ABSTRACT

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In the Mechanical Engineering Design Process, sketching has been used as a tool to foster engineers' work. However, with the integration of the computer, computer tools and software are replacing what many previously did by hand. Capstone Mechanical Engineering sketching assignments and final reports were analyzed with sketch coding schemes, including the New Content-Based Sketch Coding Scheme that was created for this research. The "Mechanical Engineering Visual Design Mediums Concept Inventory" was created to begin to understand the current role of sketching and students' conceptual understanding of sketching and CAD within the Mechanical Engineering design process. Literature and previous research enriched the content of the Concept Inventory. Sketching assignments and data from students' design notebooks were analyzed to obtain more breadth and natural data. With the various data and analyses, insight on sketching in the Mechanical Engineering Design Process is obtained.

CONCEPTUAL UNDERSTANDING AND THE USE OF HAND-SKETCHING IN MECHANICAL ENGINEERING DESIGN

By

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Dedication

This thesis is dedicated to my father, mother, and fiancé who inspire me, teach me so much about engineering and education, and supported me all of the way. And to my grandma and my brother who have been a part of this journey and can always make me smile.

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Chapter 1: Introduction

Drawing is the design engineers' way of work (Ferguson).

Creativity and innovation are becoming the ultimate determinants of successful engineering design in the public sphere. The drive for unbounded innovation is an expression of society's belief that technology will provide answers for all of the vexing problems of the day. In this environment, engineering students need to develop any skill that will improve their ability to be innovators. Writing in "Mechanical Engineering," the ASME's popular news magazine, McCormick (2007) makes the link between sketching and innovation: "Sketching is the tool for innovation, and is so vital to the engineering process that it should be taught and used as an essential part of engineering education and professional practice" (p. 35).

In Mechanical Engineering Design, hand-sketching is a skill that has been commonly used to assist in thinking processes, development of the design, and communication. During design, communication of ideas, features, concepts, and more can be accomplished quickly with sketches. Sketching goes beyond verbal communication and uses visual representation to communicate. The current sketching habits of students are unknown. Students' beliefs about sketching and its value in the design process are unknown.

This research's main purpose is to discover the role of sketching in the Mechanical Engineering design curriculum. In the long term, this information can assist in the teaching and deeper understanding of the mechanical engineering design process. In the short term, understanding the use of sketching in design can assist in improving student's skill sets and design practices.

1.1 Motivation to Study Sketching

This research was spurred by the emphasis in the engineering curriculum on Computer Aided Design (CAD). Current students use CAD daily. The practices of hand-sketching and mechanical drawings seem to be fading with the increase in computer availability and use. Students have become CAD specialists where CAD use and drawings are the main tasks of the project (Schmidt 2006). Demand for the CAD course at the University of Maryland is very high. More students continue to specialize in CAD and the demand for CAD courses exceeds the number of seats eligible each semester. There are no longer any mechanical drawing classes (a.k.a. drafting) offered in the Mechanical Engineering Department.

When design journals and sketching were encouraged in one of the semesters of capstone design, students rarely used the design journals but understood that they were a good tool and something that would be helpful if they actually used them. The quality of sketches in that semester was very poor. The students wanted to move straight into drawing designs with CAD and skip sketching. The act of sketching is decreasing; does this mean that sketching is not needed in engineering design?

1.2 Research Questions

Throughout the Mechanical Engineering undergraduate curriculum at the University of Maryland and most universities, the lack and almost absence of hand-sketching and mechanical drawing is intriguing. CAD is introduced to engineering students during their first semester at the University of Maryland. CAD is often portrayed as a substitute for mechanical drawing and hand-sketching. From the observations of the low use of hand-sketching and the need of CAD, research questions were formed.

1) Do mechanical engineering students sketch? Do they know what sketching is?
2) What are their current sketching skills and sketching knowledge levels and are these adequate for engineering design?
3) Why do mechanical engineering students sketch? How do they use their sketches?

Table 1 displays the research questions and their corresponding purposes, data types, and analyses. The research strands can be followed through the different data types and the chapters within this text.

Table 1: All Data Types' Purposes, Collection Points, and Analyses

Research Questions on Mechanical Engineering Students	Purpose Information Sought	Data Type and Collection Points	Analysis
Do students sketch? Do they know what sketching is?	To determine Mechanical Engineering students' overall understanding of sketching and CAD.	Concept Inventory; ENES100, ENME472, Variety of ENME courses	Determine common misconceptions and mastered concepts. Correlate demographic results with CI data.
What are the current sketching skills and sketching knowledge levels and are these adequate for engineering design?	To determine current sketch ability and the type of work that is done when sketches are asked for.	Sketching Assignment; Fall 2007 ENME472 Sections 0101 and 0102	Code for sketch skills Create and apply content-based coding scheme
Why do mechanical engineering students sketch? How do they use their sketches?	To analyze design reports in order to find some insight in the use of sketching	Sketching Frequency, Detail, ENME472 Final Reports	Code for sketch levels. Track the frequency of sketch use. Draw comparisons on the use of visual representations. ANOVA

From the research and its various strands of data and analyses, hand-sketching will be better understood and implemented into design. From the knowledge of hand-sketching in design, sketching is considered to be a good and useful tool. Research shows that the mechanical engineering design process is improved by the intentional use of sketching. This author believes that if the true value of the sketching process was understood by mechanical engineering students they would sketch more.

1.3 Organization of this work

This work begins with relevant literature on sketching and CAD in Chapter 2. Chapter 3 discusses results from previous sketching research within Mechanical Engineering capstone design journals and final reports. Chapter 4 introduces the New Content-Based Sketch Coding Scheme that is applied to capstone final reports. Chapter 5 presents research on sketching within Mechanical Engineering capstone sketch assignments. Chapter 6 introduces and discusses results of the Mechanical Engineering Visual Design Mediums Concept Inventory. Chapter 7 concludes this work.

Chapter 2: Literature Background

2.1 Sketching in Mechanical Design

2.1.1 Definition of Sketching

"sketch - 1 a: a rough drawing representing the chief features of an object or scene and often made as a preliminary study b: a tentative draft (as for a literary work)"
"sketching - transitive verb: to make a sketch, rough draft, or outline of
intransitive verb : to draw or paint a sketch"
(Merriam-Webster 2008)

A sketch is a drawing that was made without the use of any instruments, such as rulers, triangles, or T-squares. A sketch is a rough drawing without any placement rules or standards as compared to technical mechanical drawings[1]. Sketching is free-hand drawing that displays indications of a trial drawing. A sketch may appear unfinished. It may include sections where lines have been redrawn on top of one another as the sketcher experimented with different shapes.

A drawing depicts a concept exactly with dimensions and notations. A sketch can also have these characteristics, however a sketch has a more general purpose and ambiguity. While a drawing gives a complete depiction of the concept where there would be no questions or ambiguity as to what the concept is, its size, and how to manufacture it.

[1] Mechanical drawings are final drawings that an engineer creates to communicate the design so that machinist can produce and manufacture it.

2.1.2 Sketching: Is it a Skill or a Talent?

Hand-sketching and drawing tend to be seen as talents and not as tools that all can use and use well. Research shows that both adults and children believe that drawing is a natural skill, in children (not a talent) and a means for expression of their ideas (Anning 1997). To understand the switch to viewing drawing as a talent in adults, Anning researched the history of teaching drawing to children (1997).

In the United State during the mid to late 1800s, the art curriculum existed to aid in the development of 'Skill of Hand and Eye' and was predominantly implemented for boys. Art lessons were available in state schools for hopeful artisans. By 1900, drawing became a part of the general education curriculum for all students. The 1923 edition of Suggestions for the Consideration of Teachers includes the statement: 'drawing is just as natural to a child as speaking and writing, and ought to be as carefully treated.' The Board of Education in 1927 declared that drawing could be regarded as a means of expression, a means of representation, and an instrument of culture. In the 1930s in Eastern Europe, children were seen as naturally having artistic abilities. Since art was considered an innate ability, many teachers did not interfere with students' drawing (Anning 1997).

By the 1970s, the general belief was that teacher involvement in the development of artistic skills was needed. Anning states that children need to receive instruction and feedback on drawing (1997). Without instruction or feedback students perceive drawing in only the most practical ways. Students believe that drawing is used to: represent real objects; keep students busy without teaching; or to describe something remembered or imagined (but not currently present) in a physical and graphic form (Anning 1997). When children receive feedback and their work is valued by teachers, children understand the importance and usefulness of drawing which results in added value of sketching.

Educators have been concerned with the way in which children learn technical aspects of drawing and what stages are parts of this process. Anning researched sketching experiments and discussed the different results (1997). It was noted that children have technical issues with perspective and creating 3-D drawings on a 2-D piece of paper. Even with this problem, children are usually able to represent their thoughts in drawings with ease. Anning's subjects were able to understand what the drawings mean in the real world even if the drawings were dimensionally incorrect. Anning notes the drawings provide a rich source of information about children's thought processes (1997). Much is being lost in understanding the thinking processes of children because it is commonly assumed that their drawings are not as important as their writing. This viewpoint carries over to children by implying that their most common mode of communication will be writing, not drawing (Anning 1997).

If teachers and researchers give drawing the proper attention, then students can further develop their drawing skills and processes. Anning believes that much can be gained by treating drawing as an important mode of learning and applying further research and attention to the subject (1997).

2.1.3 Assessing Sketching Skill

McGown conducted research on sketches made by final year engineering students to study the importance of sketching in design (McGown 1998). McGown created a complexity measure for sketches that is composed of five levels of increasing detail. Level 1 sketches are the simplest; they contain lines portraying physical principles and technology without any product form details. Level 2 sketches show concept working principles with brief annotations but without product form details. Level 3 sketches display product form and details, with possible shading and brief annotations. Level 4 sketches contain product form, annotations, and detail of features. Level 5 sketches are the highest level; they are 3 dimensional or multi-view two dimensional projections showing product form. Level 5 sketches include shading, color, dimensions and annotations. These levels of sketches assist in the coding and analysis of sketches (McGown 1998).

Cham and Yang considered sketching in early design stages and how it affects engineering design performance (2007). Several attributes of the study displayed that sketching did not directly affect project rankings or grades. However, the amount of sketching can be related to individual interests and other outside factors. Students in this research were identified as those who did take a sketch/CAD course and those who did not. Those who did take the sketch/CAD class started with a higher facility in sketching than the others. Sketching skills varied among individuals. Sketching skills were determined by asking students to perform a series of sketching tasks: mechanical recall; drawing facility; and novel visualization. Student results were studied, first by applying a coding scheme composed of 5 levels of quality. Examples of student work in Levels 1, 2 and 3 are given in Figure 1 (Yang 2007). Yang did not report any results in Levels 4 and 5. These higher quality levels of sketching would include: better proportions, details, and shading.

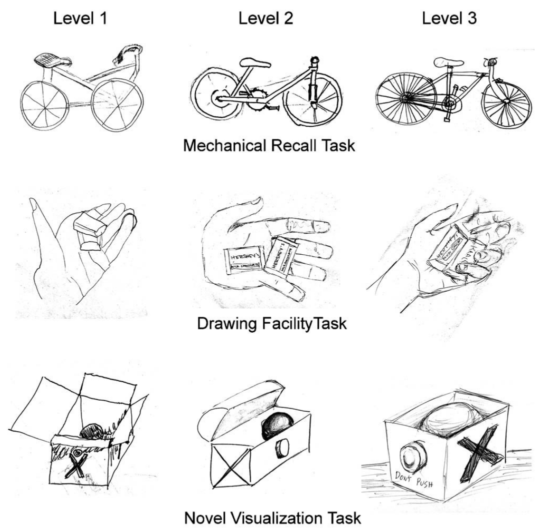


Figure 1: Yang (2007) Examples of Sketch Levels 1-3

2.1.4 Sketching as a Communication Tool

Graphical representations assist in communication. Crowe and Laseau state that not only do graphical representations promote communication but also foster visual literacy and creative thinking (1984). Like written notes, graphical representations or visual notes can be saved and used by many; the specific thoughts in the representation are no longer only in one's mind (Crowe and Laseau 1984). Conversely, sketching has been found to hinder communication between designers if the ambiguous elements of a sketch are interpreted differently (Stacey et al. 1999). This is one reason why it was necessary for engineers to develop their drawings beyond the vague sketch to a more formal type of visual representation. Reading engineering drawings is a decoding process where one knows the layout, the rules and standards of the drawing (Ferguson 1992). The standardization of engineering drawings makes it easier for designers and engineers to translate (Ferguson 1992). While looking at a drawing or a sketch, one processes the information on the 2-D piece of paper and forms the 3 dimensional object in one's mind.

2.1.5 Types of Sketching Defined by their Use

Lopez researched the use of drawings in science as a means to present data. (2005). In Lopes' work, drawing and sketches relate closely and may be considered to be the same (2005). Lithic drawings are illustrations that capture specific data and can be used to make generalizations. For example, a lithic drawing is useful to represent stones. In contrast to a lithic drawing, Lopes notes that a photograph represents a single data point (2005). Photographs can only represent that one specimen while drawings and sketches are capable of representing a type of specimen. Archeology integrates drawing techniques to provide better representations than a photograph. These techniques include placing symbols on the drawing and outside of the drawings. Drawings and sketches not only depict the look of an object but also give information on how the artifact was created (Lopes 2005).

Ferguson (1992) recognizes that there are three kinds of sketches used by engineers: the thinking sketch, the prescriptive sketch, and the talking sketch. Each type of sketch serves a different purpose. The thinking sketch aids the ordering and processing of thoughts about an object in one's mind. This occurs as a result of seeing the thoughts as they are expressed on paper during the act of sketching. Leonardo da Vinci's notebooks provide dozens of examples of how thinking sketches contribute to the compilation of ideas. Figure 2 is one of da Vinci's sketches of a flying machine idea(da Vinci Retrieved: February 28, 2008). There is another sketch within the figure that shows the concept in use.

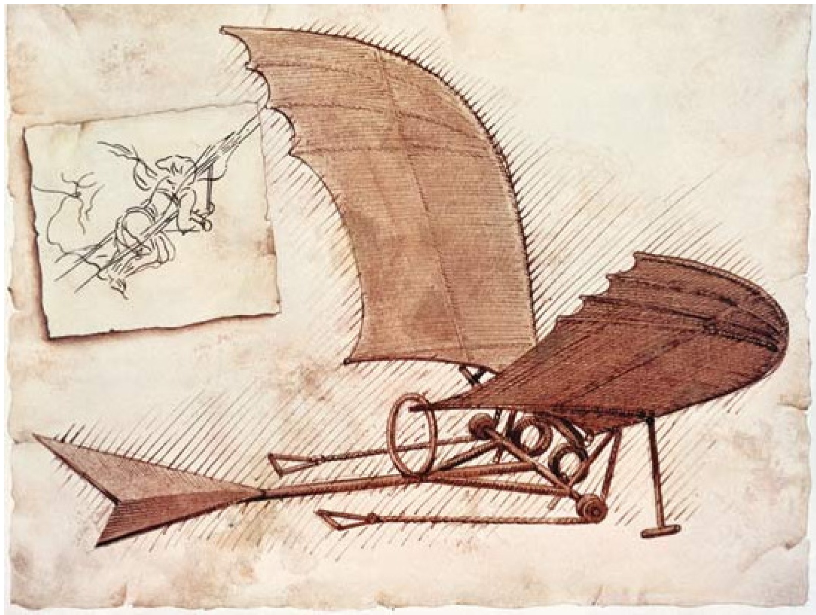


Figure 2: Leonardo da Vinci's Flying Machine Sketch (da Vinci Retrieved: February 28, 2008)

Prescriptive sketches are those created to fulfill a premeditated purpose as in the case of a sketch made during a discussion between engineer and manufacturing engineering or machinist in which the purpose is to build the artifact. Talking sketches assist in the communication between people and are a result of talking about an issue and sketching it to explain further and clearer (Ferguson 1992). Sketching is critical to the engineering analysis and design because of its abilities to store necessary information and concept details according to Rose (2005). In this way sketches act as external storage of ideas.

2.1.6 Sketches Help Develop Shared Concept

The development of the shared concept within engineering design teams occurs through viewing and discussing hand-drawn and computer generated graphical representations. The shared, perceived concept is critical to successful design in teams. Each team member needs to have a common perception of the product being designed. This understanding extends beyond exact physical characteristics of a product. The need for a shared concept is present throughout the entire product development process. In the marketing channel, designers, manufacturers, and retailers have different roles which may have an affect on the product meaning to each. Product meanings can influence communication in marketing amongst the three different roles. The sharing of meanings is critical in communication, not just transferring the meanings. Figure 3 shows an example of how designers, manufacturers, and retailers perception's overlap. It is noted that the more shared perception, the more "integrated and effective the whole system" (p.219, Hakkio 1998). Displaying information visually (which includes sketching) is important in early design phases because of the many perspectives and ideas that different parties have (Hakkio 1998).

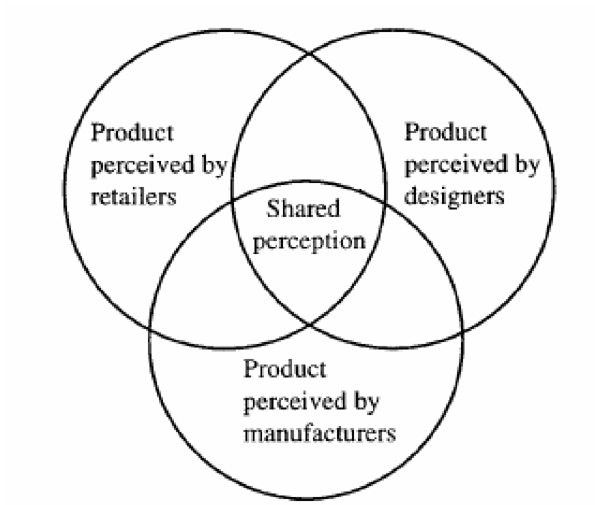


Figure 3: Product Perception (Hakkio 1998)

Language coherence is one indicator of shared perception. Latent Semantic Analysis has been applied to find language coherency in student design project teams (Dong 2005). One study of Dong's analyzed design teams in a multi-disciplinary graduate course (2004). Studying students in a course allows for the control of many external factors that could not be held constant in a professional work environment. The course required groups to document their design work and to reflect on the process both as groups and individually. The reflections encouraged students to metacognitively think about the course and the design project. Latent semantic analysis (LSA) was applied to the documentation. LSA analyzes relationships between words by applying natural language processing and vector analysis to transcribed conversations. Results indicate semantic coherence within design teams positively correlates with team performance as assessed by course faculty's ratings. Teams with low performance did not define their objectives as clearly as high performing teams. High performing teams shared product and product development process understanding, negotiate strategies, and conflict resolutions (Dong 2004).

This is more evidence to support the value of a shared perception of a design task and proposed solution.

2.1.7 Sketches Preserve Design Process Information

Documentation in fields other than engineering is still encouraged and widely practiced. Scientists continue to keep laboratory notebooks with their data and notes. Artists continue to keep portfolios of all of their work. These practices in these various fields are taught from the beginning of courses of study and continue to occur because of their assistance in the individual's work and of the habitualness of the act of documenting.

Documenting the Mechanical Engineering Design Process is a vague and rarely discussed topic. Unlike many of the well known, historic inventors and engineers who documented with dedication, today's engineers do not have such strong practices. Leonardo da Vinci's design journals are celebrated and regarded highly by the engineering community. Thomas Edison is known for his well taken notes on successes and failure. These famous individuals are models for all designers and engineers. Yet the same designers and engineers have not adopted Edison's or da Vinci's documentation habits.

An important aspect of drawing is that drawings have naturally segmented elements (van Sommers 1984). Segmenting concepts is common due to the large size of a design. A drawing can be segmented into strokes, just like the English alphabet can. An example of segments in the alphabet are when one writes the letter "t", there is one vertical segment and one horizontal segment. In sketching and drawing, line segments are seen the same way. Tversky analyzed students' line and bar graph interpretations of segmentation, order of drawings, and hierarchical structure (1999). Tversky found that sketches are capable of revealing thought through the segments in which they are constructed (1999). The order of drawings displays the order of transformations occurring in one's mind. The order of sketches shows conceptual structure and the mental organization to grasp the idea prior to communicating the information. Segmentation and organization is a natural way to think, understand, and communicate concepts by sketching and drawing (Tversky 1999).

The use of sketching as an external memory is an important aspect of sketches and visual representations (Goel 1995). Goel provides evidence that sketches done in sequence are often lateral transformations on concepts generated in early design phases. Lateral transformations are those made during concept generation when the concepts differ widely as a whole. In contrast, vertical transformations occur during final design stages that include refinement and detailing. Vertical transformations are detail changes related to the same concept. Goel's (1995) research is on cognitive aspects of sketching and he studied the behavior of professional designers in architecture, mechanical engineering and instructional design.

McGown's research, that was previously mentioned in Section 2.1.3 for the sketch coding scheme implemented, studied the use of sketches in conceptual design over a 15 week period (1998). From the sketch complexity measure, sketch size, and chronological data, it was evident that sketches were used mostly in the beginning of the design process. In the later stages of design, sketching of concepts indicated more vertical transformations (McGown 1998).

2.1.8 Value of Sketching in Design

Sketching is a tool that can support education and engineering design outcomes. Sketches assist in: learning, thinking, communication, and therefore assist design processes and outcome. Sketches allow ambiguity. The ambiguous nature of design parallels that of sketching. Sketching fosters the creation of ideas and concepts allowing them to flow from one graphical representation.

Drawing is an integral tool needed for design. Tversky states: "Design without drawing seems inconceivable" (1999). Tversky notes that drawings differ from images or pictures (1999). Drawings are representations and not presentations of reality. Drawings can add, omit, distort, emphasize, and change things that are in the reality. More insight and depth of knowledge can be seen in drawings than can be seen or understood in an image of reality, like a photograph.

The bulk of research on sketching in engineering focuses on understanding the value of sketching as a support tool during design, especially in the beginning stages of the process. Naturally there are a few studies concluding that sketching has no bearing on design outcome (Cham 2005 and Bilda 2005). The first study used a small sample and focused on sketch skill measures, not the presence of sketching. The second study was conducted with architecture students and a think-aloud protocol which is often found to be intrusive.

