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ENHANCING VISUAL THINKING IN A TOY DESIGN COURSE USING FREEHAND SKETCHING

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ABSTRACT

Engineering graduates in advancing economies are not only expected to have engineering knowledge, but also use them in creative and innovative ways. The importance of visual thinking has been critical for creativity and innovation in design. However, today's engineering students are proficient in detailed design tools but lacking in conceptual design and ideation, and engineering curricula needs to develop a more effective framework for teaching visual thinking. In this paper, we report our efforts to embed principles of design thinking and visual thinking practices, like McKim's "seeing, imagining and drawing" cycle [1]. We use a toy design course in mechanical engineering for our pilot study as a scaffold for introducing these principles in an engaging, creative, and fun environment. We introduced freehand sketching as a tool for visual thinking during the design and communication of concepts. We also report the impact of these changes through information gleaned from student feedback surveys and analysis of design notebooks. We use our findings to propose ways to provide the students with a set of balanced techniques that help them in visual thinking, communication, and design. An improved implementation of this experience is discussed and future work is proposed to overcome barriers to thinking and communication.

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INTRODUCTION

The process of design has always entailed the creation of various forms of representation [2]. Design is an iterative process of proposing and analyzing forms to achieve function. The generation of these forms—what Cross states as often being regarded as the "mysterious, creative part of designing"—depends on the ability of the designer to make internal visualizations, in the "mind's eye", and external visualizations [3]. Drawings is thus a key feature of the design process, and its role in the process changes through the different stages of design. Drawings range from the sketches made by the designer to conceptualize ideas [3, 4] to those made for the purpose of graphical communication [5] and for specifying technical details [6]. Goel [7] distinguishes non-notational, ambiguous conceptual sketches from highly notational, syntactic, and unambiguous technical drawings, suggesting that the former gives rise to three types of transformations:

- *Lateral transformations*, where the drawing or sketch can be transformed to another sketch that is related, but distinct from its prior sketch,
- *Vertical transformations*, where the idea in the sketch is reiterated and reinforced through detailing and annotation
- *Duplication*, which is a movement from a drawing to a type-identical drawing.

These transformations allow the designer to explore different ideas and variations of concepts, and are thus critical to creative exploration in early design.

There has been substantial evidence based on studies of student and professional designers that indicate sketching to be useful in concept design. Sketching helps designers handle different levels of abstraction, understand ill-defined problems [3], extend short-term memory for problem-solving [8], and aid the process of exploration that is essential to design [9]. While there are several tools and procedures that have been developed to help students of engineering design understand requirements, and generate and analyze their concepts, very few engineering design curricula engage in teaching sketching as a tool for design thinking. The traditional engineering views equate sketching to drafting, and thus dismiss it as an archaic tool replaced now by Computer-Aided Design (CAD) systems. However, there are certain restrictions that a CAD tool imposes on the designer during early design, resulting in fixation. There is thus an apparent disjoint between inferences from studies of conceptual design practices and design pedagogy.

In this study, we develop and test a pedagogical approach that introduces students to design thinking through the use of sketching, as a preamble to the detailed design stage where they apply CAD tools. We test these techniques in a toy design course, and report our preliminary outcomes in this paper.

Motivation

Conceptual design is largely seen as a cognitive process, with emphasis on visualization and externalization [10]. The term "visual thinking" has been defined differently in different fields like psychology, artificial intelligence and design. Goldschmidt [11] explains visual thinking from the design perspective as the process and reasoning behind the creation of ideas or form in design. The importance of sketching as a means of visual thinking was stressed as early as 1971 by McKim [12], who coined the term "idea-sketching". Cross [13] defines design ability in terms of internal and external visualization, and suggests that designers create drawings during early design not to communication ideas, but as a "thinking aloud" process.

The cognitive processes of conceptual design are restricted by the limitations of human memory. Miller's theory of chunking [14] states that human short-term memory is limited to seven chunks of information. Ullman suggests that in engineers, chunks can be equated to features, and provides evidence of the ability of expert engineers to store more information per chunk than novice engineers [15]. Quick sketching has been seen as a way to externalize these chunks, the sketches then serving as an extension to short-term memory [16]. In this way, it can be argued that increased skill in rapid sketching aids external visualization, helping store more information through these visualizations. The stress here is on rapid sketching, which is different from the detailed sketching often required of architecture and industrial design practitioners. It is not necessary to create a detailed sketch in order to effectively visualize a concept—a simple representation based on understanding of basic shapes and perspective is enough. Aligned with this idea Tovey et al. [17] implemented Rodger's "complexity level classification of sketches" [18] and found that sketches in the more basic levels are the most widely used for concept generation.

