al.* 2003) or for alternative representations by a different person/group (Shah 1998) as it frees the mind to examine the created construction now held by the sketch.

Multiple studies have shown that different types of representations provide access to very different types of information to designers (Suwa and

Tversky 1997, Casakin and Goldschmidt 1999, Kokotovich and Purcell 2000, Kavakli and Gero 2001, Kavakli and Gero 2002, Menezes and Lawson 2006). Other studies found that different representations were used for different purposes. For instance, architects tend to show sketches to their clients of the early-stage designs, but CAD models for the final versions (Schumann *et al*. 1996). This was coupled with a perception that designs presented in sketch are easily altered while CAD models are perceived as final designs and cannot be changed. Others studies showed that clients preferred hand sketches with high detail over other forms of visual representation such as CAD models (Macomber and Yang 2011). These preferences were also impacted by the complexity of the object being represented.

The early stages of exploring ideas (ideation) using freehand sketching pushes the mind to explore concepts in more freeform ways, "interpreting and re-interpreting" drawing concepts. This ability is not facilitated with current, traditional CAD software, which focuses on technical "drafting" versus freehand "sketching". The traditional tools merely use line strokes, i.e., weight and style (dotted / dashed etc.) to connote a spatial relationship. Their rigidity and high level of finish resolution, actually preclude new ideas, and stunt the learning of the student's ability to manipulate objects in space and improve their spatial reasoning. Freehand sketching actually encourages students to manipulate the object in space, and rotate them in their minds, whereas CAD drawing packages only show two-dimensional orthographic views of an object.

Conceptual sketching has practical purposes in that it is a very time-efficient form of communicating ideas to peers, teachers, or clients. It allows for the rapid exchange of ideas, and along with improving visual communication skills, can also benefit internal thought processes (Kahn *et al.* 2000); the introduction of drawing and visual communication skills has been shown to improve students' general academic achievement, as well as problem solving thinking, in an experimental study (Halim *et al.* 2012).

4. RESEARCH METHODS & IMPLEMENTATION

Persketchtivity was implemented alongside a new engineering visualisation class taught at Georgia Tech. This course piloted several sections of ME1770: Engineering Graphics and Visualisation, which is a mandatory requirement for engineering first year undergraduates. The traditional ME1770 course, taught between aerospace and mechanical engineering, is taught in two parts. The first few weeks focuses on isometric and orthographic sketching with dimensioning and creating working drawings for manufacturing. The remainder of the course focuses on 3D Modelling software programs (e.g. SolidWorks). These sections served as the control group. It is primarily a software "skills" based course. The pilot sections will be aimed at mechanical engineers and will focus primarily on product and mechanism design. Though addressing similar software "skills", the course seeks to abstract deeper meaning in the pedagogy, concentrating more on the student's ability to visualise 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 student's ability to draw realistic and detailed free-hand sketches while still teaching them the necessary CAD skills learned in the traditional sections.

The curriculum of the course can be thought of in two sections: (1) Drawing in perspective using both digital and analogue techniques, and (2) 3D Parametric Modelling using commercially available software. Persketchtivity will be actively utilised in the former section of the course, but could conceivably be used throughout the course for assessment. In order to adjust the curriculum in this manner, the special section will remove the instruction in basic isometric and orthogonal sketching and instead teach drawing by hand using both analogue (pen and marker) and digital (web based, tablet and stylus) methods.

The section involved approximately five to six weeks of instruction, progressing through the scenario modules (drawing exercises, cube construction, basic shapes, and complex form development). Persketchtivity was the digital foundation for the delivery of instruction, practice, and assessment of drawing and spatial ability. A single pilot section of the course (taught by Dr Linsey and Prof. Li) had both a control (non-Persketchtivity users) and experimental group (users of the software). The remainder of the pilot sections did not involve a Persketchtivity group.

Overview. Evaluation occurred by testing the sketch recognition tool within an authentic classroom. Additionally, the collection of qualitative data in the form of survey questions and focus groups supplemented quantitative results and provided for more thorough interpretation. Finally, additional measures allowed for the analysis of data by individual differences.

Participants. For the pilot section including Persketchtivity, recruitment occurred during a single undergraduate engineering class typically populated by freshman (age 18–19). Approximately 80 students over two semesters were recruited and received their choice of extra course credit or monetary compensation for their participation in the study. Class sizes were 40–45 per section. By recruiting within the same class, 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.

Research Conditions. The students were randomly assigned to one of two intervention conditions: (1) non-Persketchtivity condition (control), and (2) Persketchtivity software condition. Students in the Persketchtivity condition were taught briefly how to use the program (~15 minutes) and then they used it to complete their homework assignments. To eliminate teacher effects, all students received the same lectures on sketching; only the Persketchtivity software was taught separately. When one group of students is using Persketchtivity, the other group used paper and pen to work on their sketching assignments.

- *Condition 1 (Pen and paper control)*. In the traditional homework condition, students individually worked on homework problems. They received feedback as the instructor proceeded around the studio.
- *Condition 2 (Persketchtivity treatment)*. In the Persketchtivity condition, students worked on the same homework problems but rather than using traditional paper and pen tools, they used Persketchtivity. They drew their solutions with Wacom Tablets and received immediate electronic feedback. The software recorded each student's attempts and feedback as they worked through the process towards solution. Time spent using Persketchtivity were measured.