Long term studies in sketching and design (especially education) are rarer than short term studies due to the complexities of observing and working with designers for an extended period of time on a real problem that is a part of course or job. Longitudinal studies on sketching in engineering design do not exist. The so called longer term studies within the sketching field only cover a semester or a couple of months. The research conducted for this graduate work was spurred by a compressed semester (8 weeks) study during the summer of 2006. The use of design journals within a capstone design course was studied and analyzed within in two semester team projects (Grenier 2007). This research is presented in more detail in Chapter 3.

Schutze conducted a formal investigation focusing on the sketching process and its impacts (2003). The laboratory experiment consisted of 45 Dresden University of Technology graduate mechanical engineering students. They were divided into three groups and given a design task. The first group was allowed to sketch freely, the second group was allowed to sketch until a certain part of the design process, and the third group was not allowed to sketch at all during the design process. All groups were assigned to develop feasible conceptual designs for a garden grill that is used for cooking. There were no time limitations within this one day experiment. This design project was considered to be at a medium level of difficulty. Dependent variables in the experiment included: "quality of the solution, total solution time, experienced difficulty of the design problem and certainty regarding the correctness of the solution." (p. 91, Schutze 2003)

The first group, those allowed unlimited sketching, displayed the highest solution quality, the least amount of difficulty with the problem, and the longest total solution time. Oral interviews were conducted after the design task was completed. The interviews showed that sketching served as an aid for analysis, short term memory, communication, and documentation. From this work, it was found that sketching during the design process has a positive effect on the solution quality of design outcomes that comes the expense of design time (Schutze et al. 2003).

Agogino and Song integrated McGown's complexity measure to study student designer's sketching in a class of undergraduate seniors in design teams (2004). With McGown's measure, a genealogical idea categorization created by Shah (2003) was implemented to analyze the sketches. The genealogical idea categorization is based upon a genealogy tree where levels where Shah combines engineering and cognitive psychology perspectives to analyze ideation effectiveness that include: quantity, quality, novelty, and variety (Shah 2003). The sketches were also coded according to generation, type, medium, representation, and annotation. The more variety and use of sketching resulted in better performance in the class and project outcomes. The number of sketches correlated with design outcome as well; the more sketches, the better the design outcome. The most frequent sketching was conducted in the conceptual design phase as well (Agogino 2004).

Students' natural tendencies related to sketching needs to be better understood to improve design instruction. Cardella's research looks at four case studies on engineering students' sketches and representational activities during the one day design process (2006). All participants were audio and video taped as they were solving the given problem of designing a playground for a fictitious neighborhood. Design step codings (Identifying a need, Problem definition, Gathering information, Generating ideas, Modeling, Feasibility analysis, Evaluation, Decision, Communication, and Implementation) were applied to the transcripts. Analysis of the data was conducted on: total time spent on the problem and each design step, number of transitions between design steps, and evaluation scores of final solutions. Four students of the 50 participants were selected to represent the main findings of the study: one high scoring senior, one low scoring senior, one high scoring freshman, and one low scoring freshman. From this sample, comparisons were made on how students incorporated specific design activities into the projects by analyzing their verbal protocols. Results show that the two seniors implemented the design steps and representational activities more so than that of the freshmen. The case studies reinforce the idea that sketching supports communication and that sketching is a large part of the Problem scoping stage. Representation activities in the results are correlated with higher quality solutions. This research is limited due to the small sample size however, instructional implications are apparent by reinforcing representational activities in problem solving (Cardella et al. 2006).

One study explored how novice and advanced architecture students perceive sketches and interpret verbal descriptions of an image (Menezes 2006). The experiment was set up into 30 sessions, each session involving two students; one would be a describer and the other would be a reproducer. Four tasks were given: two description tasks, one memory task, and one review task. The description tasks gave the describer two images (one non-architectural and one architectural) to observe and describe verbally to the reproducer. After describing the two images to the reproducer, the remembering task is then conducted where the describer must then draw the two images from memory. The review task is where both subjects are to go over their drawing and comment on their experiences. 60 students at The University of Sheffield School of Architecture, half of whom were first year students and the other half were sixth year students were videotaped and analyzed in this experiment. Comparison between the first year's, novice students to the final year's, advanced students was hoped to yield differences for further study. From the video tapes of the 30 sessions, much can be analyzed however in this study the focus was on the verbal dialogue. Results show a large variety in responses from the subjects. However, differences between novice and advanced students are notable. The advanced group used more segments per minute and more verbal cognitive actions per minute for all descriptions compared to the novice group. (Segments are lines drawn, for example a square consists of 4 segments.) The drawings were judged on a scale as to how well they reproduced the original drawing. 78% of all students who had better rankings on the architectural drawing had an increased number of verbal cognitive actions (89% for advanced students and 67% for novice students) as compared to the average. From the verbal data and analysis, the research displays that advanced students used more verbal cognitive actions on average and resulted in better performance. Further analysis of the video tapes can be continued by focusing on verbal gestures and analyzing the remembering task further (Menezes 2006).

Not only does sketching support cognitive activities, it also assists in decreasing the cognitive load during design. Blindfolded and sketching conditions were applied in experiments with advanced architects by Bilda and Gero (2007). Blindfolded designers wore a blindfold while completing a design problem. The blindfolded condition showed a decrease in cognitive activity compared to the sketching activity. Sketching allows for thought externalization and relives the cognitive load but does not decrease the cognitive rate. Sketching in this study relives cognitive load and promotes cognitive actions (Bilda 2007).

During interactions in design teams cognitive actions occur but what goes on is not well understood. Stempfle analyzed three teams that were given a complex problem with specific constraints (2002). The analysis of these team interactions mostly dealt with four basic cognitive operations: generation, exploration, comparison, and selection. The interaction of cognitive operatiouns and goal and solution spaces were another focus of Stempfle's work. From the data, it was seen that increase in problem complexity resulted in teams widening the goal and solution spaces, while decrease in complexity resulted in narrowing the goal and solutions spaces. Team interactions were more content-oriented rather than process-oriented. Almost all of the content-oriented actions were solution driven. Throughout the design process, a constant interweaving of content and process actions occur within analysis and evaluations of the problem. The transitions from one process to another can be difficult for students and could be assisted with training and learning to be flexible within the design process (Stempfle 2002).

Designers use sketching to represent ideas visually especially in conceptual design. McFadzean and Cross analyze how designers sketch with Computational Sketch Analysis (CSA) (1999). CSA consists of two software programs: *Data Collector* that collects and timestamps all design session data, and *Sketch Analyser* that is a record of graphical data and a hierarchical tool that places the data in information structures. The researchers' data was obtained from design sessions where the participants described processes of externalizing graphical information to better solve the design problem. Participants used re-representation and re-structuring. Re-representation is the act of redrawing a certain concept or element of a concept. This is what happens in a sketch when a line is sketched and then one changes it. Re-structuring is the act of drawing existing elements of the concept to emphasize that specific element. CSA data suggests that designer sketching activity can be mapped to understand the cognitive processes that occur. A higher level cognitive analysis is needed for CSA. It is evident from McFadzean's and Cross' research that better understanding of cognition in design will take many methods of analysis (McFadzean 1999).

Drawing diagrams has been used to solving mathematical problems. Diagrams facilitate understanding and visualization of the specific problem allowing the problem solver to reach some conclusion and answer. Diezmann proposes that analyzing mathematical problems should include the process by which the answer is obtained and not just the answer (1995). Diagrams facilitate cognitive action but how they are used strategically is a critical part of understanding their effectiveness. The diagram drawing process was studied by having students complete a problem solving test during which they were video-taped. Some of the students were then interviewed for further analysis of their problem solving strategies. The data from the tests and interviews shows that the end result of the diagram is not always a good indicator of the students' strategy. Understanding and being aware of the cognitive processes and strategies that encompass the act of drawing is critical in assessment (Diezmann 1995).

Fourth and fifth graders' learning in an engineering design class was investigated by Roth. Collections of extensive observation in the classroom and students' logbooks and work were analyzed from the cognitive perspective (Roth 1996). The goal of the work was to understand the processes of student design work in addition to the final outcomes. A series of studies was performed in design engineering classrooms. The learning environment of this work was to allow students to experience themselves in a scientific and collaborative community and to learn from the expertise of others in this field. Learning activities included the use of design artifacts (i.e. sketches, drawing, prototypes, any product of their work) that were produced and found by the students. The design artifacts were used to structure an open ended problem better, and to negotiate with one another and make decisions. Design artifacts contributed to the students' learning. The students interacted with the artifacts and each other to learn about design (Roth 1996).

Recently, cognitive scientists have had more interest in engineering design drawing during conceptualization. More research continues to be done in this domain. Yi-Luen, Gross, and Zimring ask the questions of "what role does sketching have in design?" and, "How can one study the cognitive processes that occur during sketching?" (1999). A drawing design experiment was conducted to find the relationship among design drawing symbols, drawing intention, and universal symbols identification. The drawing design experiment was conducted with two undergraduate design students and two architectural instructors referred to as "designers". The study showed that the designers had common drawing conventions and configurations in their sketches. However, the designers had different drawing preferences for different design concerns. Finally, the designers also re-traced their work to show importance and wrote numbers to draw concepts to scale. The designers were avid free-hand sketchers as well as being knowledgeable about CAD. This research's conclusions suggest that a computer system would be capable of inferring design intentions from the drawing symbols and conventions that designers use. The "Right-Tool-Right-Time" prototype software has been configured and implemented into a computer program to fit this work's conclusions (Yi-Luen 1999).

Another aspect of sketching and drawing is animated drawing. Representations that show movement are referred to as animated. Cheng and McKelvey studied the effectiveness of animated and non-animated drawings in a learning environment (2005). The study was conducted with architectural design students. The students were shown an expert drawing example (either an animation or paper version), then asked to put the design steps the expert implemented in order. Finally, they implemented those steps into a problem similar to that of the example. The students' responses were written with a digital pen-on-paper system. The system could show the students' responses stroke by stroke. The students with animations performed marginally better than those with the paper, non-animated examples. However, the use of the digital pen proved to be an excellent way to record sketching movements and observe aspects of the drawing and design process (Cheng 2005).

2.2 CAD in Mechanical Design

2.2.1 Rise of CAD, Decline of Sketching

Technology and computers are a large part of every day life especially for the engineering student. CAD skills are replacing hand drawing and sketching in design. CAD is a skill that is integrated into current engineering design however such softwares allow for the neglect of hand sketching skills (Rose 2005). Ullman sounded an alarm over this phenomenon. Ullman emphasized the importance of hand sketching and drafting and how aspects of hand-drawing must be incorporated into CAD (1990). The abilities of having different interfaces and inputs into CAD are necessary to representing design concepts graphically (Ullman 1990). Mechanical drafting courses are required in mechanical engineering curricula since the wide use of CAD. CAD courses are now prevalent in engineering curricula – but may not be required as is the case at The University of Maryland.

2.2.2 Sketching Advantages over CAD

Ullman (1990) and Thilmany (2006) state that sketching can be quick while CAD is not fast enough for certain applications in the design processes. Sketching allows for a quick and rough representation of an idea within seconds. Currently CAD does not have such capabilities due to its interface and requirements to create the representation.

Thilmany emphasizes the tedious quality of CAD or any computer program versus hand sketching and note taking. A prime example of such an issue is when one needs to add an item on their grocery list; if one had to go back home to their computer, turn it on, bring up the word processing program, type the note, and print it (Thilmany September 2006). Brainstorming and the changing of ideas are more compatible with sketching than with CAD.

The media in which sketching and CAD occurs are very different. The type of medium has restrictions and within sketching, the pencil and paper or chalk and blackboard are not quite as restrictive as that with CAD and the mouse and monitor (Ullman 1990). CAD can also give a false sense of what can be made and cannot, because the CAD program allowed a user to make it, does not always mean it can be manufactured. Manufacturing is critical to know and understand with the use of CAD. CAD can also make a poor engineer seem as good as a good engineer due to its interfaces and error checks (Thilmany September 2006).

The use of different media for creating graphical representations, such as paper, white board, computer screen, digitizer pen, or other digital media, can be compared to gain insight on their differences and similarities in design. A comparison study on the effects of different media was conducted by Bilda and Demikran (2003). When individuals designed alone using traditional media, including solely paper sketching, the problem's goals and purposes were changed frequently as a result of the ambiguous nature of sketching. More cognitive actions occurred while using traditional media than while using digital media. Interactions may be limited in digital media due to less familiarity and ease of use. In the reported result, digital media does not cognitively support the conceptual design phase as well as traditional media does (Bilda 2003).

McCormick (2007) emphasizes the use of sketching as a vital part of the engineering design process in both education and professional practice. Sketching promotes innovation by being free of constraints that could hinder creativity. Sketches act successfully as a channel between creative and critical engineering thinking. Simple technique knowledge of sketching and visual awareness are important attributes for engineers to have(McCormick 2007).

2.2.3 Definitions of CAD Use

CAD does assist in the design process (Thilmany September 2006). Thilmany interviewed mechanical engineers in the field and found that beginners in CAD are not as proficient as others with more experience. However, CAD is simpler to use than it ever has been before. CAD assists engineers to do good work with as few errors as possible due to its interfaces and error checks. CAD files also save paper and track files chronologically (Thilmany September 2006).

Lawson (2002) researched CAD in architecture to see if creativity in design is enhanced from CAD. A test was applied to architecture students' usage of CAD. It was found that CAD software can use incorrect description of features that inhibit creative processes. A "fake" creativity occurs rather than a genuine and real creativity (Lawson 2002).

The use of CAD and creativity has been researched within industry and engineering design education by Robertson (2007). Four effects of CAD tools on engineering design creativity were found by Robertson (2007). The one positive effect was that of enhanced visualization and communication. However, three negative effects were found including: limited and narrow thinking, premature fixation, and bounded ideation (Robertson 2007).

There is no doubt that CAD has revolutionized the engineering profession and lead it to new levels of productivity. This work is not an indictment of CAD use. This research seeks to strengthen the use of all tools available to engineers and engineering students. The proper appreciation of the value of sketching will not replace CAD use; it will increase student effectiveness when they turn to CAD.

Chapter 3: Use of Sketching in Capstone Design

Mechanical Engineering Capstone Design is a well established course at the University of Maryland. Many design concepts and tools are taught and used within the capstone design course, from House of Quality to materials selection. Research within the course began with the Summer of 2006 class by implementing design journals into the class. Students' use of documentation and sketching were analyzed by the Research in Science and Engineering (RISE) researchers. To expand upon RISE work and study previous semester design work, final reports from semesters Spring 2005 to Fall 2007 were collected and analyzed. The research questions of: 1) Do mechanical engineering students sketch? Do they know what sketching is? 2) What are their current sketching skills and sketching knowledge levels and are these adequate for engineering design? are addressed within this pilot research.

3.1 RISE 2006 and Cognition

This research on sketching in Mechanical Engineering Design began with the author's involvement in the Research in Science and Engineering (RISE) program during the Summer of 2006. The RISE summer project fed into a larger research plan with the ultimate goal of understanding student learning of the design process in order to improve design education methods. RISE is a National Science Foundation funded program that recruited undergraduates to conduct research and continue research in graduate school and their careers.

In Summer of 2006 Mechanical Engineering capstone design course at the University of Maryland, undergraduate students used design journals throughout their course-long design projects. The undergraduate course is a design project class where students form teams and work through a design problem that they come up with on their own, which is then approved by the instructor(s). Design journals were not a part of the regular class requirements. The design journal use was modeled after another capstone design course at the Montana State University (Jain 2006). Jain's and Sobek's (2006) goal was to analyze time spent in each of the four main stages of the design process: Project Selection (a.k.a. Refinement); Concept Generation, Refinement, and Design. The design journal entries were required and were reviewed every day by Sobek and his research team. Sobek shared his protocol, some journal research results, and consulted with the RISE team over the course of the Summer of 2006.

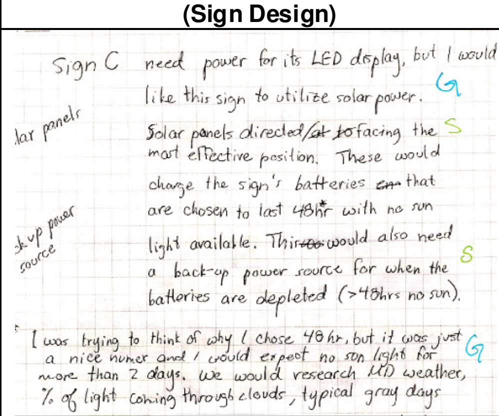
The RISE team had additional research goals beyond determining the amount of effort students spent in different design phases. Other goals included determining students' sketching skill, assessing design journal student buy-in, observing what functional roles student took within their teams, and finding cognitive processes that occur within the design process.

The RISE design journal application was implemented during the Mechanical Engineering capstone design course. The class in Summer 2006 consisted of two teams of six students (referred to as Teams K and W). The students were introduced to the use of design journals on the first day of class. Ten percent of the students' grades were dependent upon the use of their journals. Guidelines for keeping design journals (modeled after Sobek's) were given to each student along with a new, bound laboratory notebook. The RISE research team gave a sketching and journaling lecture on the benefits of the activities during the design process.

The RISE team collected student design journals every week and scanned in all pages. Journal entries were reviewed and coded for the following: (sketches and nearby notations) sketch levels and content. The sketch coding levels (McGown 1998) and content codings (Stempfle 2002) were developed by engineering researchers.

The coding of the content was used with "thinking operators" developed by Stempfle & Badke-Schaub (2002). The pilot study used a new design journal coding scheme for the written entries. Table 2 lists the categories and codes that were expanded from the four used by Stempfle. The objective of the pilot study was to determine if student thinking processes could be inferred from the journal entries.

Table 2: Summer 2006 Design Journal Coding Scheme for Notations

Content Code	**RISE Coding Cues for Design Journals** (Adapted from Stempfle,Sobek, et al.)	**Sample Design Journal Page from Student (W2) in Summer 2006 Pilot Study (Sign Design)**
Goal Clarification	**G** Objectives, requirements	 Sign C need power for its LED display, but I would like this sign to utilize solar power. G lar panels Solar panels directed/at to facing the S most effective position. These would charge the sign's batteries that are chosen to last 48hr with no sun light available. This would also need a back-up power source for when the S batteries are depleted (>48hrs no sun). back-up power source I was trying to think of why I chose 48hr, but it was just a nice number and I could expect no sun light for more than 2 days. We would research MD weather, % of light coming through clouds, typical gray days G
Solution Generation	**S** Alternatives variations options/ideas considering	
Analysis	**A** Questioning: form, function, performance	
Evaluation	**E** Questioning: design process or progress	
Decision	**D** Finalizing design ideas	
Control	**C** Verifying specifications, setting testing variables	

Interactions with engineering design teams allowed Stempfle to classify thinking in design to four basic cognitive operations: generation, exploration, comparison, and selection. The content oriented actions were taken to find a solution. Design processes are shown to have an interweaving of interactions and stages of design in order to come to the solution (Stempfle and Badke-Schaub 2002). More details on Stempfle's research are in Chapter 2.1.8 Value of Sketching in Design.

Each line of writing in the journals was coded in order to determine the degree to which different cognitive processes were used. First, the four operations highlighted in Stempfle's work were used for the coding. Table 3 displays the percent of journal entries aligned with each thinking operation summed by team. Team K spent more time on solution generation while Team W spent more time on problem exploration. Both of these cognitive operators are associated with creative thinking and widening the problem space. Keeping the design as open-ended and broadly-defined as possible leaves more options open.

Table 3: Teams K and W's Amount of Effort Spent on Each Thinking Operation (Grenier and Schmidt 2007)

	Exploration	Generation	Comparison	Selection
Team W	52%	40%	6%	2%
Team K	33%	47%	13%	7%

The more refined 6-stage coding scheme given in Table 2 was then applied to the journals. Table 4 displays the number of effort statements for a subset of four students. It is clear that one member (W2) spent much more time writing in their journal than the other students. Table 3 and Table 4 also show that most students spent the majority of their effort on solution generation and the least amount of effort on final design decisions. The relation between stages is the same for most team members.

Table 4: Effort Afforded to Each Design Stage for Four Students in Summer 2006 Pilot Study.

Student	Goal Clarification	Solution Generation	Analysis	Evaluation	Decision	Control
W2	131	165	88	17	10	0
W6	45	53	19	16	2	0
K1	3	29	7	8	3	0
K3	31	51	14	12	8	1

Not only do sentences or phrases indicate cognitive operations but sketches infer such operations as well. Sketch coding will now be discussed. Observe the sketch shown in Figure 4. An apparent decision was made to use Velcro in place of buttons for the design. The notations on the drawing indicate that specifics of the design are being thought about by the sketcher or perhaps discussed by the team

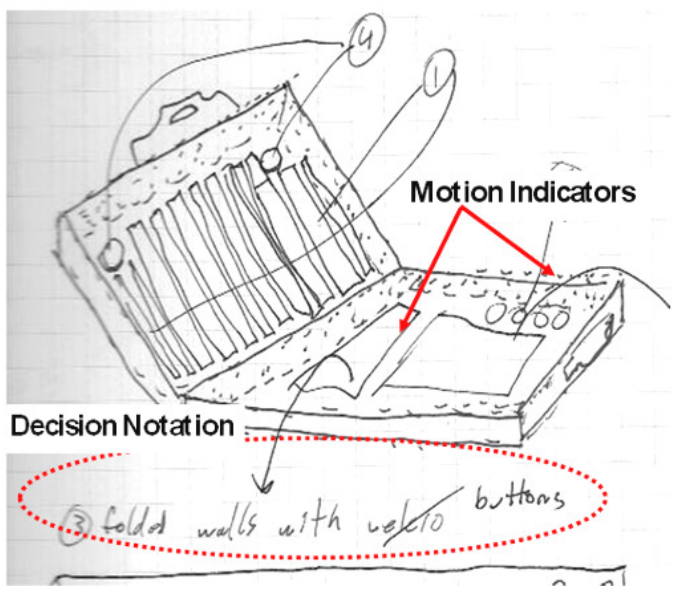


Figure 4: Annotated Sketch from Student Capstone Design Journal during Summer 2006

The Spearman Rank Correlation was applied to the rankings of sketches per student. Within this analysis, the sketches only from the specific sketch assignment given were ranked by four judges. These specific sketches within their design journal were coded by sketch quality using McGown's sketch coding scheme which was discussed in Chapter 2.1.3 Assessing Sketching Skill. In the McGown coding system 1 indicates a sketch of low quality and 5 indicates the highest quality. The sketches from the sketch assignment were chosen because they are a good basis of students' sketch skills since all students were sketching for a homework grade. As well, by taking the sketches from the sketch assignment they were made within the same time frame of a week. Table 5 displays the sketch coding results by judge for each student within Teams K and W.