Ullman et al. [4] evaluate the importance of "both formal drafting and informal sketching" and observed the high occurrance of freehand sketches made by designers during early design. Among their conclusions, they acknowledged the need to train the design engineer "not only in the standard drafting skills, but additionally in the ability to represent concepts that are more abstract and best represented as sketches". Robertson and Radcliffe [19] have pointed out some potential risks of using CAD software too early in the design process, like circumscribed thinking, premature fixation, and bounded ideation. Goel's study on the use of computational aids to drawing [2] showed that designers did not like to use software when exploring ideas, since the software required them to commit to a design before they could generate its form. Various other studies performed on the use of CAD too early in design point to similar results [2,20–22]. In other words, CAD could become an "innovation killer" if designers are not trained carefully to avoid these risks and if they do not have other skills to complement the CAD process.

Purcell and Gero [23] argue that research in the role of sketching in design problem solving can be facilitated via cognitive psychology, in the area of short-term and working memory. Their research indicated that "enacted imagery", a combination of sketches and actions accompanying sketches seemed to occur with particular designers, or where creative solutions were found. Other studies on the advantages of using sketching for idea generation along with other traditional tools have revealed similar results, like van der Lugt's "brainsketching" technique [24] and Linsey et al.'s comparison of quantity and quality of ideas obtained from different techniques [25]. McKoy et al. report that sketching, and in general, pictorial tools, are more effective for representing design ideas than other techniques used in the early design phase [26]. In spite of these findings, it seems that freehand sketching is taught in contexts that do not encourage students to see it as a way of thinking and designing, but as a way to learn current CAD frameworks better, such as in technical graphics [27,28].

Related Work

The importance of teaching students sketching has been studied time and again in the context of design. Ferguson discusses the risks of creating "mediocre engineers" by training them to rely more on analytical skills and tools, while having a poor knowledge of engineering basics, non-verbal tools and "the art" of engineering [29]. Similarly, Ullman et al. noted that in the 1990s most engineers were trained on drafting but not sketching [4]. Twenty years later Linsey et al. [25] make a similar observation: *"In general, engineers are not taught to draw, and their skill in sketching may be lacking"*.

Yang and Cham's study of concept design and sketching in an engineering design course revealed that students created a high number of non-dimensioned sketches early in the design process [30, 31], but no significant correlation between sketching skill or quantity and the final design outcome. They concede that this deviation from the findings of Song and Agogino [32] could be due to the different focus of each course: the projects studied by Song had a higher emphasis on product design and market studies, while those studied by Yang focused on engineering design and prototyping. However, there does not seem to be evidence of students undergoing exercises that expose them to frameworks that combine sketching with ideation techniques.

However, in disciplines such as architecture and industrial design, freehand sketching is taught as a means for problem solving, idea generation and concept generation, as expressed in Bilda et al. [33] and Eissen and Steur [34]. For engineers concepts such as perspective sketching have been introduced only cursorily before CAD. To view sketching only from the point of view of CAD is to undermine its strengths, and to concentrate on the "enhanced representation" aspect of CAD.

Play

Albert Einstein is quoted to have said: "We can't solve problems by using the same kind of thinking we used when we created them". If current problems have been created by over-structured design processes, and tools like CAD, we should probably look for solutions by injecting child-like thinking through flexible processes and imaginative tools, in the form of play [35,36]. Play is critical for imagination, for creating a future that does not exist and for using innovation in engineering as a creative problem solving process. In addition, it has been seen that learning, whether related to products or processes, is enhanced when the experience of learning is made "fun" [37]. Students are more engaged in a learning process that encourages play and having fun. In the next section, we explain how we incorporate play into the learning experience in an attempt to foster creativity and innovation in the design course.

PROTOTYPING THE COURSE

"ME 444: Computer-Aided Design and Prototyping" has been taught at Purdue over the past 18 years. This is an optional course, which has benefited around 2400 students to date, and is application-oriented in that the students learn CAD concepts, and applied them to a course project to design an action toy with significant geometric and mechanical complexity [38]. This class has been directed especially towards developing a self-paced CAD learning content for students.