Quantitative Measures*:* The measures in this study include both formal, standardised measures and authentic classroom measures to capture different types of learning. Additionally, qualitative measures were conducted to more accurately interpret our findings as well as collect invaluable information regarding the experience of using such instructional software.

- *Demographic Survey:* A short survey collected demographic data regarding students' (1) gender, (2) race, (3) ethnicity, (4) first generation college student, and (5) age. These were used to explore potential individual differences in response to the intervention.
- *Engineering Design Self-Efficacy:* Design self-efficacy can be thought of as self-confidence in engineering design skills. A student with high self-efficacy tends to expend more effort towards the activity, to persevere when encountering obstacles, and to show persistence in order to attain higher achievement and capabilities (Pajares 1996). Additional education can help to improve self-efficacy towards certain subjects, and it has been shown that the amount of engineering experience is highly related to engineering design self-efficacy (Carberry *et al.* 2010). Self-efficacy has strong effects on performance and behavior, for example, impacting effort expended (Pajares 1996), persistence to accomplish specific goals, or perseverance in the face of obstacles. One with high self-efficacy will persevere with continued effort even with recurring failures because of their belief in themselves (Brown and Inouye 1978). An increase in self-efficacy often leads to additional effort and persistence (Bandura 1986). For this platform, a validated measure of design self-efficacy developed by Carberry et al. (2010) was used.
- *Engineering Design Creativity Skills:* Pre- and post-measures of students' creativity skills were measured using the high-face validity Peanut Sheller design problem that in multiple previous studies has been shown to be effective for assessing mechanical engineering student design and creativity abilities (Linsey *et al.* 2005, Linsey *et al.* 2007, Linsey *et al.* 2010b, Linsey *et al.* 2011a, Linsey *et al.* 2012, Tsenn *et al.* accepted).
- *Time Spent on Sketching:* Persketchtivity measured the time each student spends working in the program. Additionally, Students in both groups were asked to keep sketching logs. They were told that logs are an effective motivation tool and needed for the study. The logs from the Persketchtivity condition will also allow us to estimate the accuracy of the logs when compared to the logged time using the Persketchtivity program.
- *Authentic Classroom Measures:* On an individual in-class assignment, sketching activities was created as transfer tasks from homework. Experts in industrial design, either the instructors of the course or practicing professionals, then rated the sketches based on qualities that indicate improvement in spatial reasoning and attention to detail. These metrics include proper application of perspective, use of convergence, scaling, and rotation of objects. There are also visual detail metrics, such as line quality, economy, visual hierarchy, and aesthetic presentation.
- *Spontaneous Use of Sketching in Later Classes*: Follow-up surveys in ME 2110, a sophomore design course, will measure the frequency at which students use free hand sketching. The student reports in ME 2110 will also be evaluated to determine the effects of both using Persketchtivity and being taught how

to sketch. It is expected that some of the ME 1770 sections will not be taught sketching as extensively as other sections. Survey of the students determine if they are spontaneously sketching in their notebooks (for example when bored in class), for communicating ideas, or for other design projects.

Qualitative Measures

- *Efficacy Ratings*. After the sketching portion of the course, the participants in each group rated on a Likert Scale on how helpful they found the first portion of the course to be. In one of the Co-PI's previous research (McTigue *et al.* 2009), students' perception of the utility of an intervention was highly predictive of the interventions' impact on their learning. In short, regardless of the condition, if participant perceived the intervention to be useful, the participant performed well on the outcome measures.
- *Focus Group*. Immediately after the initial analysis of the quantitative data is complete and trends have emerged from the data, focus groups will be conducted to fully explore such trends. Students in the experimental section were invited to participate in a focus group, which discussed the students' experiences in using the sketch software program as well as the sketching portion of the course as a whole.

5. PRELIMINARY RESULTS

The authors have begun taking both qualitative and quantitative data as outlined in Section 4 above based on the first two semesters' of ME1770. Though preliminary in nature, and focusing on the separate nature of the experimental section versus the control group, the data collected to date has some significant findings.

ME1770 students were surveyed twice during the semester: once on the perceptions of the sketching portion of the course (at the completion of sketching instruction, which occurred after the first five weeks of the term) and once on the perceptions of the course as a whole (towards the end of the term). Interviews were also conducted with the TA's for both the "special" sections and the control sections of the course. Focus groups were also conducted on the student participants at the end of the semester to ascertain their feedback in using the software platform.

From the initial results, all sections had a generally positive opinion on the sketching portion of the course. While we are still processing quantitative data results, qualitative self-reported results coming from the focus group indicate strong preferences for the freehand aspects of this pedagogy. In addition, self assessment of confidence in sketching, creativity, and visualisation is greatly improved. The students feel that this method of learning will greatly benefit them in their future engineering career. In a concurrent study (Hilton et al. 2016), the authors also evaluated the students' spatial reasoning abilities as well as Self-Efficacy in Design and showed consistent improvements in all sections. This is significant as it shows that the students are both learning the skills taught in the traditional sections of the course as well as these new sketching abilities.