Table 5: Summer 2006 472 Sketch Levels per Student

Sketch Ability: Ranked on Levels 1 to 5

Judges	1st Sketch	Overall Sketch		1st Sketch	Overall Sketch	
1	2	2	K1	1	1	W1
2	2	2		1	1	
3	2	1		2	1	
4	1	1		1	1	
1	4	2	K2	3	3	W2
2	3	2		3	2	
3	2	2		1	1	
4	3	2		3	2	
1	2	2	K3	2	2	W3
2	2	2		2	1	
3	2	2		1	2	
4	2	2		2	1	
1	1	1	K4	4	3	W4
2	1	1		3	2	
3	1	1		3	2	
4	1	1		3	2	
1	2	1	K5	1	1	W5
2	2	1		1	1	
3	4	2		1	1	
4	2	1		1	1	
1	3	2	K6	1	1	W6
2	3	2		1	1	
3	3	2		2	1	
4	2	1		1	1	

Table 6 shows the R values. Analysis was conducted on the average rating for all 6 sketches from each student's sketch assignment and their sketch fluency (the number of sketches). This analysis was modeled after the type of coding and analysis that Yang (2007) conducted in engineering design sketching. The correlation analysis was conducted on the average rating for the first sketch from the Sketch Assignment and their overall sketch fluency rating given by the judge. Many students' first sketches had higher ratings including significant difference in quality and included detail. This may indicate higher enthusiasm for the first ideas when doing the sketches.

Table 6 displays that the Spearman Rank Correlation (Lee 2000) resulted in larger R values when both teams were analyzed together (n = 12). The individual team results had a smaller n, resulting in negative correlations. Combining team data displays positive correlations. However in Table 6, both combined Team K and W results are not statistically significant because R is not greater than or equal to 0.591 in either case.

Table 6: Spearman Rank Correlations with Summer 2006 Sketches

Spearman Ranking Results	Rs
Team W Total Sketches	-0.671
Team K Total Sketches	-1.057
Both Team W and K Total Sketches	0.544
Team W 1st Sketch	-0.621
Team K 1st Sketch	-2.764
Both Team W and K 1st Sketches	0.341

Data gathered from the team design journals follows the general expectations of prior research on sketching and cognition. The literature predicted two findings for this small study. First, student design journals revealed the amount of time spent in design stages and the notation and sketch entries suggested what cognitive process was occurring at that specific time. Additionally, the information content in students' sketch notations (text coding) and sketch skill levels (sketch coding) varied by student and design process stage. An important observation that must be noted is the difficulty to get students to use their design journals. Most of the students did not display personal investment in their design journals, even with the efforts of the instructor and RISE team. However, the results of this small pilot study show that one can learn much about students' cognitive processes by examining their design journals. More details can be found in Grenier and Schmidt (2007).

3.2 Sketching in Capstone Final Reports

The intense design journaling required within the Summer 2006 Mechanical Engineering capstone design course could not be as easily integrated into the fall and spring semesters of the University of Maryland's capstone course due to the larger class sizes (between 70 and 110 students). Instead, final capstone reports' visual content was analyzed. All student teams are required to submit a final report on their semester-long design project at the end of the semester. These reports contain many visual representations. Reports' visual contents from Spring 2005 to Fall 2007 (excluding Fall 2006) were coded and analyzed. These semesters were taught under the same syllabus and course manager. Reports from Fall 2006 were excluded as they were prepared under a slightly different syllabus. The reports are considered University of Maryland property. The Department of Mechanical Engineering gave permission to use these reports for research within the department.

3.2.1: Visual Representations in Capstone Course Final Reports

A total of 262 students worked on and wrote the 48 final reports submitted during these semesters. Table 7 shows the number of reports in each semester, the average grade and the number of visuals among each semester.

Table 7: Capstone Final Reports Data Overview

Semester	# of Reports	Avg Grade	# of Visuals
Spring 2005	5	90.5	96
Fall 2005	10	89.6	409
Spring 2006	7	88.9	161
Spring 2007	19	88.0	601
Fall 2007	7	87.0	230

The summary data indicate that students do use a variety of visual representations in the final reports. Figure 5 displays the percentages of each category of visual representations (Photographs, CAD, Line Drawings, and Sketches). This shows that students are creating visual representations on some type of media (paper, journal, etc.) and holding them for review and refinement until the final reports are compiled. Thus there are activities that could be directed towards reporting in a design journal and the motivation can be the value in interim documentation to prepare for more formal reports.

Sketches were not required in reports before Fall 2005. From Fall 2005 forward, each final report was required to include sketches of the best five design concepts. Sketches remain around 38% of the total visualizations in final reports. This indicates that students are including more than the required five sketches.

The incidence of CAD drawings varies greatly in percentage and absolute number as shown in Figure 5. Students may need some direction on when it’s appropriate to use CAD drawings.

Photographs represent more than 20% of the visuals used in reports. This reflects the fact that every student has a digital camera built into his or her telephone, and the digital camera is almost as common as a laptop. More in-depth analysis on the subject matter and the details included codes for each photo visual is necessary to determine how the photographs are being used.

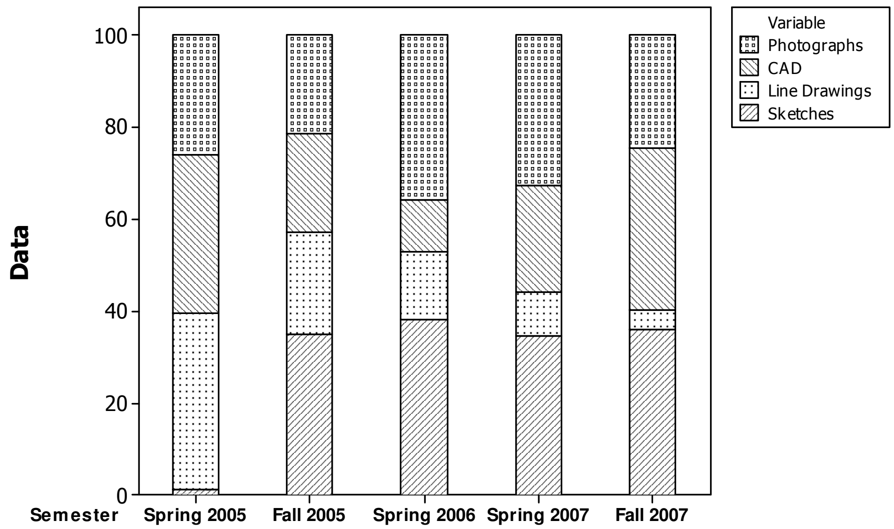


Figure 5: Percentages of Visuals in Final Reports

ANOVA was done to determine the validity of analyzing the Final Report data together when it spanned several semesters, teams, and design projects. ANOVA was applied to each type of visual. A result of a p-value less than 0.05 is significant. The ANOVA results in Table 8 show no statistically significant differences between the numbers of visuals by type included in the reports when grouped by semester for CAD drawings and Photographs. Since there was only 1 single sketch in the group of five 5 Final Reports in Spring 2005, it’s not surprising that there is a significant difference. However, after excluding that semester, ANOVA indicates no significant differences in the Final Report samples of sketches.

Table 8: ANOVA for Visual Type by Semester (Westmoreland et al. 2008)

DOF	Visual Type	Pooled Standard Deviation	F-Value	P-Value	Result
47	Sketches	7.613	3.07	0.026	**Significant**
47	Line Drawings	4.499	4.54	0.004	**Significant**
47	CAD Drawings	8.579	1.05	0.394	
47	Photograph	10.17	0.13	0.970	
42	Sketches *Excludes S05*	4.138	0.85	0.475	

The Pearson Correlation (Lee 2000) values were calculated to determine if visual representations types within the capstone Final Reports were correlated. Table 9 shows the results of the Pearson correlation for N=48 and p=0.05. The total number of visual representations for all five semesters were analyzed and found to have no linear relationships. The strongest correlation is between the number of CAD drawings and photographs with a correlation coefficient of 0.456. An interesting fact from the Pearson correlation is that line drawings decrease as all of the other visual representations increase.

Table 9: Visual Representation Type Pearson Correlation (Westmoreland et al. 2008)

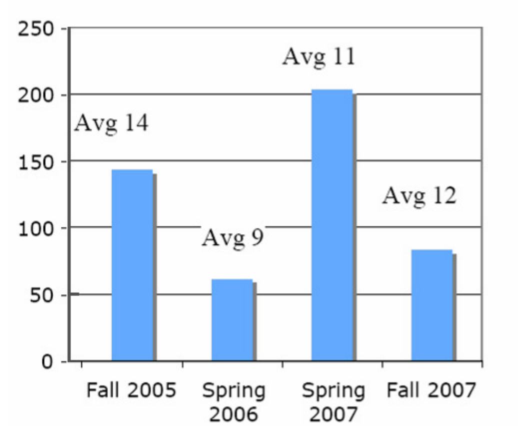
Variables	# of Sketches	# of CAD Drawings	# of Photographs	# of Line Drawings
# of Sketches	1	**0.394**	**0.364**	**-0.314**
# of CAD Drawings		1	**0.456**	-0.129
# of Photographs			1	-0.141
# of Line Drawings				1

3.2.2: Sketches in Capstone Final Reports

The sketches from the Final Reports are focused on within this report. Chapter 4 goes into further detail on Final Report sketches. Sketches were coded by: identification number, page number, design phase, subject, McGown (1998) sketch coding level, and Yang (2003) sketch coding level. The new content-based sketch coding scheme proposed in this thesis is also applied to the sketches.

The total number of sketches per report varies per semester as seen in Table 10. Spring 2007 had 19 final reports while Fall 2007 had 7 final reports; this explains the difference in total number of sketches. The average number of sketches per team within semester is labeled above the bar of each semester (Table 10). The averages are fairly consistent falling between 9 and 14 sketches per team.

Table 10: Total Number of Sketches in Final Reports



The design phase in which a sketch occurred was determined by the sketch placement within the final report. The majority of sketches within the reports were included during concept generation. A factor determining the placement of sketches in these reports is that an individual sketching assignment was given to each student during concept generation. However, sketches were also found within the detailed design phase, which is when CAD usually takes over the design process. Sketches may be used for another purpose outside of concept generation. More research is needed on the sketches and their intended purpose when used in the various design phases.

The frequency and types of sketching in Capstone Final Reports varies from team to team. Coding of more specific details relative to mechanical engineering design will allow for more insight on sketching. Further details on design phases, subjects, and details of sketches are analyzed and discussed in Chapter 4.

3.3 Conclusions from RISE 2006 Research and Final Reports

The RISE 2006 and Final Report research shows that students are sketching however not to the extent or quality that is expected. Most sketches are low in quality (according to McGown's (1998) sketch coding scheme). Many of the students from Summer 2006 did not sketch in their design journals unless they were required to do so. The sketches required can easily be found in students' design journals.

Sketches were also found in Final Reports. Sketching is mainly used within the concept generation design phase which is partly due to the sketch assignment given during concept generation. The majority of effort within the design process is given to goal clarification and solution generation. The majority of design decisions occur in the later stages of the design process as seen with the use of the design journals. From this pilot research, further research with larger data sets was inspired to delve into more specifics.

Chapter 4: Creation of a New Content-Based Sketch Coding Scheme for Mechanical Design

Sketch coding schemes have been created by researchers to determine the quality of sketches. Capstone design student sketches for a Paper Boat design assignment were analyzed using two existing coding schemes and the results are discussed. A new sketch coding scheme was created to analyze the nature of engineering students' sketches, rather than students' sketching skills. The new sketch coding scheme is content- based. This allows for more specific findings and inferences about the intention behind the sketch.

4.1 Paper Boat Project Coding

During fall 2007, the Mechanical Engineering Department held 2 sections of the capstone design course: ENME472 Sections 0101 and 0102. Section 0101 followed the same standard syllabus and schedule used since Fall Semester 2005. ENME 472 Section 0102 was an experimental section of the capstone design course. Hereinafter ENME472 Section 0101 will be referred to as "472-1" and Section 0102 will be referred to as "472-2". 472-2 focused on developing student skills of sketching, documentation, and prototyping in addition to conducting the standard semester-long design project. The capstone project interim and final report deadlines were the same for both sections. The course manager, Dr. Linda Schmidt, oversaw both sections and approved 472-2's modifications. Rebecca Currano, a Stanford University Mechanical Engineering Design Doctorial student, was the Section instructor and this author (Ashley Grenier, University of Maryland Mechanical Engineering Master's student) was the teaching assistant.

One of the non-traditional elements of the experimental capstone design section 472-2 was the Paper Boat project. The Paper Boat Project was an introductory, two week project assigned to the senior capstone Mechanical Engineering course, 472-2. Ostensibly, the assignment was to create a boat out of paper-based materials. The objectives of the assignment were as follows:

- Immediately engage students with the course;
- Introduce students to one another;
- Begin learning about and using their idealogs; and,
- Practice sketching through homework assignments and idealog postings.

In short, the Paper Boat Project provided a quick and simple design problem to prepare students for the semester-long design project.

The Paper Boat Sketch Assignment is studied here because the assignment displays the students' sketching skill levels as they entered the class. Students also had freedom to use sketching in whatever way they believed would assist during concept generation. For example, some students chose to doodle concept images and others applied the rules of Free Body Diagrams to their sketches. The sketch assignment also encouraged the expression of different design concepts and ideas, all the while allowing variety in type and detail of sketches submitted for credit.

4.1.1 Methodology of Paper Boat Sketch Coding in Section 472-2

The students' first assignment of the semester was to sketch concepts of a paper boat that they would build and test. Students were instructed to sketch in their idealogs. As used in this course, idealogs were bound paper notebooks where students would record project and meeting notes, concept ideas, tasks, and whatever else was needed to assist in the design process. Creating an idealog was a course requirement and part of each student's grade in 472-2. The Institutional Review Board (IRB) at the University of Maryland approved the sketching data collection in the ENME472 course, under the project title: "Idealogs in team-based design". The IRB Application Approval and Consent Form are found in Appendix A.

The Paper Boat Sketching Assignment allowed students to explore ideas during the Concept Generation phase of design. The Paper Boat project had specific design requirements and goals. The paper boat was to carry a load and float down three tiers of the ODK Fountain on UMD's campus mall. The larger the ratio between load weight and boat weight, the better the student's grade. Figure 6 shows two boats in the ODK Fountain at the University of Maryland.

Figure 6: ODK Fountain at the University of Maryland during the Paper Boat Race

The sketch assignment given was:

> "During your team project's Concept Generation phase, many ideas of design concepts as a whole and their specific parts are flowing in and out of your brains and conversations. To help yourself and your team mates to better see and understand these design concepts, sketch your ideas on paper by hand. Include annotations on sketches to aid in communicating your thoughts and goals of the concept to others and to aid in reminding yourself what you were trying to communicate.
>
> Sketch four of your concepts for this project in your idealog. Include a brief overview of each concept with annotated parts and call outs."

Students sketched the four design concepts in their idealogs. Criteria for grading the sketch assignment included: the number of sketches completed; the clarity of the sketch; presence of appropriate labels and annotations; and, the degree of design thoughtfulness indicated by the sketches. There were no points deducted for poor quality sketching if the sketch meaning was made clear by multiple views, labels and annotations. Each assignment was graded with a check plus, check, check minus, or zero. Figure 7 is a page from a Paper Boat Sketch Assignment that received a check plus. Figure 8 is a page from a Paper Boat Sketch Assignment that received a check minus. The differences between clarity of sketches and degree of thoughtfulness can be seen between these examples.