The course served a much-felt need during a time when CAD was a value-added skill for an engineer. In today's market, neither the CAD software platforms nor skilled CAD software operators are particularly rare commodities. With the rise in outsourcing, innovation has become the driving force behind the economy, and engineering education needs to update curricula to produce more creative engineers who will add value through innovation.

This course provided the right scaffold for the "learning by doing" approach, and thanks to the culmination of the course in the design of toys, was a natural choice to inject the aspects of creative exploration through fun and play. Inspiration from other courses on innovation and results from research on engineering education, design education and cognitive sciences was an important starting point [30, 39–41]. Our approach aimed to empower the students with frameworks for play, value-based innovation, and creation of concepts using the language of the designer: freehand sketching, at the appropriate stages in the design process [4, 17].

The new class continues to use the hands-on laboratory sessions to teach CAD (see figure 2). However, the lecture contents were modified to incorporate workshops for fostering collaborative learning, equipping students with idea generation techniques, and an understanding of play value [35], which is important for toy design. In order to encourage the divergent-convergent process and the generation of more innovative ideas, freehand sketching was chosen as the main tool.

If sketching can be considered to be 2D prototyping [4] we could say we are encouraging students to prototype earlier and cheaper in the design process, and enable them to "explore without risk". There are no modifications downstream for this class, which means students would still use CAD for detailed design, and the SLA machines for physical prototyping. Students would still be given a budget for printing and getting other components they would need. The core idea of the new approach is as follows:

- Teach students the CAD content they need to know to be proficient, but do not let them start the idea generation and conceptual stage of the project using CAD.
- Students will be allowed to create the CAD model of their design only after a few iterations of divergent and convergent concept generation/selection processes, using freehand sketching, design and visual thinking, and other tools provided through the play and toy workshops.

We thus maintained a parallel hands-on sketching and design thinking aspect to the students learning, alongside the computer-based training.

Creativity is also influenced by the environment where work is done. In a pedagogical environment, it is important to have a

FIGURE 1. TOYS DESIGNED AND BUILD IN ME444 IN PREVIOUS YEARS

space that is flexible, for instance, the ability to change the focal point of the interaction from one that is between the students and the instructor to one that is among the students: “Learning Studios” as opposed to conventional classrooms [42, 43]. In order to implement the new class approach we have taken advantage of the 6000 square feet of design and build space, and the Feddersen collaborative lecture hall, recent additions to the school of Mechanical Engineering at Purdue University. A classroom with a capacity for 120 students, with large tables facilitating in-class team work and overhead projectors for more flexibility of resources during lectures or workshops was selected. High ceilings and excellent illumination also contributes to improving the students environment in order to encourage them to be more creative [44].

It has also been shown that during the creative, concept generation stage of design, it is beneficial to have the generated ideas all displayed to the design students at once [12]. To prototype this idea for the purpose of the course, it was sufficient to extend the functionality of spaces that are traditionally not included in the category of “innovation spaces”, like the classroom [45]. We achieved this by the modification of seating arrangements in the room during the workshop sessions, and through the use of team-specific display boards for team members to share sketches of their ideas with each other. Instructions or hints pertinent to the entire class were at the same time displayed on the projection systems used for the lectures. Both these are shown in figure 3. As seen, the prototype setup allows design teams their own space for generating and sharing ideas, while visually not interfering with the work of other teams.