In addition to the qualitative focus groups, the authors can also show the progress and improvement in the sketches of the student participants. Before and after instruction pictures are shown in Figs. 7A/B and 8A/B. Even to the untrained eye, one can see the improvement in sketching technique and visualisation. Please note that the before "A" pictures are drawn from reality (from an object that is placed in front of them) and the after "B" pictures are of a product design of their own mind (from the imagination).

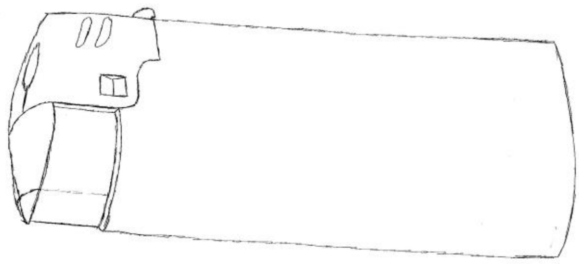

Figure 7A: *Student Sample – Before Instruction.*

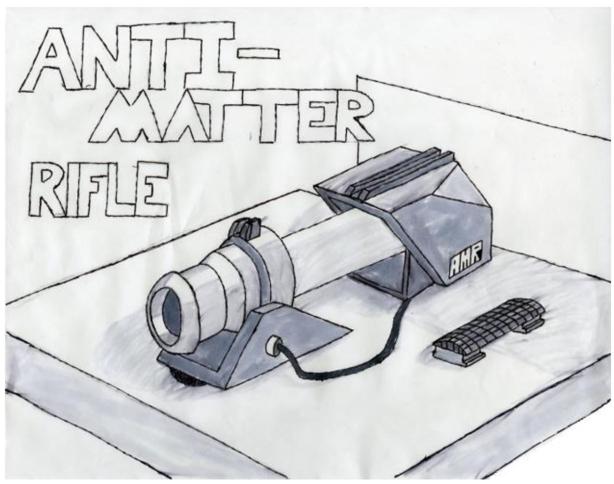

Figure 7B: *Student Sample – After Instruction.*

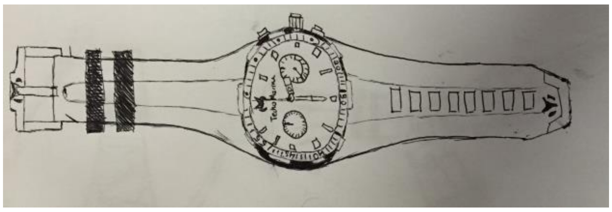

Figure 8A: *Student Sample – Before Instruction.*

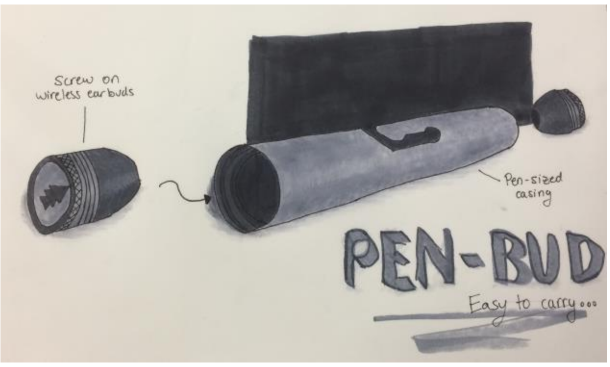

Figure 8B: *Student Sample – After Instruction.*

6. CONCLUSION AND NEXT STEPS

The authors are greatly encouraged by the findings, which have been consistent over the two semesters. The sketching instruction is well received and self-efficacy scores and survey results are encouraging. From this the team can conclude that the new sketching pedagogy should be adopted across all sections of ME1770 and would recommend switching to this new instructional approach. To this end, the team has begun training other instructors in these freehand methods, in order to scale to more sections of the course.

However, the scores currently focus mostly on the differences in pedagogy between the control– traditional CAD – drawing instruction versus the freehand, perspective drawing sections. Though there is a consistent positive opinion expressed on the new sketching pedagogy, the data has yet to be analysed to consider the specific impacts the *online platform* contributed to the survey results. The research team needs to collect more specific data within the experimental section to determine the effects of using the online Persketchtivity software vs. hand sketching instruction and homework. Initial qualitative interviews have pointed to significant added benefits, such as real time analysis of sketching practice, and the ability to repeat exercise quickly and fluidly in order to develop kinaesthetic (muscle) memory, but the team has yet to quantify the benefits of the platform.

On the online platform itself, development continues to progress. Besides the 2D Drawing Sheet exercises, which have been fully implemented, two of the basic primitives (cube, cylinder) have also been coded into the sketch recognition engine. However, the cone and sphere remain to be implemented. The next challenge will be the combination of basic shapes into more complex forms and creating the user interface that leads students through the subsequent exercises.

With further research and experimentation, the team hopes to continue to develop and refine the platform in order to better understand the correlation between visualisation, creativity and confidence.

7. ACKNOWLEDGEMENTS

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