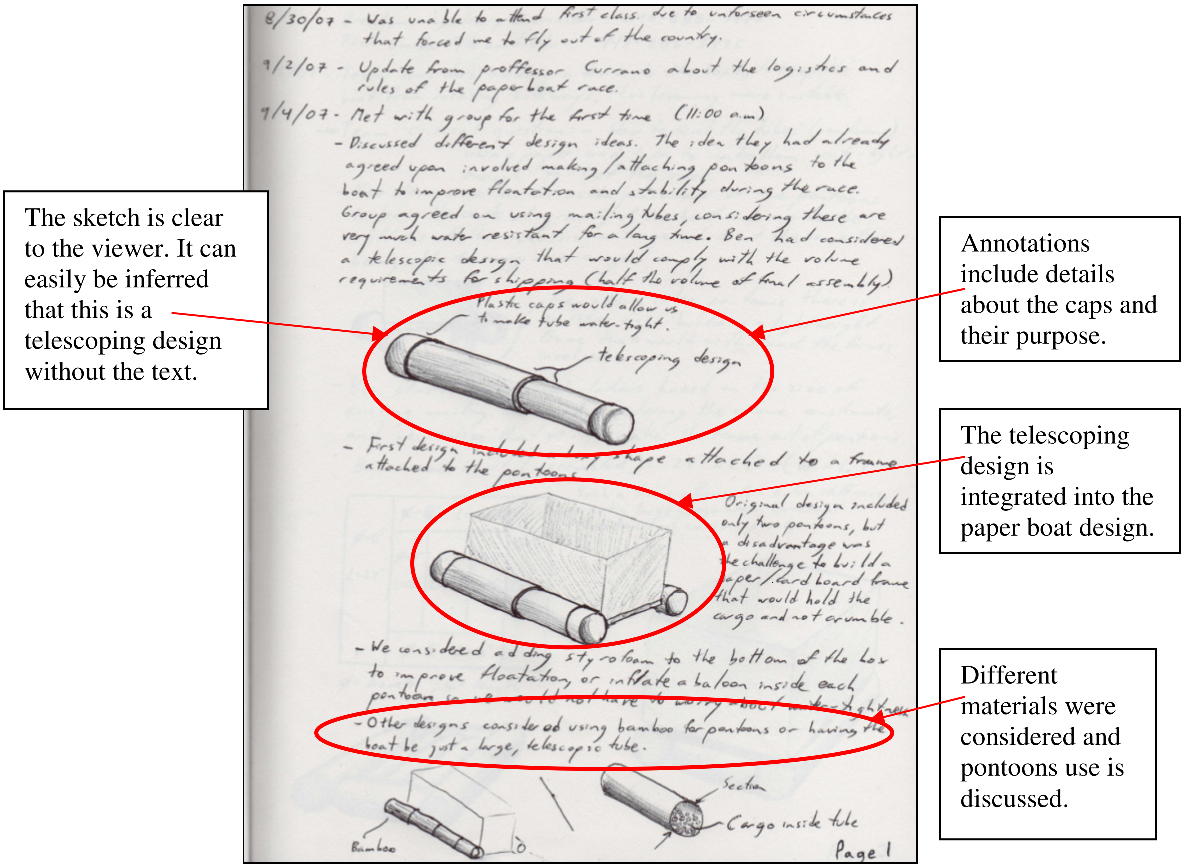


Figure 7: Check Plus Paper Boat Sketch Assignment

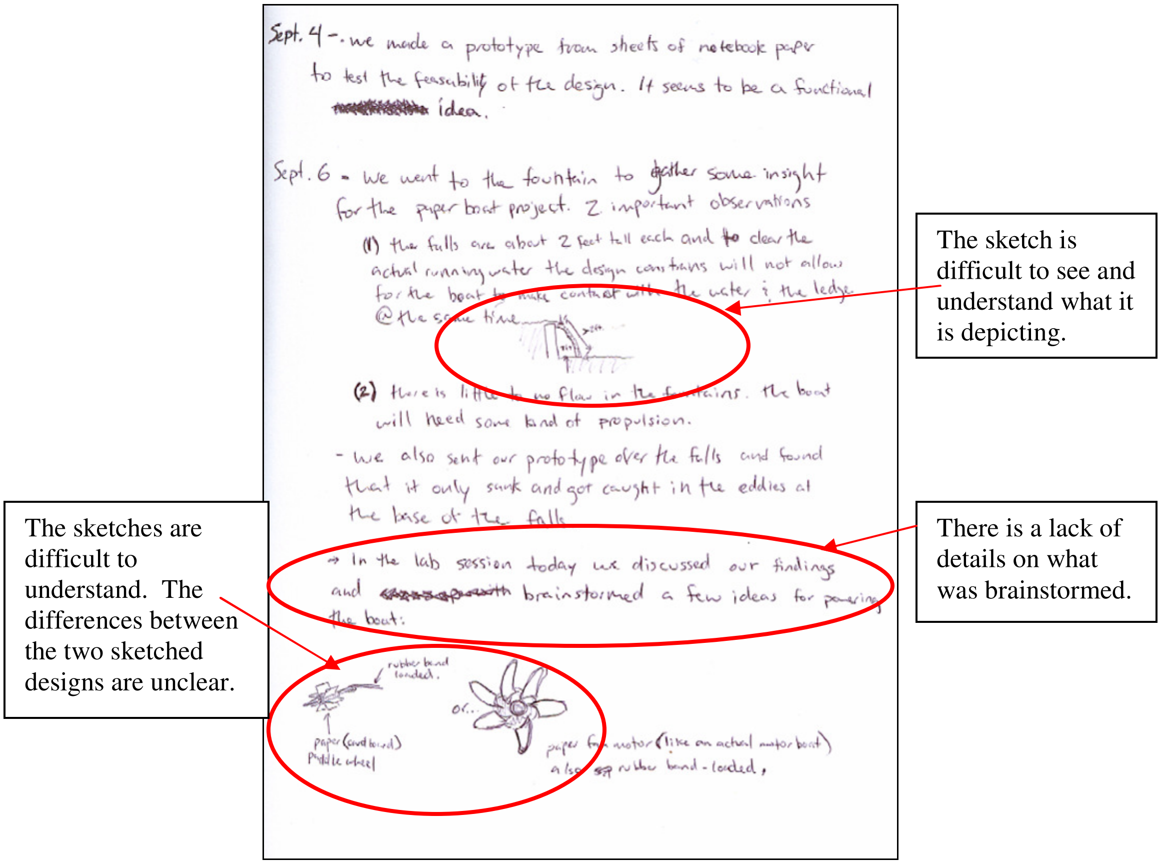


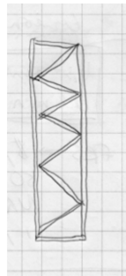
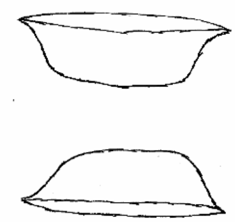
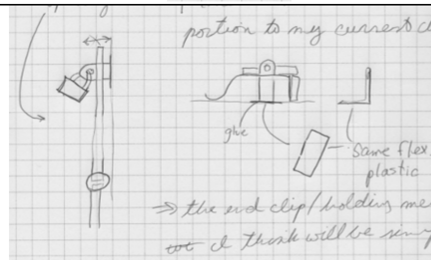
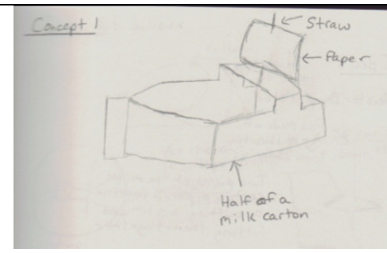
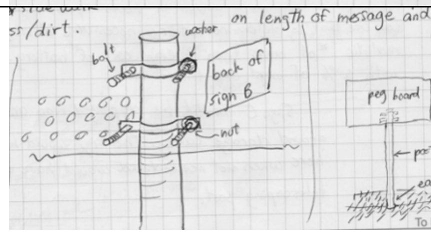
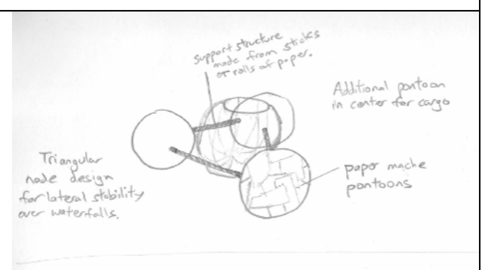
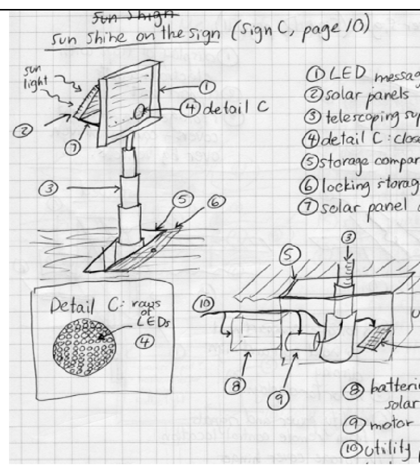
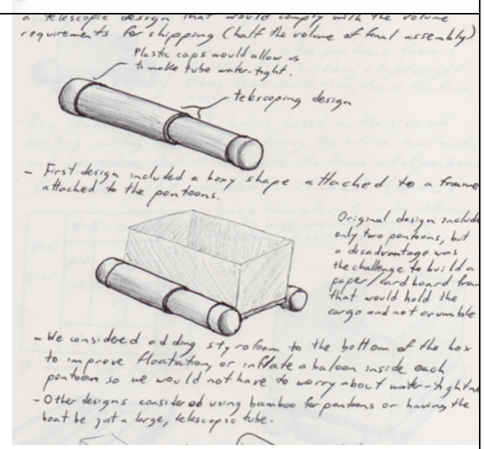
Figure 8: Check Minus Paper Boat Sketch Assignment

The Paper Boat design sketches were reviewed and classified according to McGown's (1998) and Yang's (2007) sketch coding schemes. The coding was conducted by two Mechanical Engineering design graduate students. The two people that coded the sketches will be referred to as Researcher 1 (R1) and Researcher 2 (R2). R2 was the author of this thesis. R2 was more familiar with the project, the students, and had previous experience with the coding schemes. R1 was new to the project, students, and sketch coding schemes.[2] Dual coding was done to test coding scheme reliability, differences in application, and strengths of both coding schemes.

[2] Researcher 1 was Sophoria Westmoreland, a University of Maryland Mechanical Engineering graduate student.

The McGown (1998) and Yang (2007) sketch coding schemes were applied by the researchers. Sketch coding schemes have been created to learn more about design and the design process. McGown's research produced a coding scheme to differentiate between sketches done in the early stages of the design process. McGown created a 5-level sketch coding scheme based upon complexity of sketches and demonstrated sketching skill. (More details can be found in Chapter 2). The coding scheme was created to analyze and characterize sketches drawn by final year engineering students. Descriptions of McGown's sketch levels and matching examples are given in Table 11. The author assigned the codes for the examples. Examples within Table 11 are taken from the RISE 2006 data (Chapter 3) and the Paper Boat Sketch Assignment. McGown's Level 5 is reserved for the most detailed sketches; Level 5 sketches are two or three dimensional drawings displaying total product form complete with all dimensions and annotations (McGown et al., 1998). There were no Level 5 sketches submitted from students.

Table 11: Illustrations of McGown's Sketch Levels

McGown's Sketch Level	Sketch Sample from UMD Study in Summer 2006	Sketch Sample from 472-2 Paper Boat Sketch Assignment
Level 1 sketches consist of line drawings that portray basic principles without any details and limited labels.		
Level 2 sketches show a concept's working principles without product form details, but may include brief annotations.		
Level 3 sketches display product form and may contain shading and brief annotations.		
Level 4 sketches show product form with annotations, illustrations of features and detail, and may include dimensions.		

Yang's coding scheme is the second one applied to the Paper Boat sketches. While McGown's research goal was to learn more about sketching during design's earlier stages, Yang's goal was to examine the role of sketching in design and its impact on engineering design outcomes. Yang's sketch coding scheme was based on drawing style, and level of detail. Yang also used 5 levels of sketching performance from least skilled to most skilled. Level 1 sketches display the lowest drawing ability. Level 5 sketches display the highest drawing ability (Yang 2007). Chapter 2 includes all known details on Yang's sketch coding criteria.

To reiterate, the Paper Boat sketches were coded by R1 and R2. Each researcher coded each sketch twice, once with McGown's scale and once with Yang's. R1 and R2 applied the coding schemes to the sketches separately. The author created an Excel spreadsheet with each sketch numbered and recorded with its 4 corresponding codes: R1's McGown and Yang codes and R2's McGown and Yang codes. Creating the database allowed for summary calculations and analysis of the 418 sketches (not all 459 sketches were coded by both researchers) from the Paper Boat assignment. The results are discussed in the next section.

4.1.2 Results and Analysis of Paper Boat Coding

First, the coding of the Paper Boat sketches was analyzed to determine inter-coder reliability or, how well the two researchers agreed on the coding. The Paper Boat Sketch Assignment was completed by 35 of the 36 students in the 472-2 class. The assignment instructed students to sketch four concepts. A total of 459 sketches were submitted for this assignment, 13.11 sketches per student on average. There are more than four sketches submitted from each student because students would sketch multiple views, parts, etc. Some students included more than four concepts within their assignment. A total of 418 of the 472-2 sketches were used for this comparison of coding schemes. (Coder R1 was unable to code some of the assignments.)

Table 12 displays the number of sketches by McGown and Yang skill levels[3], coding scheme, and researcher. Table 13 displays the same information as percentages. There are two clear observations to make. Table 12 and Table 13 indicate that the majority of sketches are both McGown and Yang sketch levels 1 and 2. Table 12 and Table 13 also show differences between coding scheme interpretations by researcher, thus the question of inter-coder reliability should be addressed first.

Table 12: Total Number of Sketches in Each Level

	McGown		Yang	
Levels	**R1**	**R2**	**R1**	**R2**
1	188	103	359	295
2	212	296	46	106
3	14	15	10	11
4	4	4	3	6
5	0	0	0	0

Table 13: Percentages of Sketches in Each Level

	McGown		Yang	
Levels	**R1**	**R2**	**R1**	**R2**
1	44.98	24.64	85.89	70.57
2	50.72	70.81	11.00	25.36
3	3.35	3.59	2.39	2.63
4	0.96	0.96	0.72	1.44
5	0	0	0	0

Table 14 and Table 15 better clarify differences between R1 and R2 sketch coding for both schemes. Table 14 displays McGown sketch coding by R1 and R2 in a fashion that emphasizes areas of agreement. The data was obtained with "if" statements applied to the database. A sample statement is "If(AND(R1=1, R2=1), 1,

[3] Recall that McGown and Yang sketch coding schemes have 5 skill levels. In each scheme 1 is the lowest level and 5 is the highest level. It is natural to report them together, differences are addresses later in this chapter.

0)”. This means if R1 and R2 both coded a sketch as a level 1, then a 1 will be placed in the upper left hand corner cell, if that is not true a 0 is placed in the cell.[4] The cells were then summed according to the “if” statement.

Table 14 shows that the greatest agreement between R1 and R2 is found when identifying sketches as McGown’s sketch level 2. The definition of McGowan’s level 2 is that the sketch shows a concept’s working principles without product form details, but may include brief annotations. The largest discrepancy between researchers R1 and R2 is within identifying Level 1 sketches (85). McGown’s level 1 sketches are line drawings that portray basic principles without any details and limited labels. The researchers’ differences in judgment are probably due to interpreting “limited and brief annotations.” There are various small discrepancies among the other skill levels but nothing of significance. The diagonal cells in Table 14 and Table 15 represent the number of sketches in each code level that both R1 and R2 agreed upon.

Table 15 repeats the comparisons for Yang’s coding scheme. Table 15 shows the same difference in classifying sketches as Yang level 1 or 2. The researchers agreed that 294 sketches were in Yang’s level 1 class.

Table 14: McGown Coding on Paper Boat Sketch Assignments

McGown	1	2	3	4	5	R1
1	103	0	0	0	0	
2	85	210	1	0	0	
3	0	2	13	0	0	
4	0	0	0	4	0	
5	0	0	0	0	0	
R2						

[4] The cells in Table 14 and Table 15 are numbered first by column, then by row. Table 14 (2,1) holds a value of 0, and (1,2) holds a value of 85.

Table 15: Yang Coding on Paper Boat Sketch Assignments

Yang	1	2	3	4	5	R1
1	294	1	0	0	0	
2	64	41	0	0	0	
3	0	4	7	0	0	
4	0	0	3	3	0	
5	0	0	0	0	0	
R2						

Table 16 displays the number of sketches coded by specific levels. R1 labeled 186 sketches as both McGown and Yang level 1. R2 labeled only 97 of those same sketches with both McGown and Yang level 1. Considering sketch level 2, there is less agreement. R1 appeared more likely to give a lower level in both schemes. There were 125 sketches coded as a McGown level 2 and a Yang level 1 by both researchers. As well, there are only a small number of sketches labeled as McGown level 1 and Yang level 2. If sketch levels 1 and 2 were combined, researchers would have almost perfect agreement. Table 16 indicates that McGown's and Yang's definitions can be applied differently to the same sketches. McGown's definitions distinguish more sketches by placing them into either level 1 or level 2 classes than Yang's definitions.

Table 16: Total Number of Sketches by Researcher

McGown	Yang	R1	R2	R1 & R2
1	1	186	97	97
2	2	42	95	37
3	3	7	6	5
4	4	3	4	3
1	2	2	6	1
2	1	168	196	125

The Pearson correlation coefficient was calculated to evaluate the correlations between R1 and R2 Paper Boat Sketch Assignment coding. The Pearson correlation determines to what extent the relationship between two random variables are linear, and, therefore correlated instead of random. Table 17 displays that the relationships between R1 and R2 within McGown and Yang sketch coding schemes from the Paper Boat Assignment sketch data.

Table 18 displays the p-values that are associated with the linear correlation values in Table 17. A p-value of 0.05 and lower means that there is a statistically significant correlation. R1's and R2's correlation on the coding of McGown level sketches is statistically significant (p-value = 0.048). R1's and R2's correlation on the coding Yang level sketches is also statistically significant (p-value = 0.006). The relationships among R1 and R2 coding with McGown and Yang sketch coding schemes are strong, 0.881 and 0.972 respectively. Of the variables compared, the most important for inter-coder reliability is that of R1 McGown to R2 McGown and R1 Yang to R2 Yang, and those correlations are 0.881 and 0.972 respectively. Pictorially this makes sense when looking at Table 14 and Table 15.

Table 17: Pearson Correlation Paper Boat R1 and R2 Values

	R1 McGown	R2 McGown	R1 Yang	R2 Yang
R1 McGown	1	0.881	0.641	0.803
R2 McGown		1	0.202	0.425
R1 Yang			1	0.972
R2 Yang				1

Table 18: Pearson Correlation Paper Boat p-Values

	R1 McGown	R2 McGown	R1 Yang	R2 Yang
R1 McGown	*	0.048	0.243	0.102
R2 McGown		*	0.744	0.475
R1 Yang			*	0.006
R2 Yang				*

The Pearson correlation was conducted comparing R1 McGown to R1 Yang and R2 McGown to R2 Yang to see if there is any relationship between McGown and Yang sketch coding schemes. This data is not statistically significant (p-value =

0.243 and 0.475 respectively). A stronger relationship occurs with R1 McGown to R1 Yang (0.641) than that of R2 McGown to R2 Yang (0.425). As well, R1 McGown was compared to R2 Yang and R2 McGown to R1 Yang. This data correlation is not statistically significant nor was it expected to be as they are different coding schemes.

4.1.3 Discussion of Paper Boat Coding

The Paper Boat Sketch Assignment research revealed differences between McGown (1998) and Yang (2007) sketch coding schemes and how they are interpreted and applied by researchers. Coder reliability exists when applying McGown and Yang coding schemes to the Paper Boat sketches. The Pearson correlation analysis shows that the application of the coding schemes by different researchers was consistent for this sample. There was some disagreement in classification of sketches as levels 1 and 2. The differences were overshadowed by the large number of classification coding agreements. The differences between researchers may be a result of coding scheme(s) misunderstanding by one or both researcher(s) and/or lack of information and detail within the coding scheme(s).

Consider the many sketches coded as McGown level 1 by R1 and McGown level 2 by R2. R1 found 188 McGown level 1 sketches. R2 found 103 McGown level 1 sketches. If any notation was present on the sketch, R2 classified the sketch as a McGown level 2. R1 labeled sketches according to their quality as the main indicator for level 1. Therefore R1 consistently labeled sketches of low quality as McGown level 1 whether or not they included notations. This was the major discrepancy among McGown coding by researchers. The definition of annotations and labels may be the source of the discrepancy. The recommendation for applying McGown's coding scheme is to be very specific about the difference between annotations and labels. A label is a single word, or a noun referring to a concept, while an annotation has more details with descriptors and details beyond one noun.

The Yang coding scheme was easier to consistently apply. The lack of information and details on Yang's sketch coding scheme allowed for a range of interpretation. Within Yang coding of the Paper Boat Sketch Assignment, there was no consistent difference between the coding of various sketch levels. The openness of Yang's sketch coding scheme to interpretation is also a disadvantage. Application of Yang's coding scheme may not be repeatable due to the lack of explanation of sketch levels. Yang level 1 is the most populated class. 294 of 418 (70.3%) sketches were coded by both researchers as Yang level 1. The Yang coding scheme did not provide criteria to differentiate between the low quality sketches found in this assignment. McGown's class descriptions refer to notations in addition to quality of sketch.

The correlation values for R1 and R2 were very high (0.881 for McGown and 0.972 for Yang coding schemes) seemingly implying broad agreement in sketch classification. However, there were some differences, especially among R1 McGown level 1 and R2 McGown level 2 coding. Both Yang and McGown coding results indicate that R2 could be more lenient in their coding than that of R1, or R1 is harsher in coding.

The Paper Boat Sketch Assignment analysis led to the following major observations:

- McGown and Yang sketch coding schemes primarily assess the skill of the sketcher.

- The vast majority of 472-2 students are low quality sketchers.
- All of the 472-2 teams completed the Paper Boat project regardless of their sketching performance.

Therefore, to the extent that sketches were useful in the Paper Boat design project, the McGown and Yang sketch coding schemes did not recognize all of the valuable elements of the sketches.

4.2 New Content-Based Sketch Coding Scheme

The results of the Paper Boat coding inspired our research team to build upon those previous coding schemes and create a more specific sketch coding scheme for mechanical engineering design. There are visual methods of design description used within mechanical engineering that may fall into the category of general design sketching; Free Body Diagrams (FBDs) and exploded views of assemblies are examples of types of visual depictions in sketches or drawings that would not normally found in designs done by artists or architects. Yet, FBDs and assembly views convey special meaning and indicate more focused design analysis than just a general sketch of an object's form. The specific visual elements and styles of these types of drawings are not addressed in either McGown or Yang's sketch coding schemes. Their sketch coding schemes were adequate for assessing general sketching skill level but not for other purposes of analyses. More details of new content-based sketch coding scheme are in Chapter 2. There is an opportunity for more visual attributes of engineering student sketches to be considered and coded to develop a more content-based sketch coding scheme.

A content-based sketch coding scheme was created to analyze the type of visual representations used by mechanical engineers in design reports. The content-based coding scheme integrates aspects of McGown and Yang schemes and extends them to allow differentiation among the content of the sketches. McGown's and Yang's schemes are more quality and skilled based than content-based. The proposed content-based scheme aims to classify the sketch based on its probable purpose. The question the new coding scheme seeks to answer is: "Why are they drawing the sketch or the line within the sketch?"

The content-based coding scheme parameters are listed in Table 19. The new coding scheme elements included subject matter of each sketch and details on the type of sketch. Additionally, the code includes the design phase for which the sketch was created. The design phases are defined as: concept generation, embodiment, detailed design or redesign. The design phase can be inferred by either: when the assignment was given (for sketches in a specific assignment) or the section of the report in which the sketch appears.

Table 19: Coding Scheme Parameters (Westmoreland et al. 2008)

Code	Description of Code
Visual Number	Indicate Visual, Report and Page Number
A- Visual Type	Sketch, Line drawing, CAD, Photograph, or Simulation Output
B- Design Phase	1 Concept generation 2 Embodiment design 3 Detail design 4 Redesign
C- Sketch Lesson Indicator	
D- McGown Sketch Level	
E- Yang Sketch Level	
F- Subject Matter of Visual	1 Entire artifact or artifact component of subsystem 2 Exploded view of assembly 3 Artifact feature 4 Artifact in operation 5 Free body diagram
Details Included on Visual	G- Part of Multiple Object Sketch H- Motion Indicators I- Isometric view J- Set of orthogonal views K- Part of a set of visuals L- Applied forces indicated M- Multiple views of one object N- Dimensions

A- Visual Type

For further research of representations within Mechanical Engineering design, the type of visual was coded as one of the four categories: Sketches, Line Drawings, CAD Drawings, and Photographs, as discussed in Chapter 3. Sketches, CAD drawings, and photographs are fairly self explanatory. In this research, line drawings are straight edge drawings or Non-CAD Program drawings. During this work, it can be seen that there are more visuals other than sketches within these final reports. Types of visuals can have different purposes and contexts.

B- Design Phase

The design phase associated with a sketch is critical data in the coding scheme. The design phase in which a sketch occurs signals the timing of the sketch and what types of decisions and tasks are going on while the sketch was created.

C- Sketch Lesson

Another code implemented was that of Sketch Lesson. If there was a sketch lesson given within the class, it is important to note if students grasped sketching concepts and are implementing them into their work. Visual type and sketch lesson are not factors examined within this segment of the research since only sketches will be analyzed and a sketch lesson was not given during any of the semesters of the final reports.

D and E- McGown and Yang Sketch Levels

McGown and Yang sketch coding schemes were implemented as well to obtain quality details of the sketches. These coding schemes are further described in Chapter 2.

The classes of subject matter (F) and detail type (G-N) given in Table 19 must be discussed further. The subject code includes variations on the object of the sketch to fit the types of visual representations seen in mechanical engineering report work. The five classes of subject matter code are discussed below.

F1- Entire Artifact Subject

The entire artifact or artifact component of subsystem (F1) subject code is applied to sketches that display the artifact as a whole entity. Figure 9 is sketch that portrays an entire artifact with specific features. This sketch is considered a McGown and Yang level 4, which is a high skilled level sketch. The entire artifact sketch (F1) signals overall thought on the entire system and how parts will interact with one another and how it will be used.

F2- Exploded View of Assembly Subject

The exploded view of assembly subject code (F2) is for sketches with parts of an artifact separated in a fashion where it is easy to interpret how those parts fit together. Figure 10 is a sketch of an exploded view of assembly (F2). It is coded as McGown level 2 and Yang level 1, which indicate low sketch skills. The sketch shows thought of assembly and how individual pieces interact with one another.