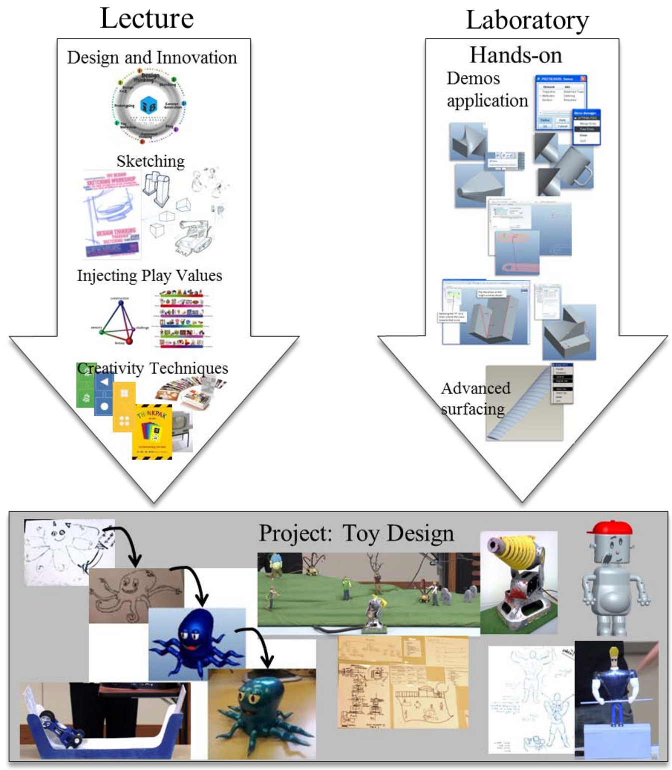

FIGURE 2. REDESIGNED ME444 OUTLINE

FIGURE 3. COLLABORATIVE IDEATION ENVIRONMENT

We intend to extend the idea of the flexible design space to the laboratory space as well, in order to provide students with a space with better affordances for design and innovation [45].

Related Courses At Purdue University

It was also important to check the plan of study and to identify previous mandatory classes on related topics. Unless strictly necessary, the overlapping of topics between courses are best avoided. After analyzing the plan of study we the following related class:

CGT163: Introduction to graphics for manufacturing. This is a required class where students learn the basics of CAD for engineering. Students are taught to sketch existing objects in order to improve their spatial ability [28] and better understand the CAD environment. Idea generation or creativity is not the objective the course, and the sketching taught here more formal—not for concept generation or evaluation.

This examination of the curriculum showed us that our University confirms the diagnosis made by Ullman, Linsey and Yang: engineers are not being taught freehand sketching as a way to think through ideas, problem solving or visual thinking.

Freehand Sketching Module

We thus hypothesized that teaching basic techniques in freehand sketching would help them generate quicker and more effective external visualizations of their ideas, and thus foster their creativity. To this end, we designed dedicated "sketching workshops" and carefully interwove them into the course schedule. The content of the workshops was determined through discussions with an industrial designer with experience in toy design as well as features identified in research mentioned in our literature review. The basic outline of the sketching workshops was distilled to six concepts: tools, lines, perspective, form, context and motion.

Students were introduced to "soft pencil" sketching, construction of complex shapes from imagination using primitives, and high speed shape construction. They were taught basic concepts like two point perspective, use of ellipses, tips for drawing straight lines and the use of dark and light lines. Expression of movement is important, so the use of annotation, scale, and context for the toy were also explored. Cut-away and exploded views of concepts were also encouraged, to help students discuss more details once the concept starts getting more complex. An example given to students for one of the assignments is shown in figure 4. In contrast to the technical drawing approach, the soft pencil approach embraces the more "messier" sketching style, and introduces students to the concept of thinking and talking sketch [29], [46]. It also encourages students to not worry about mistakes and concentrate on improving the idea.

We provided students with the tools for this module: a blue (soft) pencil, and a black marker, which acts as the "hard pencil". Note that eraser is not in the list: mistakes are allowed and with the proper combined use of pencil and marker would suffice to create clear representations of concepts. The other required tools are paper: a plain single sheet of paper is probably the best option for this mission. However, with a view to keeping the information together and for the purpose of individually analyzing each student's progress through the semester, a notebook

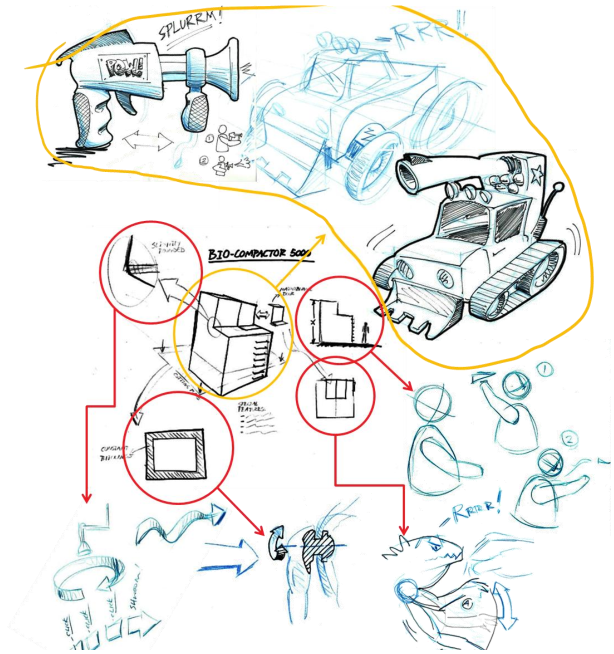

FIGURE 4. EXAMPLES FROM THE SKETCHING WORKSHOP (INSTRUCTOR DRAWINGS)