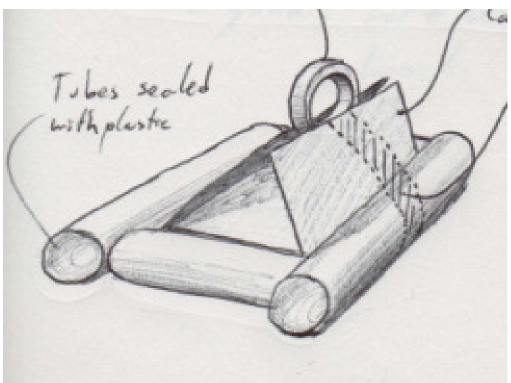


Figure 9: Entire Artifact Subject (F1)

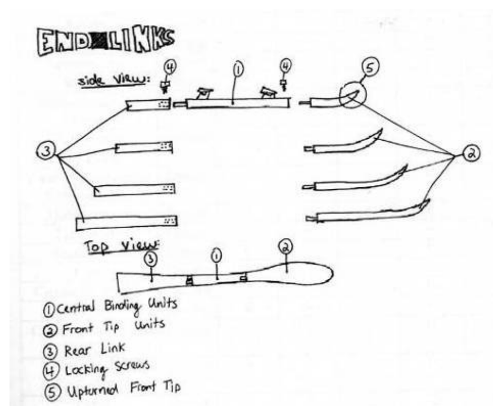


Figure 10: Exploded View of Assembly Subject (F2)

F3- Artifact Feature Subject

The artifact feature subject code (F3) is applied to sketches that are of a specific part or physical characteristic of the overall artifact. Figure 11 is an example of an artifact feature sketch that includes motion indications as well. This is a McGown level 2 and Yang level 1 sketch. Artifact features (F3) indicate thoughts on specifics of functioning.

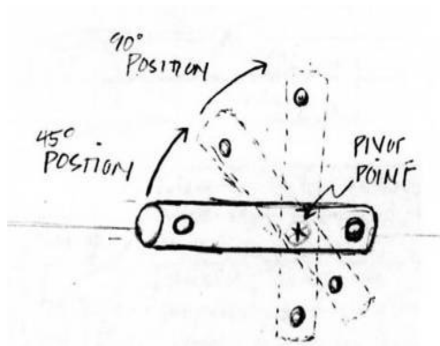


Figure 11: Artifact Feature Subject (F3)

F4- Artifact in Operation Subject

The artifact in operation subject code (F4) is important within mechanical engineering design because the human interaction with products is a critical aspect to consider within design. Figure 12 is an example of an artifact in operation sketch. The human is interacting with the artifact (spoon) in two different scenes. Dimensions are included within this sketch as well. This sketch is a McGown and Yang level 2. Artifact in operation (F4) sketches show thought on how the product will be used and implemented in various contexts. Also, artifact in operation (F4) sketches can assist in showing relative size of the artifact.

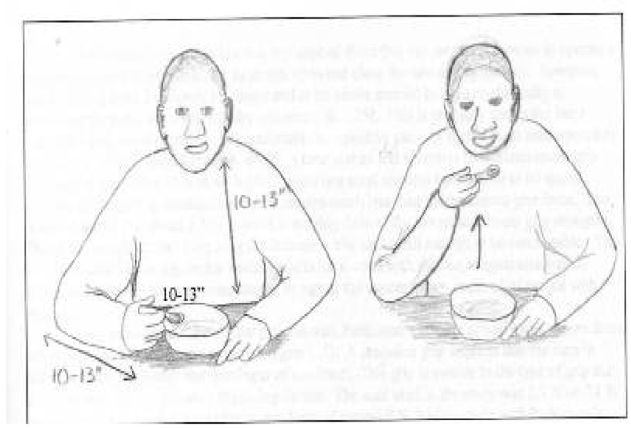


Figure 12: Artifact in Operation Subject (F4)

F5- Free Body Diagram Subject

Free Body Diagrams (FBDs) (F5) are one type of sketch commonly created by engineering students during design. The FBD subject sketch (F5) can include formatting indicators, such as force arrows, coordinate axis, and labeling. An example of such a sketch is given in Figure 13. This sketch is a McGown and Yang level 1. The Free Body Diagram sketch (F5) given in Figure 13 includes the follow detail codes: motion indication (H) and applied force (L), as well it depicts a set of sketches (K), as discussed below.

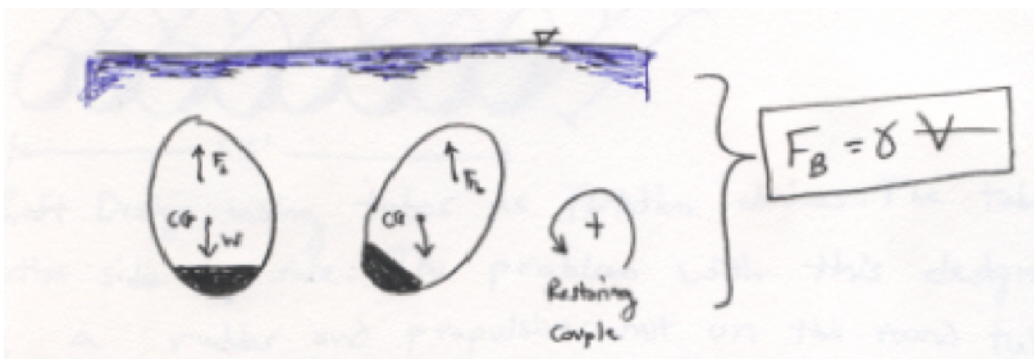


Figure 13: Free Body Diagram Subject (F5)

The detail codes within the new content-based sketch coding scheme designate what details were thought by the researchers to be prevalent in mechanical engineering sketches. Sketches may have none of the specified details or multiple types of details. The detail code notes specific characteristics within a sketch. Some characteristics may be used with more than one sketch subject.

G- Part of a Multiple Object Sketch

The multiple object sketch code (G) is for sketches that are on the same page but are very different from one another and vary in subject. Figure 14 shows an example of multi-object details (G) where there are at least three different ideas within the group. The group includes a function structure, a sketch of a connector with isometric and orthogonal views, and some aspects of the artifact in operation.

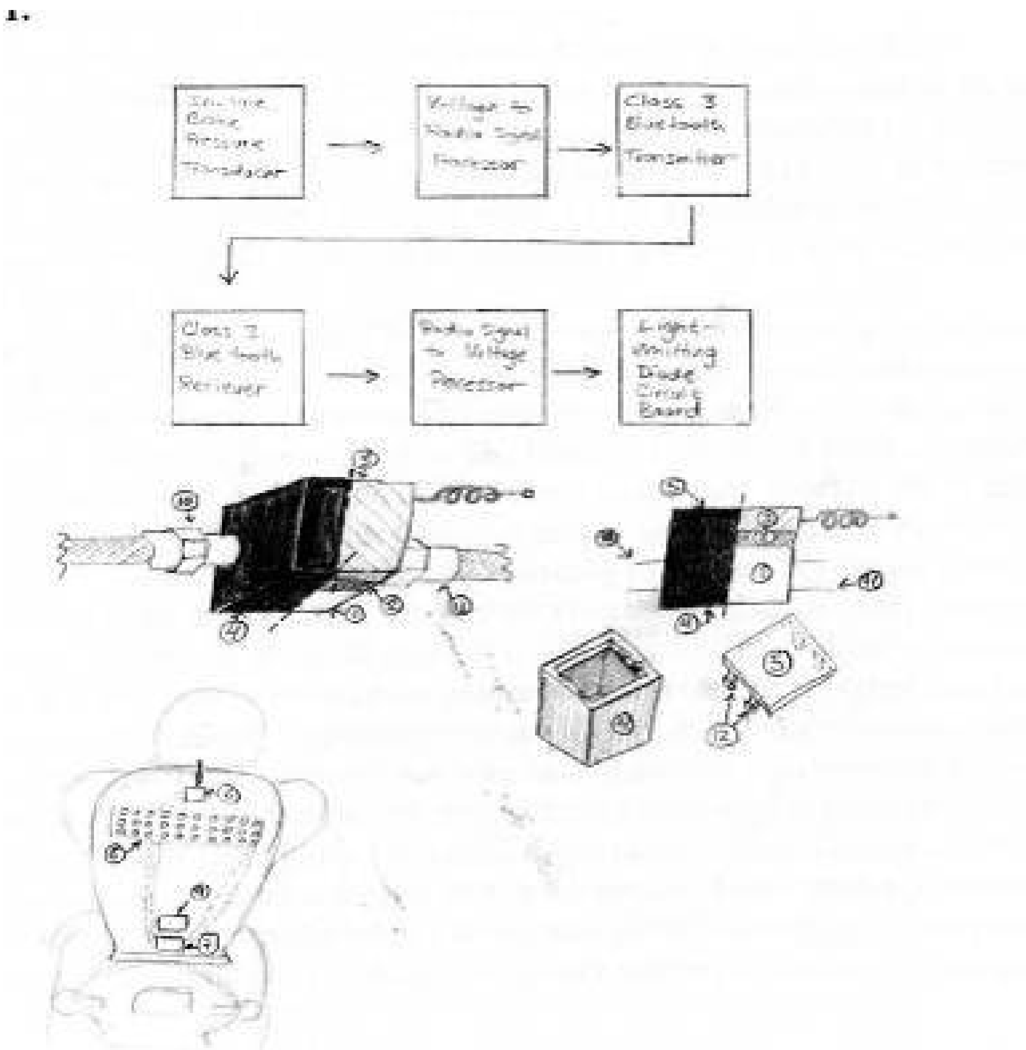


Figure 14: Multi-Object Sketch (G)

H- Motion Indications

Motion indications (H) are usually arrows or directional lines that are an attempt to show movement on a static plane of paper. Motion indications (H) signal thoughts on how the artifact will relate to the physical world.

I & J- Isometric and Orthogonal Views

Isometric (I) and orthogonal views (J) are typical views within mechanical engineering drawings. Drafting courses include lessons on views in detail. However, the CAD Mechanical Engineering elective teaches computer generated views. A standard format is taught within CAD courses that includes the isometric view in the top right corner of the sheet, and three orthogonal views in the top left corner and the bottom row. Students often transfer these formatting traditions into sketching because they already know them.

K- Part of a Set

Figure 15 shows an example of a sketch set that would be labeled as a part of a set (K) detail. Within this set of sketches, there are orthogonal views of the artifact. Sets of sketches (K) indicate deeper thought on one concept or various thoughts on different concepts. A set of sketches (K) are within the same page and are related to one another.

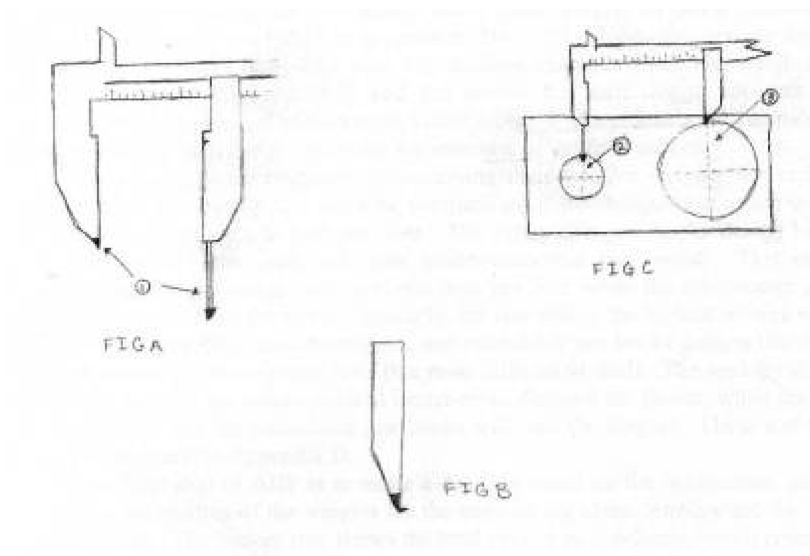


Figure 15: Part of a Set Detail (K)

L- Applied Forces

Applied forces (L) within sketches coincide usually with sketches that have the subject of Free Body Diagram (F5). Applied forces indicate thought on how the artifact will be implemented and what forces and stressed will be encountered in service.

M- Multiple Views

Figure 16 is an example of a sketch with multiple views (M). Unlike a sketch set detail (K), the multiple view code is for sketches that are related but separated with notations that make them more independent from one another.

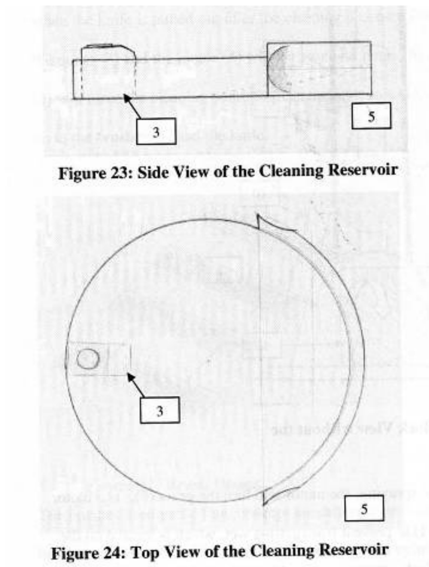


Figure 16: Multiple Views Detail (M)

N- Dimensions

The final detail code of the new content-based sketch coding scheme is dimensions (N). Dimensions are a more formal detail that would not be expected within concept generation. However, dimensions were seen in many of the sketches in student's final reports and sketching assignments. The presence of dimensions usually indicates finalization of a concept. Dimensions (N) are an important aspect of artifact details within the design and manufacturing process.

4.3 Application of the New Content-Based Sketch Coding Scheme to the Paper Boat Sketch Assignment

The Paper Boat sketch assignments from Section 0102 in Fall 2007 were analyzed with the new sketch coding scheme. The researcher added "Annotations" as a detail element to the coding scheme due to the amount of annotations quickly seen within the first few assignments analyzed, see the bottom row in Table 20. The Paper Boat Sketching Assignments were all completed within the concept generation phase of the design process. There was no sketch lesson given to the class prior to this assignment. The instructors wanted to see what students' current sketch ability was as they came into the class. The sketch coding was input into a table to compile the data. Table 20 is an example of the data compilation. The total number of McGown Code Levels, Yang Code Levels, and sketch Subject codes were calculated according to the number in each level (1 through 5, in all three cases). The number of detail codes was totaled according to each team member. The yellow highlighted region of Table 20 displays all of the sums of data points. The total number of occurrences for codes D through F were calculated with "If" statements according to each levels (1 through 5). Codes G through O were calculated with "Sum" statements.

Table 20: Paper Boat Sketch Coding Example for Team Member 3 of Team 3

Team Member	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3					
Visual Number	1	2	3	4	5	6	7	8	9	10					
A. Type of Visual	1	1	1	1	1	1	1	1	1	1	Total Number of Occurrences				
B. Part of Design Phase	1	1	1	1	1	1	1	1	1	1					
C. Sketch Lesson	0	0	0	0	0	0	0	0	0	0	1	2	3	4	5
D. McGown Code Level	2	2	2	1	1	1	2	1	2	1	5	5	0	0	0
E. Yang Code Level	2	2	2	1	1	1	1	1	2	1	6	4	0	0	0
F. Subject	1	1	1	1	1	1	1	1	1	1	10	0	0	0	0
G. Part of A Multiple Subject Object	0	0	0	0	0	0	0	0	0	0	0				
H. Type of Detail: Motion Indications	0	0	0	1	0	0	0	0	0	0	1				
I. Type of Detail: Isometric	0	0	0	0	0	0	0	0	0	0	0				
J. Type of Detail: Set of Orthogonal Views	0	0	0	0	0	0	0	0	0	0	0				
K. Type of Detail: Part of a Set	1	1	1	1	1	0	0	0	0	0	5				
L. Type of Detail: Applied Forces	0	0	0	0	0	0	0	0	0	0	0				
M. Type of Detail: Multiple Views of 1 Objec	0	0	0	0	0	0	0	0	0	0	0				
N. Type of Detail: Dimensions	0	0	0	0	0	0	0	0	0	0	0				
O. Annotations	1	1	0	0	1	1	1	1	1	1	8				

Figure 17 and Figure 18 are of two sketches from the Paper Boat Sketch Assignment . Figure 17 shows sketch visual number 7 from Table 20. The sketch is a McGown level 2 and Yang level 1. The difference in levels between coding schemes is related to use of annotations which makes this a McGown level 2. Also, Yang's coding scheme defines this as the lowest quality of sketch due to proportions and views being off.

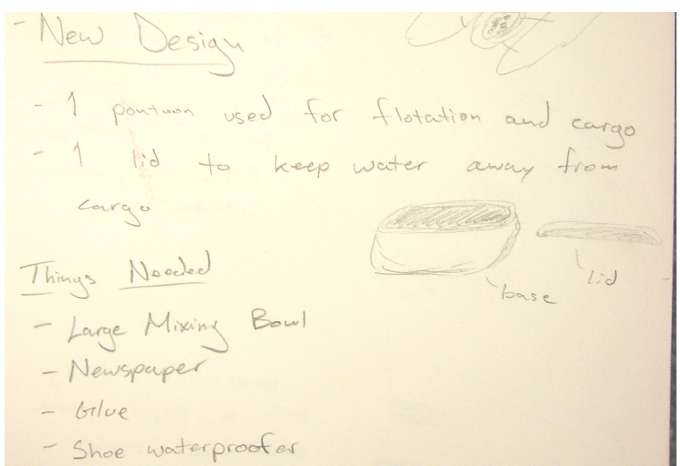
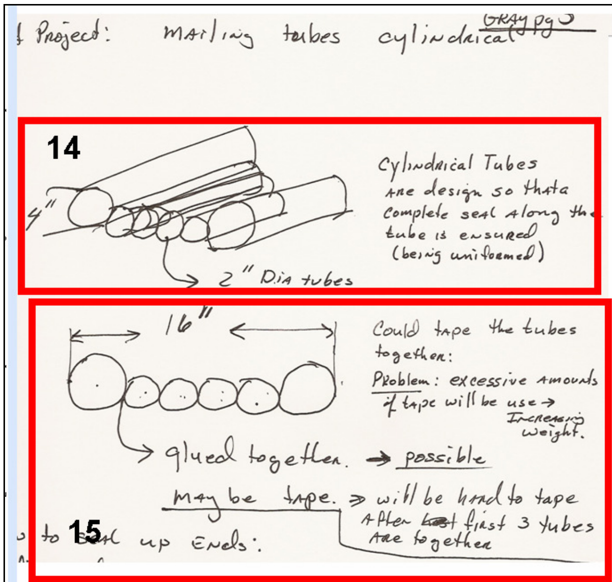


Figure 17: Paper Boat Sketch Example from Team Member 3.3 and Visual Number 7

Figure 18 displays another student's sketches. The sketches and the coding are within the same figure. The sketches are very similar and result in the same coding: McGown level 2, entire artifact sketch (F1), part of a set (K), dimensions (N), and annotations (O).



Team 10		
Team Member	10.1	10.1
Visual Number	14	15
A. Type of Visual	1	1
B. Part of Design Phase	1	1
C. Sketch Lesson	0	0
D. McGown Code Level	2	2
E. Yang Code Level	1	1
F. Subject	1	1
G. Part of A Mutlple Subject Object	0	0
H. Type of Detail: Motion Indications	0	0
I. Type of Detail: Isometric	0	0
J. Type of Detail: Set of Orthogonal Views	0	0
K. Type of Detail: Part of a Set	1	1
L. Type of Detail: Applied Forces	0	0
M. Type of Detail: Multiple Views of 1 Object	0	0
N. Type of Detail: Dimensions	1	1
O. Annotations	1	1

Figure 18: Paper Boat Sketch Examples and Codings by Team Member 10.1

The Paper Boat sketches were mostly entire artifact sketches. This is not surprising considering the assignment instructions and the criteria of the Paper Boat project. Figure 19 displays the percentages of sketch subject codes by team. Nine teams of four students each sketched the entire artifact of a paper boat concept. Artifact features were the next most common sketch subject. A third of the teams used Free Body Diagrams within their sketch assignments. Only one of the nine teams sketched a paper boat concept in operation. No exploded views were sketched within this Paper Boat sketch assignment. This gives a rank order of the importance of different subjects for conceptual design sketches as determined by students.

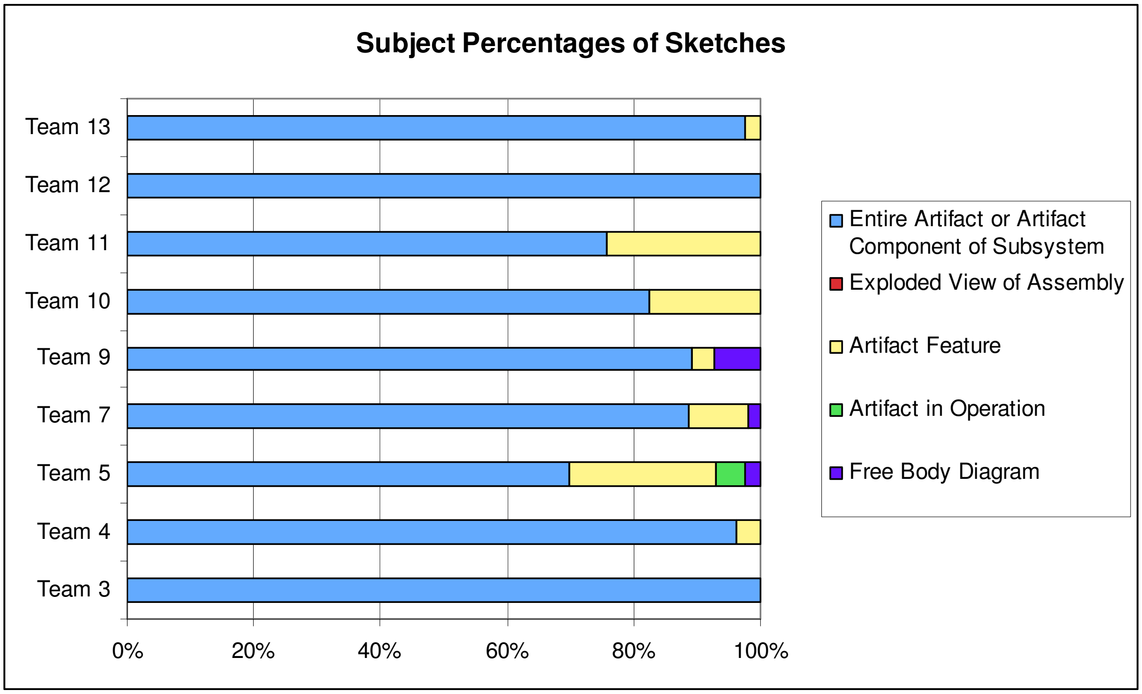


Figure 19: Paper Boat Subject Coding Results

Table 21 shows the percentages of Paper Boat sketches according to sketch details. The data varies among team. Note that for a given team, the percentages do not add up to 100% because one sketch could have multiple codes or no code. The additional code: Annotations, is the most prevalent detail of the Paper Boat sketches. About half of the sketches were part of a set (K), which is when a concept was drawn and multiple sketches of the concept were drawn together. Unlike the Final Report sketches, very few Paper Boat sketches were isometric (I) or orthogonal views (J) of an artifact. Details including: part of a multiple subject object (G), multiple views of 1 object (M), and applied forces (L) have the lowest occurrence within the set of Paper Boat sketches. No sketches were coded as a multiple view of one object (M) because no sketches of a concept were separated as seen in the example in Figure 16. The part of a set (K) code and multi-view (M) code are very similar to one another, so it can be difficult to distinguish the two. Like the Final Report sketches, motion indications (H) were more prevalent within sketches than applied forces (L) within sketches.