was preferred. Having a design notebook and keeping sketches is a practice used by great inventors through history. Leonardo da Vinci's widely recognized sketches, as well as other famous sketches by Thomas Alva Edison and Alexander Graham Bell were used as inspiration for the students. Every student was provided with a notebook with plain white pages, and were told to keep track of their work on the notebook.

Along with the sketching motivation and training the workshops included ideation techniques, as discussed in the next section. Students were encouraged to explore the affordances of sketching - how sketches can improve ideation, and help discuss, combine, refine and create more concepts. Some sketching assignments were handed out for practice prior to, and in parallel to the ideation stage of their toy design projects.

METHOD

We used a live class setup for our study instead of choosing control groups, for two reasons: this was a pilot study intended to inform the design of a more detailed and statistically sound experiment to be conducted in the future, and using a live class setup would provide us with insights on the challenges of incorporating the contents in the course of a semester, with the normal pressures of assignments, tests, and projects that students need to cope with. Of the 68 students in the class, most were seniors in Mechanical Engineering and Biomechanical Engineering. While the study was embedded in the class, student participation in surveys and experiments was purely voluntary, and not linked to any reward system. The students were also provided with guidelines where applicable, like with the design notebook usage, but there were no enforced rules.

In order to have data which allow us to track the changes experienced by students during the semester, we relied on the following three approaches:

Pre-Workshop Survey

We conducted a survey on students prior to their exposure to the new material in the class. The objective of this survey was to understand the students' background in CAD and freehand sketching.

Notebooks And The Mug Experiment

The other source of information for our analysis was the design notebook. The notebooks were intended to provide an idea of how every student assimilated the content from the sketching and ideation workshops, and to help us evaluate their progress. In order to have a clear comparison of the students' sketching skills before and after the workshops and training, we came up with what we called the "mug experiment". Students were given a short design task before the first sketching workshop, and they were asked to perform exactly the same task in the last week of the semester. The required task was as follows:

Sketch a "mobile mug", which is able to move over your desktop. The mobile-mug will be able to find its way on your big and messy desktop to be closer to you, and to make sure you drink your coffee before it gets cold. Restrictions:

- *There are no restrictions; you can choose any system you think is better for the mobile mug to navigate over your desktop.*
- *You can also add some notes to explain how your concept will work.*
- *Take it easy and enjoy the challenge.*
- *Time: 5 minutes.*

The task was designed to evaluate the students' ability to conceptualize a product that does not exist, and generate an external visualization of the concept. In keeping with the idea that quick sketching is the key to effective visual thinking, the five-minutes time limit was imposed. The same task was given to them at the end of the semester, so we could evaluate their perception and execution of the same process after they were equipped with the required tools and techniques.

Post-Workshop Survey

We also conducted a survey on students after their exposure to the new material in the class. The main objective of this survey was to check whether and how their perception of CAD,sketching, and their confidence with sketching changed. The pre- and post-workshop surveys in combination would gauge the students' reception to the change in the course approach.

RESULTS AND DISCUSSION

At the end of the semester, we consolidated the students' design notebooks and feedback through surveys. Out of the 68 students that took the course, 40 students had completed all the surveys and the mug experiment. For the sake of consistency, only these 40 sets of results were used for our evaluation.

Pre-Workshop Survey

The results from the students' comfort in using a CAD software of their choice were divided into two categories: those who had taken CAD training outside CGT163, and those who had not. The distribution is shown in figure 5. More than half the students seem to have taken external training in CAD, and most of the students reported that they were "somewhat comfortable" using CAD. We infer that this is indicative of both their perceived importance of CAD skills, and perhaps their motivation to take ME 444.