Table 21: Paper Boat Sketch Detail Percentages per Team

	Team 3	Team 4	Team 5	Team 7	Team 9	Team 10	Team 11	Team 12	Team 13	Averages
G. Part of A Multiple Subject Object	0	0	0	0	0	0	0	0	0	**0**
H. Motion Indications	3.45	3.77	18.60	1.89	0	5.00	0	1.69	6.98	**4.58**
I. Isometric	0.00	5.66	2.33	7.55	0	0	0	0	20.93	**5.66**
J. Set of Orthogonal Views	0.00	0.00	4.65	0.00	56.36	0	19.51	15.25	36.05	**17.65**
K. Part of a Set	51.72	60.38	51.16	39.62	27.27	5.00	43.90	33.90	70.93	**44.88**
L. Applied Forces	0	3.77	2.33	1.89	7.27	0	0	0	1.16	**1.96**
M. Multiple Views of 1 Object	0	0	0	0	0	0	0	0	0	**0**
N. Dimensions	0	0	18.60	5.66	12.73	27.50	2.44	3.39	39.53	**14.38**
O. Annotations	93.10	96.23	58.14	94.34	94.55	97.50	100.00	57.63	93.02	**86.93**

The detail codes are rank ordered to more easily see the highest use of details within the Paper Boat sketches in Table 22. Annotations (O), part of a set (K), and orthogonal views (J) are the most dominant details. Multi-subject (G) and multi-view (M) details are the least dominant details. Note that the detail of annotation (O) is unlikely to be the most prevalent in the usual designer's notebook. The detail of annotations (O) in this case was most prevalent due to the specific instruction of the Sketch Assignment.

Table 22: Rank Order of Sketch Details in Paper Boat Sketch Assignment

Rank Order	Detail Codes
1	O. Annotations
2	K. Part of a Set
3	J. Set of Orthogonal Views
4	N. Dimensions
5	I. Isometric
6	H. Motion Indications
7	L. Applied Forces
8	G. Part of A Multiple Subject Object
8	M. Multiple Views of 1 Object

4.4 Application of the New Content-Based Sketch Coding Scheme to Final Report

Testing of the new content-based sketch coding scheme began with analysis of mechanical engineering capstone design final reports. Final reports are a requirement for the University of Maryland's Mechanical Engineering Capstone Senior-Level Design Course. The course allows senior-level students to experience the entire design process with a semester-project of their choice and guidance of the professor.

All of the final reports analyzed were produced under the same syllabus and led by the same course manager with involvement by various co-instructors. Final reports were team written with teams composed of 5 to 7 students. Each team chose a problem to solve and each final report is on each team's semester project. Each report was given an identification number and a page-by-page review of each report was conducted to number each sketch and code it accordingly (Westmoreland 2008).

An average of 11 sketches were in each Final Design Report. Spring 2005 (the earliest semester of final reports obtained) contained the fewest sketches (a total of one sketch) than in later semesters. This significant difference could be contributed to either different teacher expectations within in the final report, or students' lack of ability to include the sketches in the final report. When looking at Spring 2005 data, it is critical to remember that the reports of the semester included only 1 sketch, while the reports from other semester have from 61 to 212 sketches each as seen in Table 23. The most sketches (317 out of 500) sketches were placed within the concept generation design phase of the project.

Table 23: Number of Sketches within Semester and Design Phases

	Fall 2005	Spring 2006	Spring 2007	Fall 2007	*Totals*
Concept Generation	80	45	125	67	*317*
Embodiment	11	0	35	8	*54*
Detail Design	49	16	52	8	*125*
Re-Design	3	0	0	0	*3*
Totals	*143*	*61*	*212*	*83*	***499***

Dr. Linda Schmidt, the course manager, required each student to complete a sketching assignment of their concepts during the concept generation phase beginning in Fall 2005. Sketching is not as prevalent in the other three phases of embodiment, detail design, and redesign. However, sketching contributes to those design phases at times as seen in Figure 20. Re-design is a phase that rarely occurs within the capstone design project class due to the brevity and compactness of the course. A prototype is required at the end of the semester, along with teams' final reports and presentations. Re-design would normally occur after this first prototype which the semester does not allow for unless the students continue on their own, outside of the class.

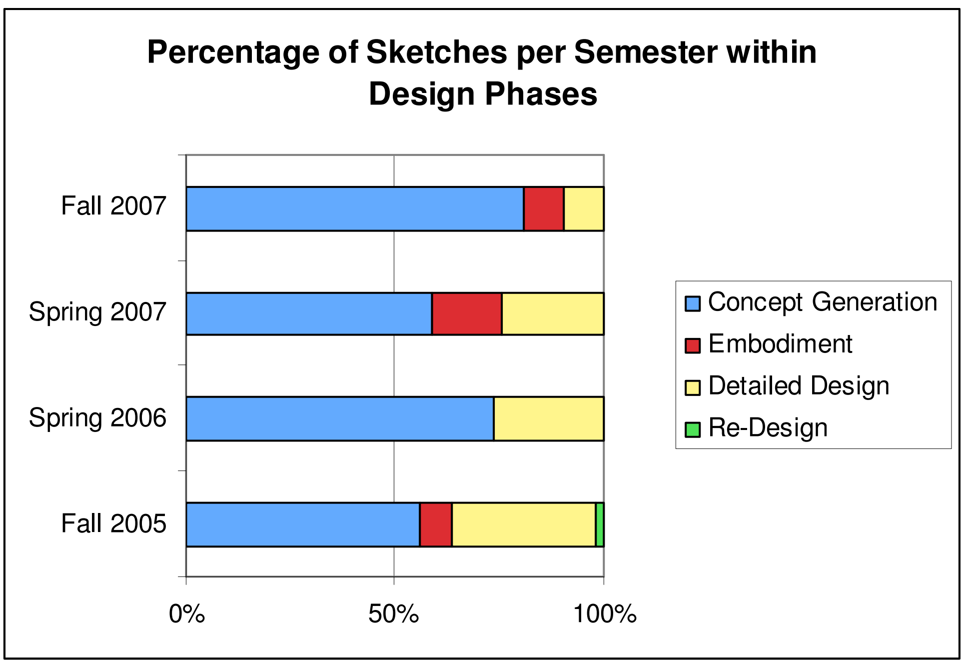


Figure 20: Final Reports' Sketches within Design Phases

The data from Table 23 was compiled from all of the teams' final reports within each semester. Figure 21 displays the number of sketches per team according to semester. The average number of sketches within final reports per team (excluding Spring 05) is 11.88. Considering that each student within the team submitted at least 5 sketches and on average six students compose a team, 30 sketches from the Sketch Assignment (SA) were available to implement into the final report. However, all of these sketches were within the concept generation phase and not all were put into their final report as can be seen with the data. With an average of 12 sketches per final report (excluding Spring 05) and not all within concept generation, it can be noted that sketching occurs outside of the SA.

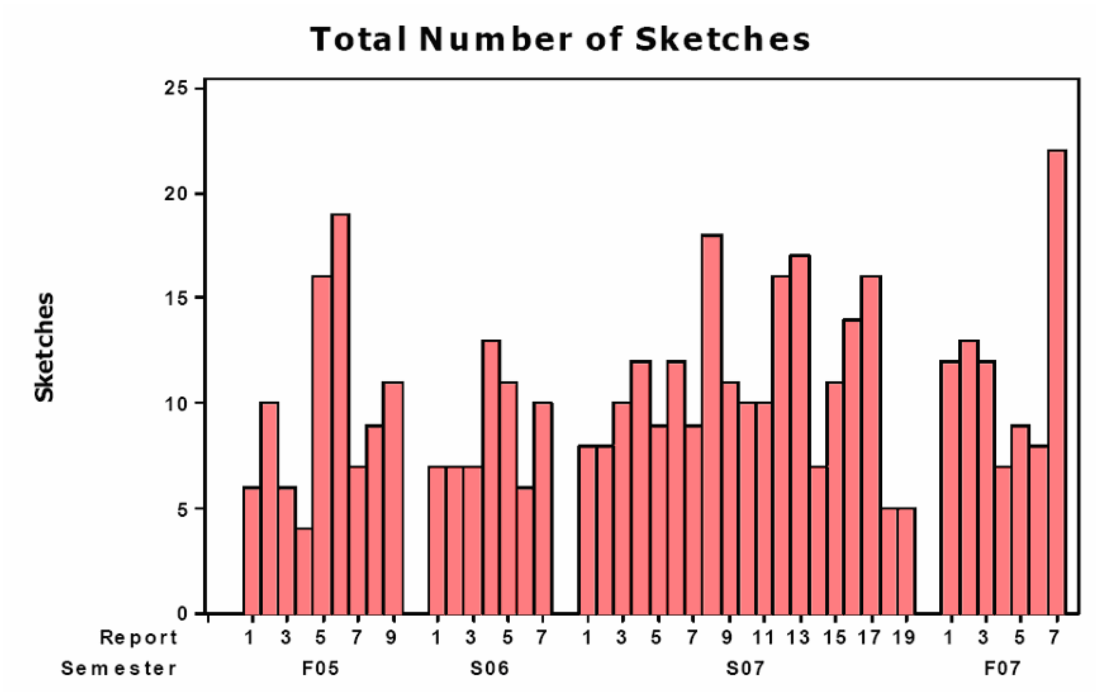


Figure 21: Number of Final Report Sketches per Team

ANOVA calculations were performed on the sketches grouped by semester in order to determine if the number of sketches per semester were from the same population. Table 24 summarizes the ANOVA results. ANOVA tests to see if the samples come from the same population. If the P-value is not less than 0.05, then it can be concluded that the number of sketches per semester are from the same population. Table 24 shows that the reports can be treated as being from the same population. Put another way, the reports can be treated as though differences due to the projects, students, and semesters were not significantly impacting the number of sketches.

Table 24: ANOVA for Sketches by Semester

DOF	Visual Type	Pooled Standard Deviation	F-value	P-value
42	Sketches	4.138	0.85	0.475

The sketches were next analyzed by their Subject coding. All five subjects are portrayed within the Final Reports for each semester. Figure 22 displays the dominance of sketches' of entire artifact. Fall 2007 has the most variety of subject matter sketches compared to other semesters.

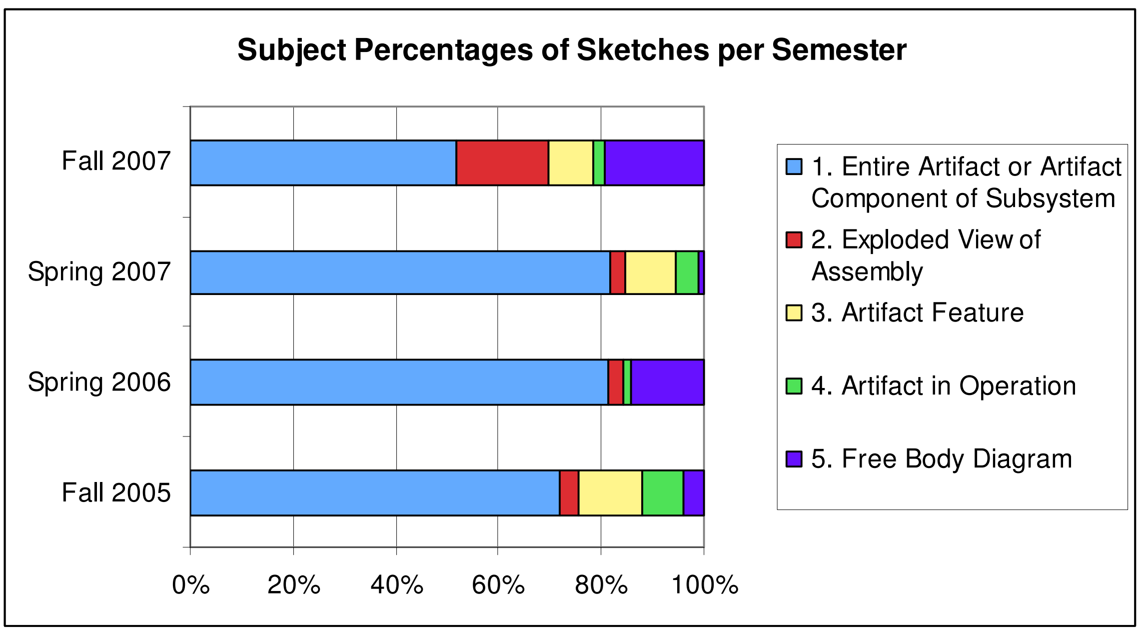


Figure 22: Final Reports' Sketch Subject Matter Coding

Final report sketches were analyzed by coding them with McGown and Yang sketch levels as well. Lower level McGown and Yang sketches are prevalent throughout the final reports. Figure 23 and Figure 24 show that most sketches are within levels 1 and 2 of McGown's and Yang's sketch coding schemes. The low quality sketches may be a result of many sketches occurring within concept generation or students' lack of sketch skill. As well, the lack of higher level sketches may be a result of CAD use within later design phases.

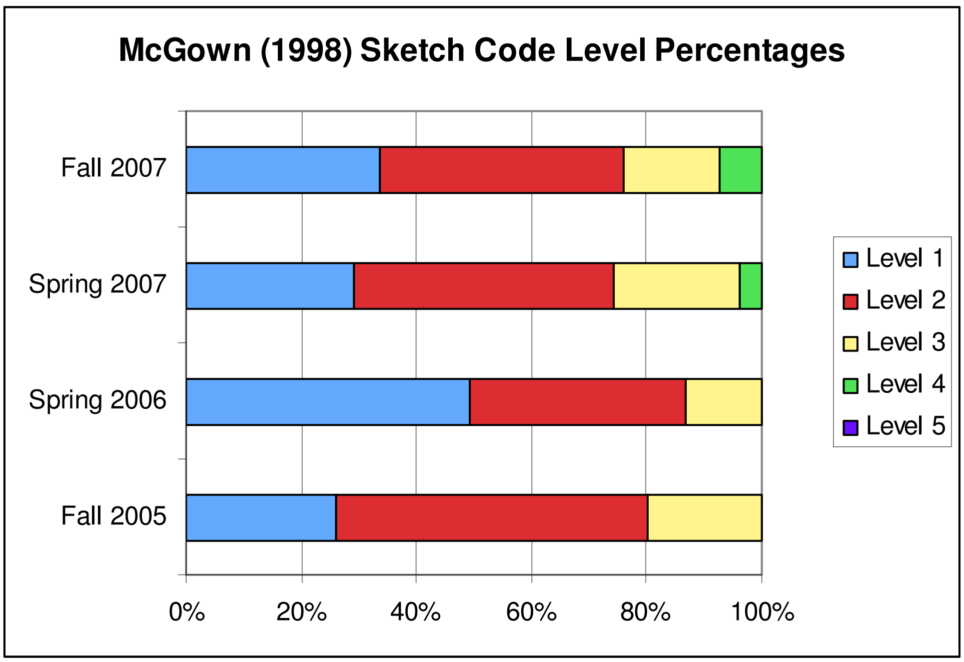


Figure 23: Final Reports' McGown (1998) Levels

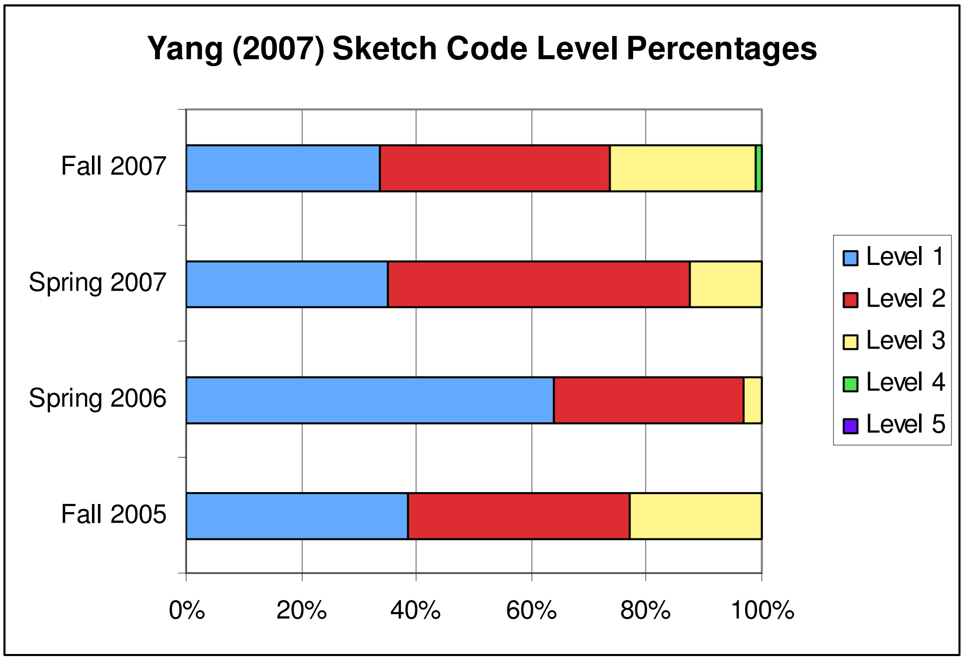


Figure 24: Final Reports' Yang (2007) Levels

The sketching analysis continued on the topic of type of details included in each sketch. Analysis was conducted to see if a large number of entire artifact subject (F1) sketches are correlated to concept generation. Concept generation allows for more ambiguity than later stages due to the details and decisions that must be refined and made. Sketch data from Fall 2007 Final Reports were analyzed with "if" statements to see the relationship between sketch subject (F) and design phase (B). For example, if a sketch was created during concept generation (B1) and the sketch subject code was the entire artifact (F1) then it was counted within cell 1 in Table 25. The percentages of sketches labeled as Subject (F) 'X' and Design Phase (B) 'Y' are displayed within Table 25. A total of 83 sketches were from Fall 2007 Final Reports. The most frequent occurrence between subject (F) and design phase (B) is within concept generation and the subject of entire artifact, as predicted. Out of a total of 83 sketches, 35 sketches were presented within the concept generation phase and of the entire artifact (42%). The subject matter of exploded view of assembly (F2) and Free Body Diagrams (F5) were also prevalent within concept generation (B1). The other design phases are not as highly represented. However, 8% of sketches were within embodiment (B2) and were of artifact features (F3). The change in focus from entire artifacts (F1) to artifact features (F3) seems to be a natural progression from concept generation (B1) to embodiment (B2). The movement back to entire artifact sketches (F1) within detailed design (B3) is interesting and implies that features are being decided upon and being implemented into the entire artifact. The recursive nature of design can been within this use of entire artifact sketches (F1).

Table 25: Fall 2007 Final Report Sketches Percentages by Subject and Design Phase

Fall 07, SUM %	Entire Artifact (F1)	Exploded View (F2)	Artifact Feature (F3)	Artifact in Operation (F4)	FBD (F5)
Concept Generation (B1)	42.17	16.87	0	2.41	19.28
Embodiment Design (B2)	1.20	0	8.43	0	0
Detail Design (B3)	8.43	1.20	0	0	0
Redesign (B4)	0	0	0	0	0

Table 26 shows the percentages of details among final report sketches. The percentages were calculated by taking the total number of occurrences within in a semester and dividing by the total number of sketches within that semester. About half of the coded sketches are isometric views of artifacts. A significant portion of the sketches contained a set of orthogonal views as well. Details including: Part of a Multiple Subject Object and Applied Forces have the lowest frequency within the final report sketches. All Free Body Diagrams contain applied forces and motion indications. Motion indications were more prevalent within sketches than applied forces within sketches. Arrows to show movement and direction are more common than specific forces (i.e. gravitational force, shear force, moments, and normal force).

Table 26: Final Report Sketch Detail Percentages per Semester

	Fall 2005	Spring 2006	Spring 2007	Fall 2007
G. Part of A Multiple Subject Object	7.69	0	1.89	19.28
H. Motion Indications	36.36	19.67	20.28	34.94
I. Isometric	57.34	55.74	47.17	51.81
J. Set of Orthogonal Views	34.27	65.57	38.21	30.12
K. Part of a Set	50.35	3.28	27.83	31.33
L. Applied Forces	4.20	1.64	2.83	19.28
M. Multiple Views of 1 Object	32.17	62.30	39.15	33.73
N. Dimensions	13.99	0	16.51	22.89

The details of motion indicators (H), applied forces (L), and dimensions (N) were analyzed together. The goal of this analysis is to see: if a sketch has motion indicators (H), then will it have applied forces (L) and/or dimensions (N), and vice versa. Table 27 shows the number of sketches with codes: H, L, and N and combinations of those codes from the Fall 2007 final reports. Keep in mind that a total of 83 sketches are within Fall 2007 Final Reports. There are more sketches (6 total) labeled with all three codes of H, L, and N, than that of two of the three codes. One team (Team 3) had a total of 8 sketches, 5 of which had both motion indicators (H) and applied forces (L). Sketches of the other 6 teams did not have such a relation. The number of times only one of H, L, or N is a detail of sketch significantly outweighs the combination of details happening together. Motion indicators (H), applied forces (L), and dimensions (N) are independent of one another.

Table 27: Details of Motion Indicators, Applied Forces, and Dimensions for Fall 2007 Teams

F07 Team	1	2	3	4	5	6	7	SUM
H,L	-	-	5	-	-	-	-	5
H,N	1	1	-	-	-	-	-	2
L,N	-	-	-	1	-	-	-	1
H,L,N	-	1	1	-	2	-	2	6
H	5	4	7	3	3	1	6	29
L	1	1	6	1	3	1	3	16
N	7	4	1	1	3	-	3	19

4.5 Discussion of the New Content-Based Sketch Coding Scheme

The application of the new sketch coding scheme to sketches in the Final Reports and the Paper Boat sketch assignments revealed differences among use of sketch details in different settings. Findings based on the Final Reports and the Paper Boat sketches cannot be compared to one another without taking into account the differences in assignment and project details. About half of the sketches within the Final Reports are isometric views and orthogonal views. Within the Paper Boat assignment, many sketches were part of a set of sketches but not necessarily orthogonal views (17.65% average) or isometric views (5.66% average). This difference between the Final Report and Paper Boat sketches may be a result of differences in the purposes of the sketches. Final Reports are the last professional presentation of the design project. More orthogonal and isometric sketches are included in the Final Reports because orthogonal and isometric sketches are standard for creating a set of mechanical drawings. The Paper Boat sketches did not need to be so formal due to the fact that the project was a short-term, introductory assignment and the students were reporting results within the concept generation phase.

Low skill level entire artifact sketches were found within every design phase of the Final Reports but were most prevalent within concept generation. Re-design also had a large number of sketches within the Final Reports. However, it can easily be noted that the concept generation phase has the highest frequency of sketches compared to the later design phases. This may indicate that students transition to CAD or other tools after conceptual design.

Low quality sketches, as measured by the McGown and Yang coding schemes' levels 1 and 2, dominate the Final Reports and Paper Boat assignments. This indicates that students either do not have high sketching skills, there is no need for high quality sketches, or the McGown and Yang levels do not capture what is important in sketching for these assignments.

Conclusions for this chapter on sketch coding schemes applied to capstone final reports and a sketching assignment include:

- Students have low sketch skills as measured by the McGown and Yang standards.
- McGown's sketch coding scheme is a well defined scheme and can be implemented with ease. However in coding sketches, considerable confusion could occur between what is a label and what is an annotation in McGown's scheme occurred here.
- Yang's sketch coding levels are not well defined and if applied, Yang's coding scheme may not be repeatable. Yang's coding scheme does not include as many poorer levels of quality which results in mostly level 1 sketches from the Final Reports and Paper Boat sketch assignments.
- From the final report analysis, sketching occurs the most within concept generation. However, the assigned sketch assignment influences this number.

- All projects (both Final Report and Paper Boat) outcomes were successful, even with sketching skills at low levels as measured by McGown and Yang.
- Content of sketches assists in understanding the purpose of the sketch. The content is not related to sketch quality as measured by the coding schemes used.

Chapter 5: Impact of Capstone Sketch Assignment

Communicating ideas about physical artifacts is much more reliable when visual aids are used. Sketching encourages cognitive activity in a way that writing text does not. As noted in Chapter 2, sketching serves as an external memory aid and promotes creativity. Sketching can foster communication of ideas amongst team members. Not only do sketches provide a physical and visual aid to show other people but sketching can also be an activity done in real time, in plain view of team members. This opens a dialog about the artifact being sketched.

The Mechanical Engineering Capstone Design course at the University of Maryland includes a sketching assignment as regular design project homework. Students are required to sketch and annotate their work describing concepts relating to their design project. This assignment was created in response to frequent incidents of miscommunication between the professor and students when project ideas were discussed without drawings or sketches. The assignment became a standard part of the Capstone Design course in Fall 2005.

The sketch assignment was given to both sections of ENME472 Fall 2007. Differences between the two sections were outlined in Chapter 4. Section 0101, called 471-1, followed the standard capstone design syllabus. Section 0l02, referred to as 472-2, was the experimental section. A sketching lesson was given to students of 472-2 between their two assignments (i.e., 472-PB and 472-2SA), located in Appendix B. The sketch lesson focused on the importance of sketching, not on how to sketch. These differences will allow for more comparisons among sketches submitted in fulfillment of the assignment.

The research questions that will be addressed from the sketch assignment research are: “What are the sketching skills and knowledge of students? For what purpose is sketching used?” Sketching knowledge refers to what students understand about sketching.

5.1 Description of Sketch Assignments

During the Fall 2007 semester, 472-1 included the one sketch assignment (SA) on their main semester project. The 472-1 syllabus contained the typical requirements followed by previous semesters of the course. 472-2 was an experimental section that emphasized prototyping, idealogging, and sketching all the while working on their semester project.

There were two sketch assignments required from students in 472-2. The first SA was on the Paper Boat Project described in Chapter 4. The second 472-2 SA was given after a 45 minute sketching lesson. Students were given the same assignment as the 472-2 Paper Boat sketch assignment. The only difference was that the topic of their sketches was on the main semester-long design project.

As stated in Chapter 4, the sketch assignment for both sections was:

> “During your team project’s Concept Generation phase, many ideas of design concepts as a whole and their specific parts are flowing in and out of your brains and conversations. To help yourself and your team mates to better see and understand these design concepts, sketch your ideas on paper by hand. Include annotations on sketches to aid in communicating your thoughts and goals of the concept to others and to aid in reminding yourself what you were trying to communicate.

Sketch four of your concepts for this project in your idealog. Include a brief overview of each concept with annotated parts and call outs."

The grading guidelines for the 472-2 PB sketch assignment described in Chapter 4 were also applied to this second sketch assignment (472-2SA). The SA grade was based on the number of sketches completed; the clarity of each sketch; presence of appropriate labels and annotations; and, the degree of design thoughtfulness indicated by the sketches. The assignments were graded with a check plus, check, check minus, or zero. Each 472-2 assignment was worth 3% of the student's entire course grade each. If students performed poorly or did not do these assignments 6% of their grade was affected, which can significantly change the students' final grades.

Reference numbers will be given to Sketch Assignments (SAs) to distinguish them with ease, as such:

- 472-1SA, for 472-1's only semester-project SA given
- 472-2PB, for 472-2's Paper Boat SA (first SA given in 472-2)
- 472-2SA, for 472-2's semester-project SA (second SA given in 472-2)

The three SAs from both sections were coded with the proposed content-based sketch coding scheme described in Chapter 4. The SAs context details are shown in Table 28.

Table 28: SA Context Details

472-1SA	472-2PB	472-2SA
• Fall 2007 ENME 472 Section 0101 • No Sketch Lesson • Concept Generation Phase • Week 2 of the semester • Semester Project Concepts • Student formed teams	• Fall 2007 ENME 472 Section 0102 • No Sketch Lesson • Concept Generation Phase • Week 2 of the semester • Paper Boat (2 week introductory project) Concepts • Randomly assigned teams	• Fall 2007 ENME 472 Section 0102 • Sketch Lesson • Concept Generation Phase • Week 4 of the semester • Semester Sponsored Project Concepts • Student formed teams

The 472-1 teams were formed by the students. Students were allowed to form their own teams of 5 or 6 students. The 472-1 teams found a specific problem to solve which was then approved by the professor and course manager. Their sketch assignment was essentially the same as 472-2SA except they were required to sketch 5 concepts on paper.

472-2 Paper Boat teams were formed by the instructor at random and consisted of 4 students each. The 472-2 main project teams were formed by allowing students to form their own teams of 4 to 5 students each. 472-2 teams worked on a semester design problem that was sponsored by a company or entrepreneur. The teams were given their top choice of the sponsored projects.

5.2 <u>Results and Analysis of Sketch Assignment Coding</u>

The sketches from each Sketch Assignment (SA) were analyzed with various coding schemes. The number, skill level, subject, and details of sketches were coded and analyzed.

5.2.1 Number of Sketches within Sketch Assignments

The total number of sketches done by each student varies amongst SAs. The sketches were counted individually. For example, if there was a set of three orthogonal views of a concept, they would be counted as three sketches. The total number of sketches is much larger for 472-1SA and 472-2PB than that for 472-2SA (Table 29). 472-1SA required sketches of five concepts. Both 472-2PB and 472-2SA required students to sketch only 4 concepts each. The number of sketches submitted for 472-2SA is about half of the total number of sketches from the other two SAs. The number of students changes from 472-2PB to 472-2SA due to one or two students who did not complete the assignment. A total of 36 students were registered for 472-2.

Table 29: Total Number of Sketches per SA

SA	472-1SA	472-2PB	472-2SA
Total Number of Sketches	393	459	211
Total Number of Students	38	35	34
Average Number of Sketches per Student	10.34	13.11	6.21

The average number of sketches per student varied among SA as seen in Table 29. The first SA given in 472-1 and 472-2 resulted in a high number of sketches per assignment. About 10 sketches were submitted per student for 472-1SA.

About 13 sketches were submitted per student for 472-2PB. 472-2SA averaged about 6 sketches per student which is a significant decrease from the other two SAs.

The data were grouped into team averages in order to perform more meaningful calculations. The number of sketches done by all of the members of each team was divided by the number of members. The assignments were performed by students working in teams, so averages over teams will eliminate and differences arising from project variations. This is especially important when analyzing sketching submissions for 472-1SA and 472-2SA.

ANOVA was applied to the number of sketches per team member from each SA. Table 30 displays the ANOVA results which state the results are significant, meaning that the average number of sketches per member per team are not from the same population. This is shown by the very low probability that a F-value of 11.31 could be obtained. There was a significant decrease in the number of sketches submitted by students of 472-2 when asked to sketch concepts for their design projects. The difference is more than can be accounted for by just the difference in concept number. 472-1SA required sketches for five concepts while the 472-2 assignments required sketches for four concepts. The 472-2PB sketch average per team member for 4 sketches is actually higher than that for 472-1SA. The same students sketching paper boat designs at an average of 13.259 each reduced their average to 6.169 for their project SA, and the paper boat design was much simper than their project. The only other factor that could explain the change in 472-2 student sketching behavior is the sketching lesson provided between assignments.

Table 30: Number of Sketches per Team Member ANOVA

Comparison of Number of Sketches per Member per Team

	Average over Teams			ANOVA Results		
	472-1SA	*472-2PB*	*472-2SA*			
No. of Teams	7	9	8	*F-Value*	*p-value*	*Differences*
Sketches/Member	10.276	13.259	6.169	11.31	0	Significant

5.2.2 Skill Level of Sketches within Sketch Assignments

Sketching skill level can be assessed with McGown and Yang coding schemes. Paper boat sketches were classified with McGown's sketch coding scheme. The percentages of sketches of each McGown's sketch coding level by team groupings are displayed in Figure 25, Figure 26, and Figure 27. A few McGown level 4 sketches were submitted, but no level 5 sketches. As seen in Figure 25, the percentages of level 2 McGown sketches are very high (about 85%) within 472-1SA; this results in a low percentage of Level 1, 3 and 4 sketches in 472-1SA. 472-2PB consists of more McGown level 1 sketches than that of 472-2SA. 472-1SA and 472-2PB are the first SAs assigned to the students in sections 472-1 and 472-2, respectively. 472-1 began with a higher McGown level of sketching skill than that of 472-2. This data reflects that either the students in 472-2 started with lower sketching skill than that of 472-1, or that the Paper Boat project assignment context did not inspire or allow time submission of better sketches.

Within 472-2's second SA (472-2SA), McGown level 2 sketches are the most prevalent (about 70%) with a smaller percentage of Level 3 and 4 sketches. One team out of the eight teams contained McGown level 1 sketches in the 472-2SA, while 472-2PB's eight out of nine teams submitted McGown level 1 sketches. According to McGown coding, the level of sketching quality improved from 472-2PB to 472-

2SA, as seen in Figure 26 and Figure 27. The percentages of McGown levels 2 and 3 sketches also increased in 472-2SA after their paper boat assignment.

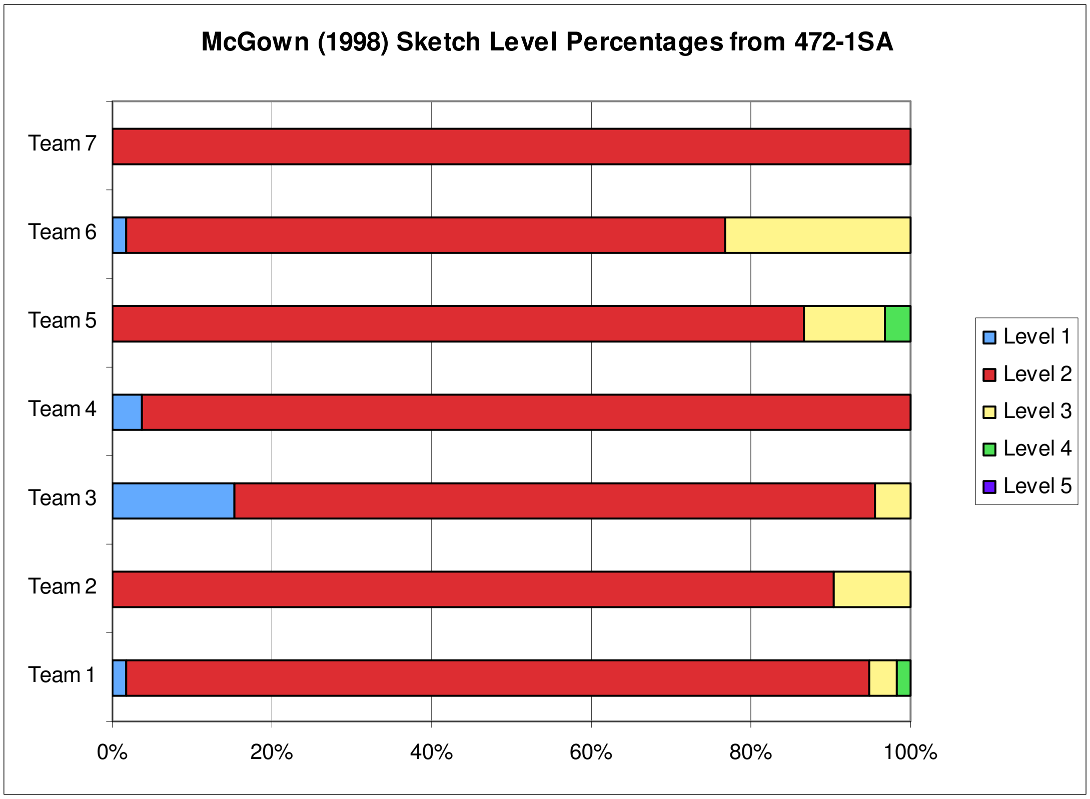


Figure 25: 472-1SA McGown Levels

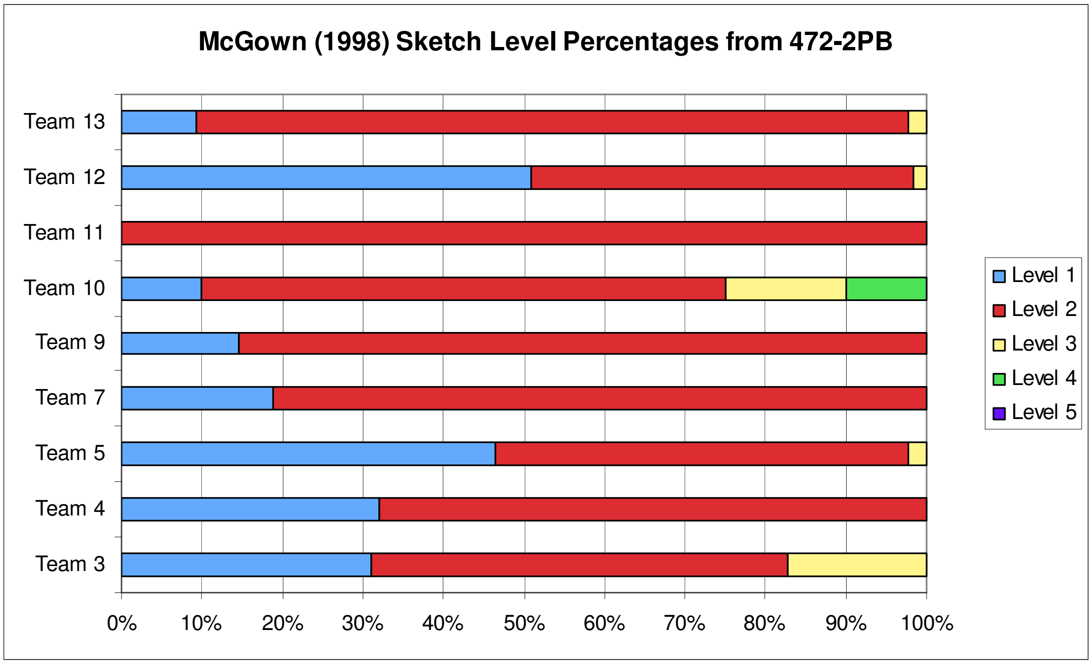


Figure 26: 472-2PB McGown Levels

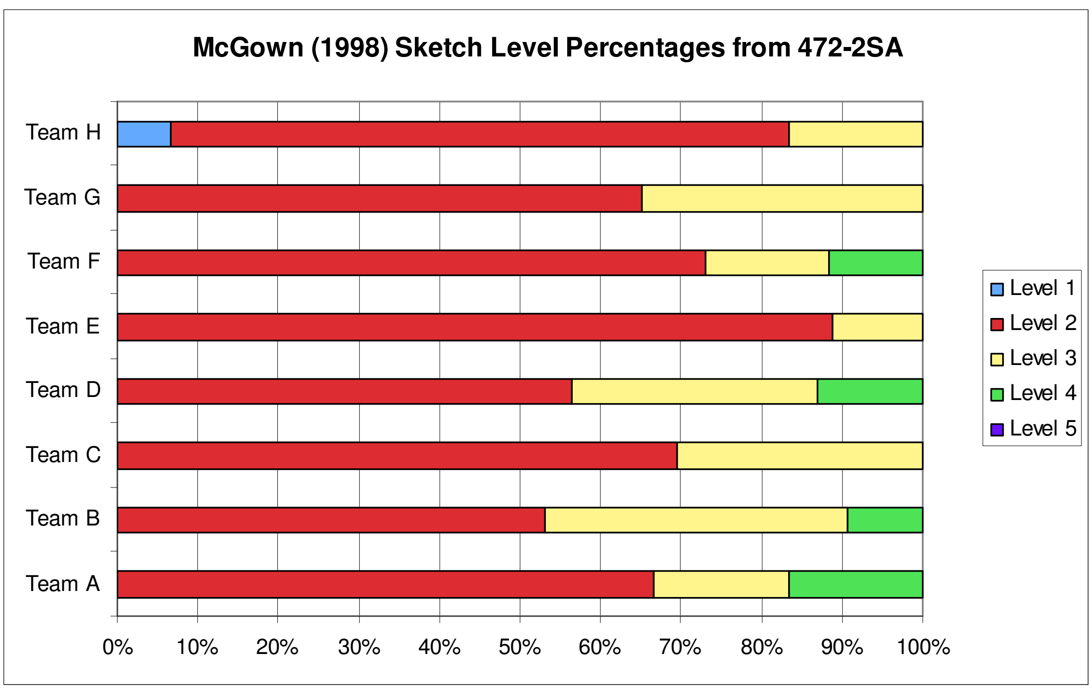


Figure 27: 472-2SA McGown Levels

The average McGown sketch level ratings per member per team were compared using ANOVA. Table 31 shows that McGown levels 1 through 3 differed significantly between sections. The ANOVA concludes that McGown levels 1 through 3 sketches are not the same for all assignments. This confirms what the bar charts implied. McGown level 4 sketch rating was found to be insignificant which results from the consistently low number of level 4 sketches.

Table 31: Average Team McGown Sketch Level Ratings ANOVA

Comparison of Average McGown Sketch Level Ratings per Team

	Average over Teams			ANOVA Results		
	472-1SA	472-2PB	472-2SA			
No. of Teams	7	9	8	F-Value	p-value	Differences
McGown Level 1	0.319	3.019	0.05	11.32	0	Significant
McGown Level 2	9.21	9.713	4.269	6.19	0.008	Significant
McGown Level 3	0.6952	0.4167	1.4625	5.56	0.012	Significant
McGown Level 4	0.0524	0.1111	0.03875	2.36	0.119	
McGown Level 5	0	0	0	NA		

To better analyze the sketches by McGown levels, the data was normalized and then ANOVA was applied. Table 32 displays the results of ANOVA conducted on the percentages of McGown sketch level ratings per team. The normalized data analysis shows that the sketches by McGown level come from the same population within every level, which means that there is no difference in sketch levels.

Table 32: Percentage of McGown Sketch Level Ratings per Team ANOVA

Comparison of Percentage of McGown Sketch Level Ratings per Team

	Percentage over Teams			ANOVA Results		
	472-1SA	472-2PB	472-2SA			
No. of Teams	7	9	8	F-Value	p-value	Differences
McGown Level 1	0.0916	0.2222	0.0448	1.42	0.264	
McGown Level 2	0.09837	0.13983	0.13161	1.61	0.224	
McGown Level 3	0.1143	0.14	0.1175	0.08	0.92	
McGown Level 4	0.1429	0.1111	0.125	0.03	0.97	
McGown Level 5	0	0	0	NA		

Sketches were also classified with Yang's sketch coding scheme. The percentages of sketches in each SA coded with Yang's sketch coding scheme are displayed in Figure 28, Figure 29, and Figure 30. No Yang level 5 sketches were created within any of the students' SAs. As seen in the figures below, the percentages of levels 1 and 2 Yang sketches are the most prevalent. 472-1SA and 472-2SA are similar in regards to Yang sketch level percentages. 472-2PB consists of more Yang level 1 sketches than that of 472-2SA. Similarly to McGown's sketch coding, Yang displays higher skill level (fewer Yang level 1 sketches) from 472-2PB to 472-2SA. Recall that Yang's skill levels are not as finely graded as McGown's.