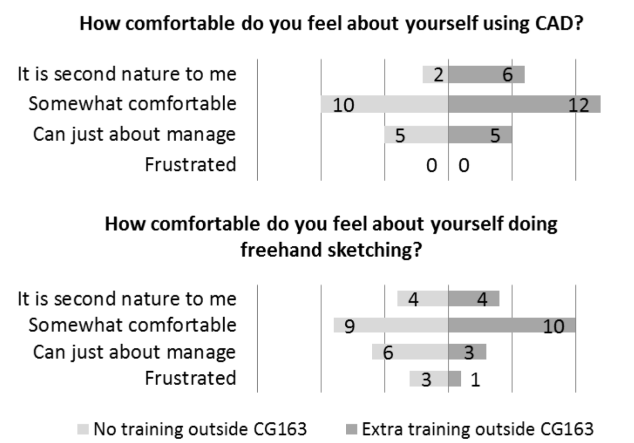

FIGURE 5. RESULTS FROM PRE-WORKSHOP SURVEY. STUDENTS' CONFIDENCE USING CAD AND SKETCHING

Results from the students' comfort in freehand sketching is also divided into the same two groups: those who had taken training in sketching outside the required CGT163, and those who had not. Figure 5 also shows this distribution. It can be seen that 10% of the respondents seem to be frustrated in their ability in sketching. Further data analysis showed that these students fall in the category of "somewhat comfortable" in their CAD skills. This result suggests that while these students are less comfortable with their sketching skills than with their CAD skills, they still prefer to take a CAD class—ME 444—which stresses the students' perceived importance of CAD skills. In addition, based on the course content of CGT163, it is safe to say that more than half of our students had not been exposed to visual thinking and sketching as a tool for creativity and ideation.

Notebooks And The Mug Experiment

It is difficult to come up with a consistent and objective measure for analyzing how "good" sketches are. We approached the measurement from the point of view of the techniques they were taught in the sketching workshop. We divided the techniques into three categories of measure: style, skill/confidence, and design context. We used these criteria to evaluate 2 sets of sketches in the design notebook: Mug experiment 1 prior to the workshops, and the Mug experiment 2 in the final week.

Category 1: Style This category includes characteristics which reflects on the overall look of the sketch, and also can influence the perception of it. For example, a more engineering drawing style—like a clean draft—could give the impression of a finished idea, therefore discouraging discussion and further transformations of the concept. We expected to see an increase of sketches using 3D views (perspective) as the main source of information, having 2D as supporting views for specific details. The use of the combined soft and hard pencil approach was also evaluated, to determine if the students saw value in these tools.

Figure 6 presents the results obtained for all the categories. A paired-samples t-test (see table 1) shows that increase in the number of 3D drawings in Mug 2—which is shown in figure 6—is significant. This is an indicator of the influence of the workshop.

There was no significant change in the use of freehand sketch style and engineering style. However it was good to see that 65% of the students worked with a relaxed freehand sketching style before the workshop, and a small increment was seen after the workshop. Similar results were obtained for the decreasing of engineering style drawings.

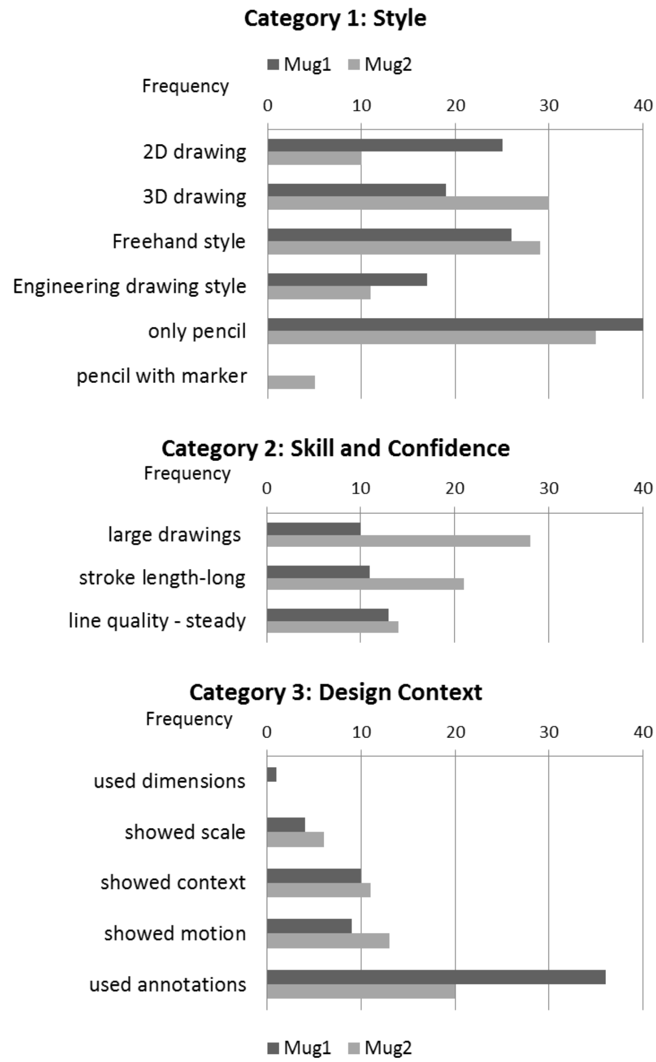

FIGURE 6. EVALUATION OF SKETCHES BY CATEGORIES

TABLE 1. T-TEST RESULTS FOR CATEGORY 1

	2D	3D	Freehand	Engineering	Pencil	Pencil marker
t Value	3.78	-2.91	-0.9	1.64	2.36	-2.36
Pr	0.0005*	0.006*	0.3724	0.1097	0.0234*	0.0234*

Analyzing the tool usage, we saw that all the students relied only on the pencil to do the sketches in Mug experiment 1, in spite of being provided with both pencils and markers. The Mug 2 experiment revealed unexpected results: most students—87.5%—did not use the pencil-marker combination, although this technique was taught during the workshop. The t-test result still indicates a significant increment on pencil-marker usage, since the mean value for Mug 1 was zero. When checking intermediate sketches (after Mug 1 and before Mug 2) we found that most students used the pencil and marker approach consistently. We think that after ideation and conceptualization process the students turned completely to the CAD stage and manufacturing of the toy and stopped sketching, and were out of practice and not carrying the markers anymore. This situation raises the question of their perceived value of using these tools but also shows the situations derived from working in a non-controlled environment.

Category 2: Skill and Confidence An increase in the sketch size was expected here, in addition to an increase in stroke length and line steadiness which could led to cleaner sketches. Sketches larger than 1/4 of page size were classified as large. Figure 6 supported on table 2 shows that sketch size and stroke length had significantly improved. Line quality did not show improvements, but we noticed that, for some people, unsteady lines form part of their personal style while sketching. Also, a steady hand comes with practice, an aspect which could be stressed in future iterations.

TABLE 2. T-TEST RESULTS FOR CATEGORY 2

	Large sketch	Long stroke	Steady line
t Value	-5.02	-2.91	-0.3
Pr	0.0001*	0.0059*	0.7672

Category 3: Design Context From the training provided in the workshops, we expected to have an increase in the use of features showing scale through the use of dimensions or context—how the product is operated—and an increase in graphic expressions of motion and the use of annotations to clarify ideas. Figure 6, however, shows only a small increase in these characteristics, which in terms of the t-test (table 3) are not significant. Regarding annotations we were surprised to see a significant change from using annotations to not using annotations, this is clearly contrary to our expectations and to the workshops. These results could partly be attributed to lack of practice, and partly to the lack of a final incentive for their effort in these experiment. It is worth mentioning again that the students were encouraged to participate in the experiments and surveys, but not required. In addition, the second mug experiment was conducted at a time when students were wrapping up their toy designs, and this could have affected their sketching performance, as acknowledged by Yang [31] who suggested that *"last minute efforts at sketching are not consistent with a good outcome"*. In future iterations, care would need to be taken to provide sufficient incentive for the sketching process, as well as check points (more "Mug" experiments) along the semester.

TABLE 3. T-TEST RESULTS FOR CATEGORY 3

	Dimmensioning	Scale	Context	Motion	Notes
t Value	-0.57	-1	-0.3	-1.16	4
Pr	0.5703	0.3235	0.7672	0.2532	0.0003*

Post-Workshop Survey

As shown in figure 7, students report some improvement in their confidence in freehand sketching. While 50% of the students declared being equally comfortable with sketching as they were before the workshop, 40% reported an improvement while 10% downgraded their perception. Additionally 87.5% said they got new ideas about how to use sketching and 62.5% said would not have used sketching in the same way if not for the workshop. Remarkably no one expressed to be still frustrated.

In addition, student feedback on their perception of freehand sketching were both encouraging and interesting. Some of these comments are quoted below:

"Before the workshop, I felt freehand sketching was just another way to show ideas and concepts, not as important as having sketches in computers. Now, I feel that it should be incorporated in every design class because of its flexibility, ease and usefulness."

"I am now more willing to use free hand sketching as a legitimate engineering tool, especially for generating ideas in the beginning."

"I will now begin the design process with freehand sketching. Also, I will now produce multiple sketches instead of trying to get the design perfect on the very first sketch."

"I realized that it is a very useful tool that doesn't necessarily require a large amount of time to get your idea through."

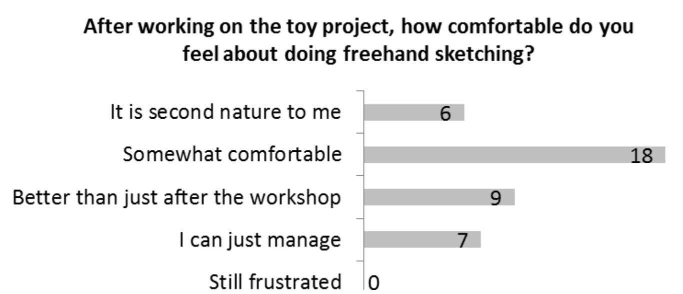

FIGURE 7. CONFIDENCE WITH SKETCHING AFTER PROJECT.

The above comments suggest that some students had the perception of freehand sketching as not being a serious engineering tool. This could probably be due to the traditional engineering perception which relates engineering design with CAD and freehand sketches with artists, industrial designers and children. Students added that the classroom atmosphere was conductive to learning and the course and instructor stimulated them to think creatively. They also strongly felt that the course enhanced their understanding of fundamental principles and showed how to apply these principles to practical engineering situations. A final instructor and external judges' evaluation of the toy designs indicated higher levels of innovation when compared to toys from earlier semesters. While these are encouraging in terms of how the changes were received by the students, the nature of the surveys and the execution of the mug experiments are not statistically conclusive, nor were they intended to be: we intend to inform our next iteration of experiments through our findings from this study.

CONCLUSIONS

This paper reports the results of a pilot study, that sought to introduce freehand sketching as a tool to foster creativity and aid visual thinking in engineering designers. Our literature survey shows sufficient evidence to the fact that quick sketching aids visualization, and thus enables designers to explore the creative design space more effectively [3,9,12,13]. Application of knowledge that emerges from research is important in order to avoid or correct mistakes in education practices and tools, and improve the capabilities of our future engineers.

With a view to correct the inappropriate use of CAD too early in the design process, we introduced sketching to students of a toy design course that used CAD and prototyping techniques. We distilled the basic sketching skills required to a set of six topics, and used sketching workshops to introduce these to students in a toy design course.

Results from t-test are useful to understand which ideas need to be more stressed for the next iteration. The implementation was successful on increasing the amount of perspective sketches as well as an increment of sketches size and stroke length. This is an indicator of students feeling more comfortable about sketching, and on their learning of the value of free-hand sketches for their performance as designers.

Use of pencil and marker was a partial success because students did use them during intermediate sketches, but failed to carry their tools and use it for the final experiment (Mug 2). Use of annotation also presented undesired results. It was desired that students keep using annotations since literature review presents results stating that the hybrid approach of using sketches along with words and comments [25]. The significant decrease on using annotations suggest a failure on stressing its importance.

The no conclusive changes on context related characteristics (dimensioning, scale, context, motion) gives a signal about the necessity of being more insistent about their importance. Those characteristics are also part of the added value which differentiates our approach from more traditional drafting training.

An evaluation of the influence of these workshops indicated a change in student perception of the importance of sketching in design. However, an evaluation of control groups in the same course could help evaluate the difference in student performance and creativity. In addition, based on student feedback, it would seem that an increase to the space and time dedicated to the sketching workshops would result in better honing of sketching skills, and therefore the effectiveness of their use in the early design process. We will use the findings from this pilot study to inform the further refinement of this new course in order to create a new generation of visual thinkers and innovative designers.

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