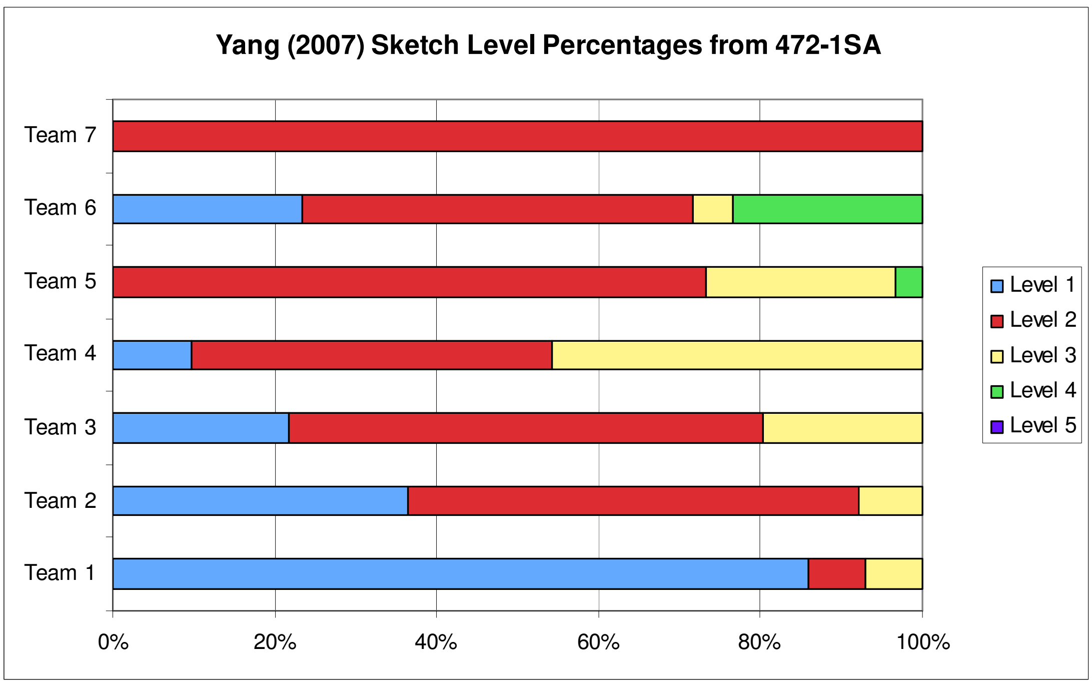


Figure 28: 472-1SA Yang Levels

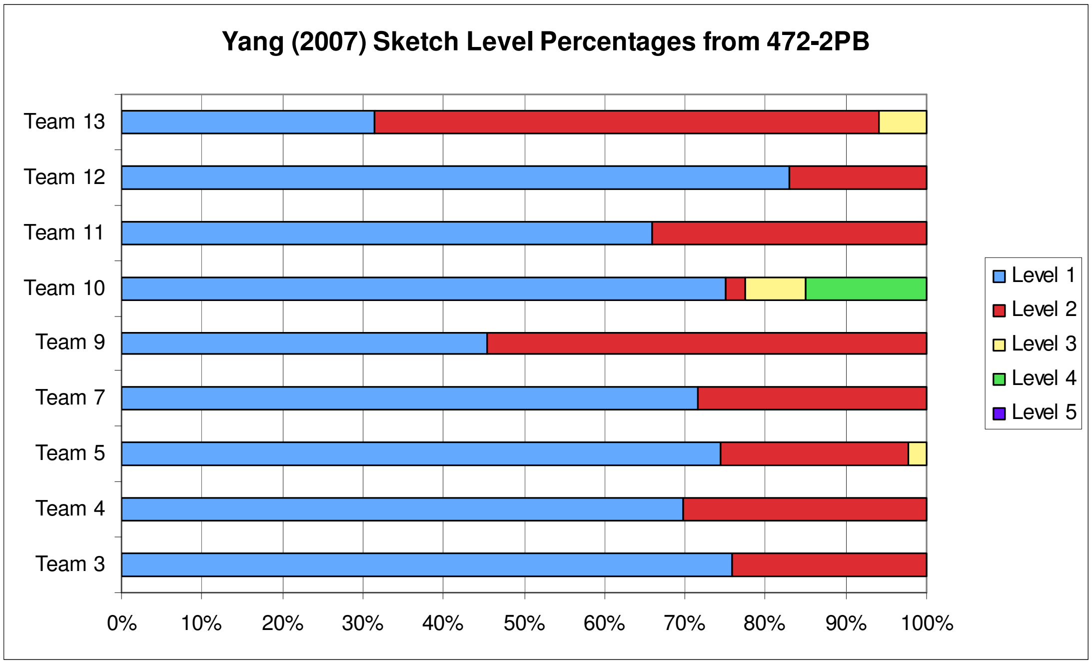


Figure 29: 472-2PB Yang Levels

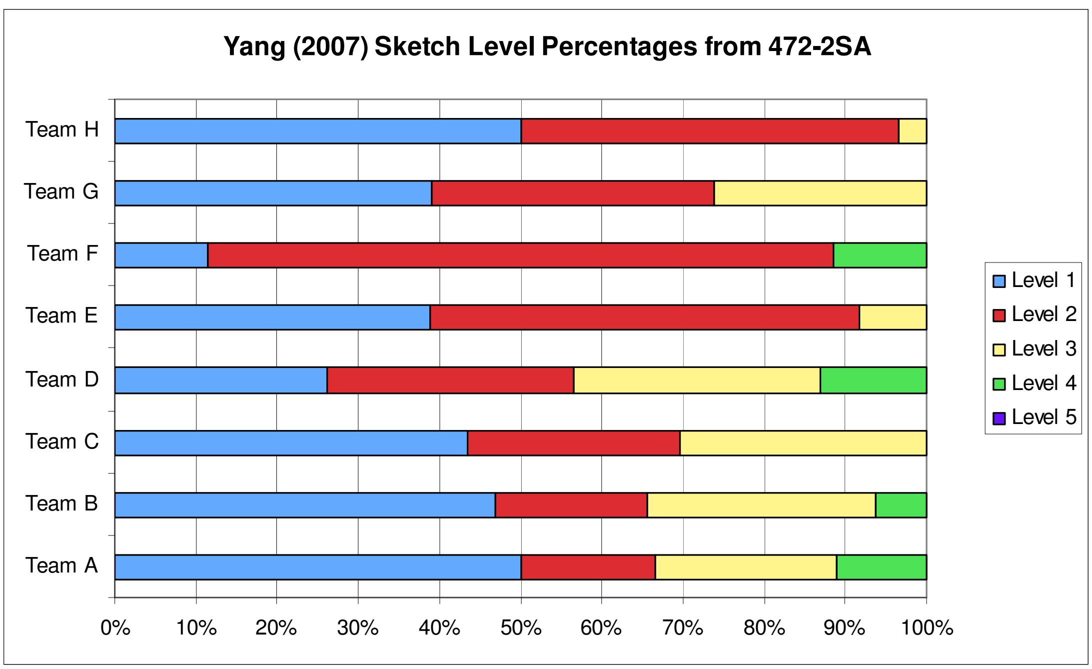


Figure 30: 472-2SA Yang Levels

Figure 31 displays McGown and Yang number of sketches in each level together. From Figure 31, the differences between McGown and Yang sketch coding schemes can be seen. The coding schemes can be compared due to one researcher (the author) coding all of the SAs, which means one interpretation of the coding schemes (unlike that in Chapter 4.1). McGown levels 1 and 2 are significantly different number-wise. McGown has a large number of level 2 sketches with much fewer level 1 sketches. Yet Yang levels 1 and 2 are much more evenly distributed. Levels 3 and 4 in both McGown's and Yang's coding scheme have fewer sketches within these SAs. From Figure 31, McGown and Yang sketch coding schemes differ in the classification and definition of levels. The skill of sketching did not change, Table 32 confirms this.

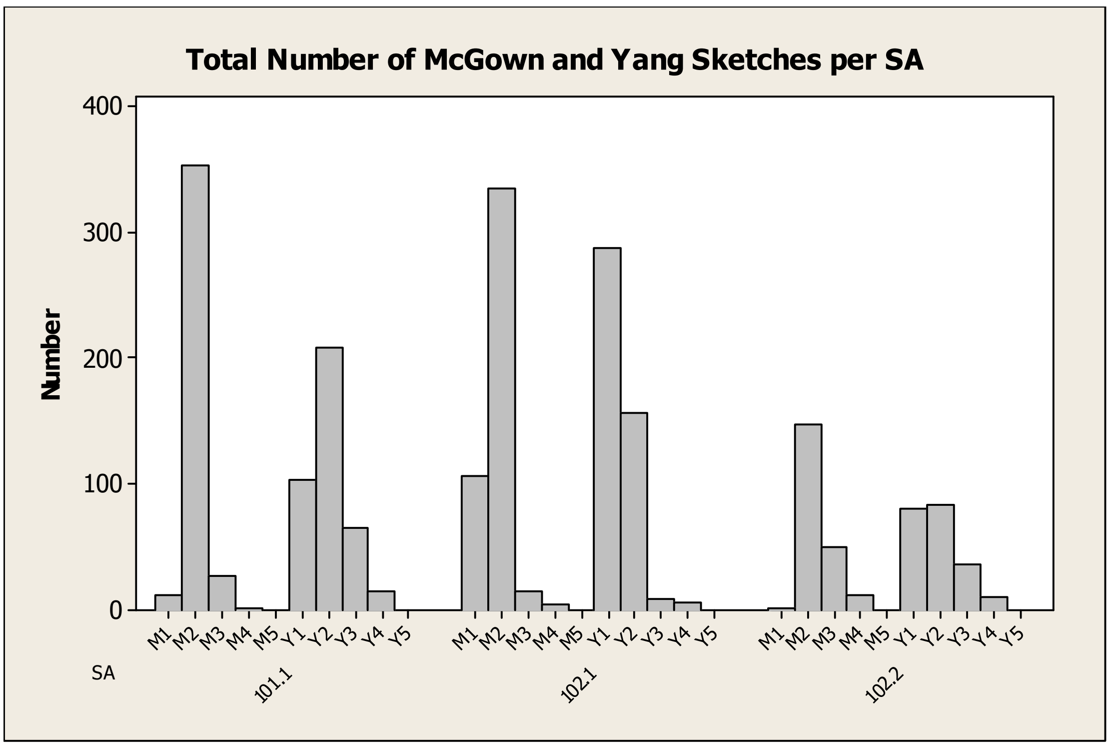


Figure 31: Compilation of Total Number of McGown and Yang Sketches

5.2.3 Subjects of Sketches within Sketch Assignments

The new content-based sketch coding scheme should reveal more information about sketches than skill in drawing. Sketches coded by subject revealed the high number of Entire Artifact (F1) within all SAs submitted. Figure 32 displays the total number of sketches submitted according to subject code per SA. Within this figure and hereinafter, 101.1 is synonymous with 472-1SA, 102.1 with 472-1PB, and 102.2 with 472-2SA. In Figure 32 it is easy to see the prevalence of entire artifact (F1) sketches. The other four subject matter sketches are rare compared to entire artifact. Artifact feature (F3) sketches are more prevalent than that of exploded views of assemblies (F2), artifacts in operation (F4), and FBDs (F5). The trend seems consistent in all assignments.

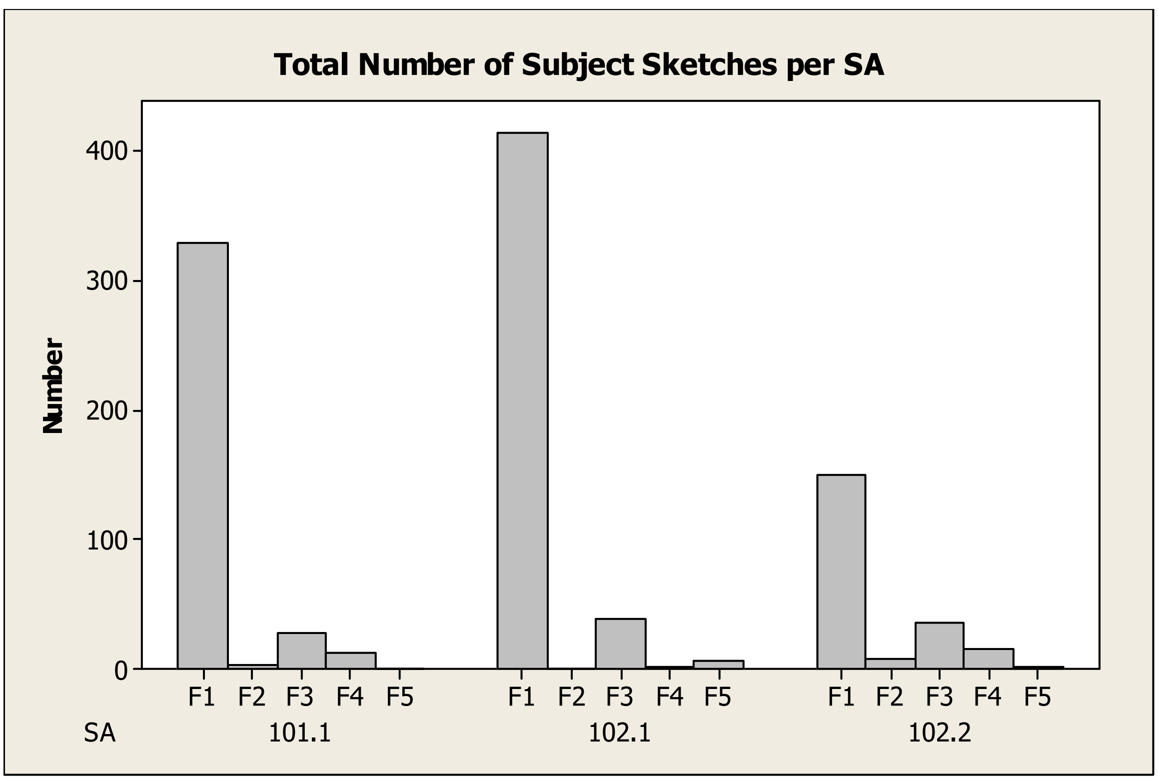


Figure 32: Number of Sketches by Subject per Team within SAs

Figure 33 shows the average number of sketches per student with subject coding by team. The data is much like that in Figure 32; however the values eliminate difference in team size. It is easier to see the difference between number of team sketches among SAs in Figure 32. 472-2SA (102.2) submitted less than half of entire artifact (F1) sketches compared to the other two SAs. However, the average number of artifact feature (F3) sketches submitted for 472-2SA (102.2) is higher than that of the other two SAs.

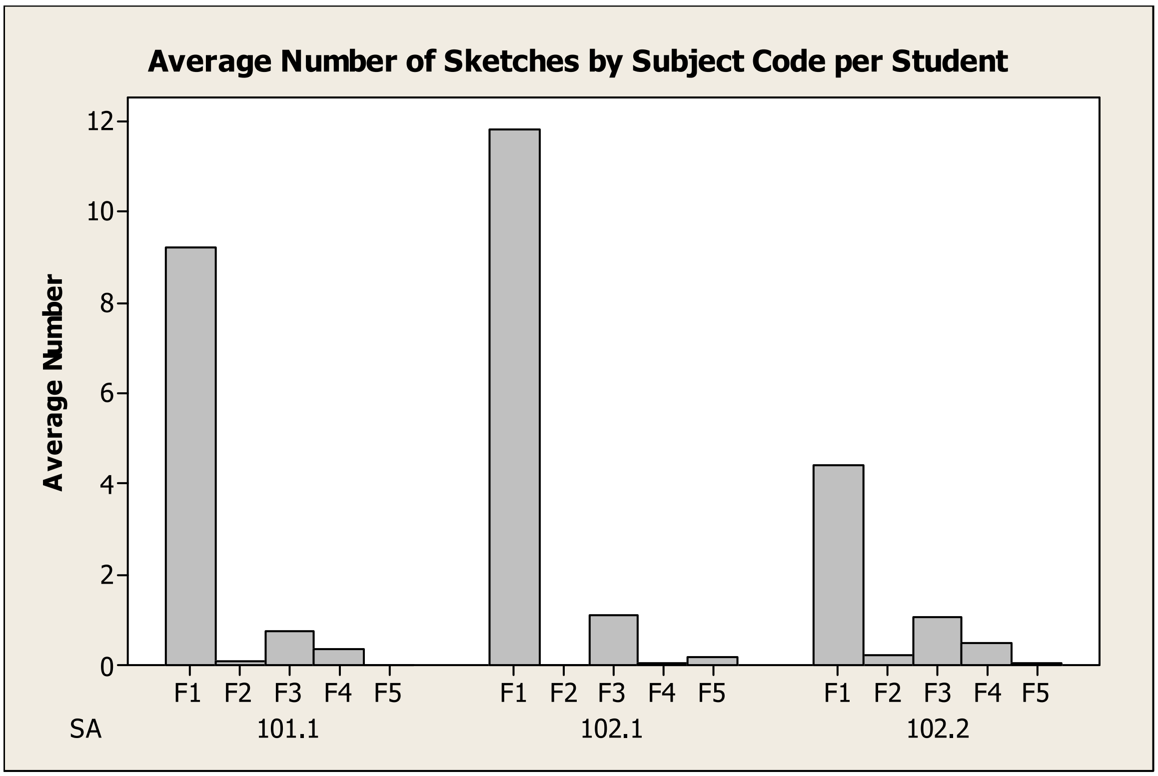


Figure 33: Average Number of Team Sketches by Subject

Figure 34, Figure 35, and Figure 36 display the percentages of sketches by subject coding per team within each SA. These graphs show more details of the SA data. A few teams submitted all entire artifact (S1) sketches. FBDs (S5) were rarely submitted. There is a clear increase in subject matter variety from 472-2PB to 472-2SA.

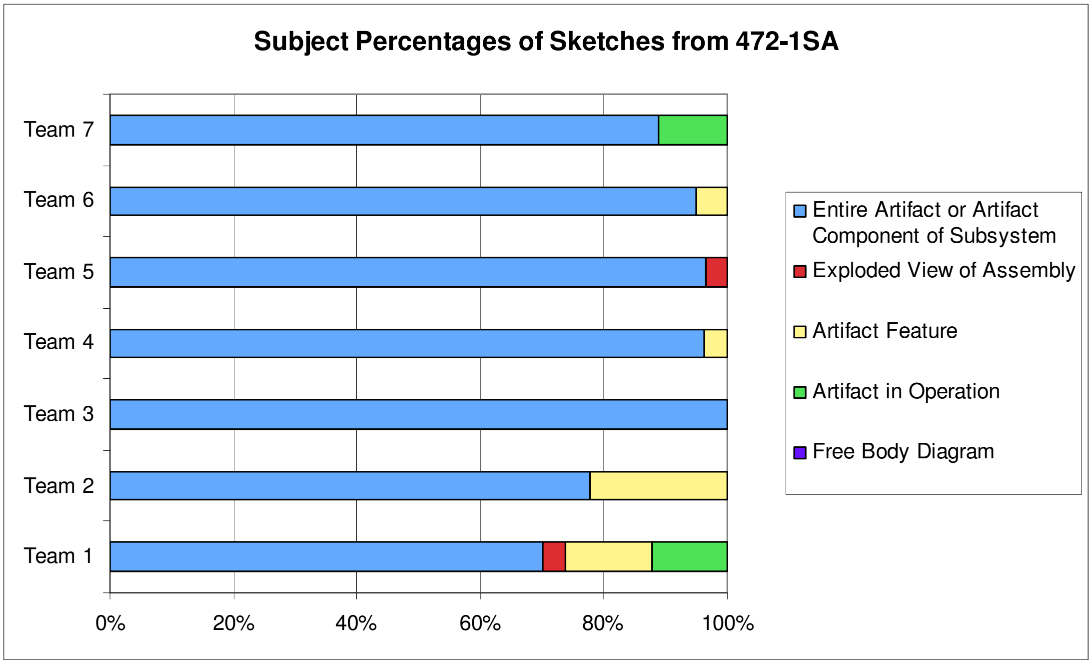


Figure 34: 472-1SA Subject Codes

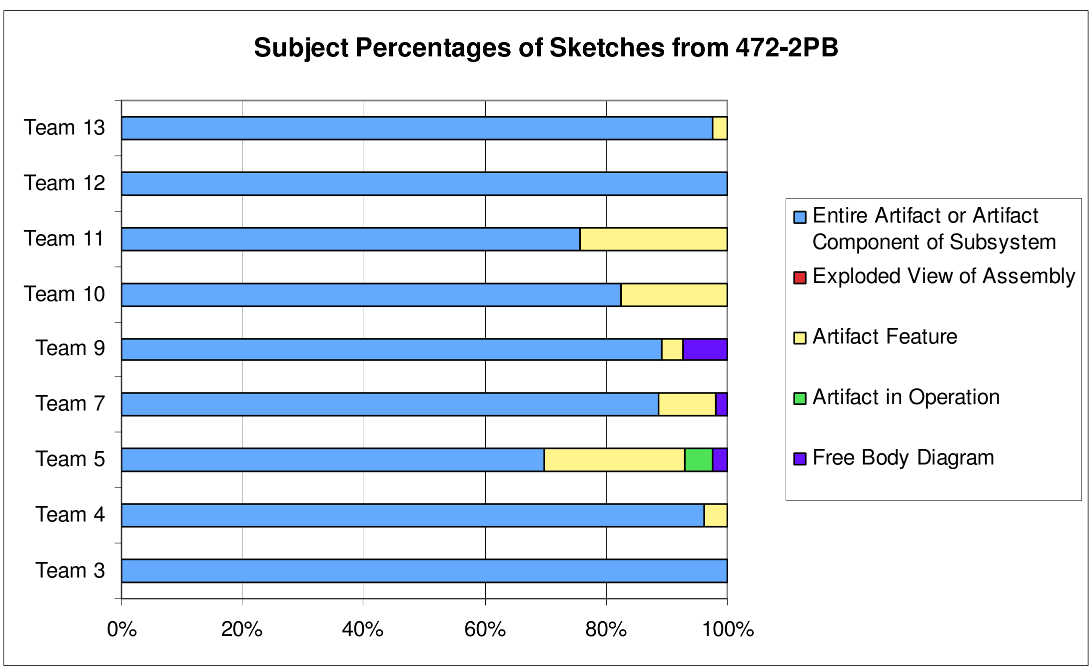


Figure 35: 472-2PB Subject Codes

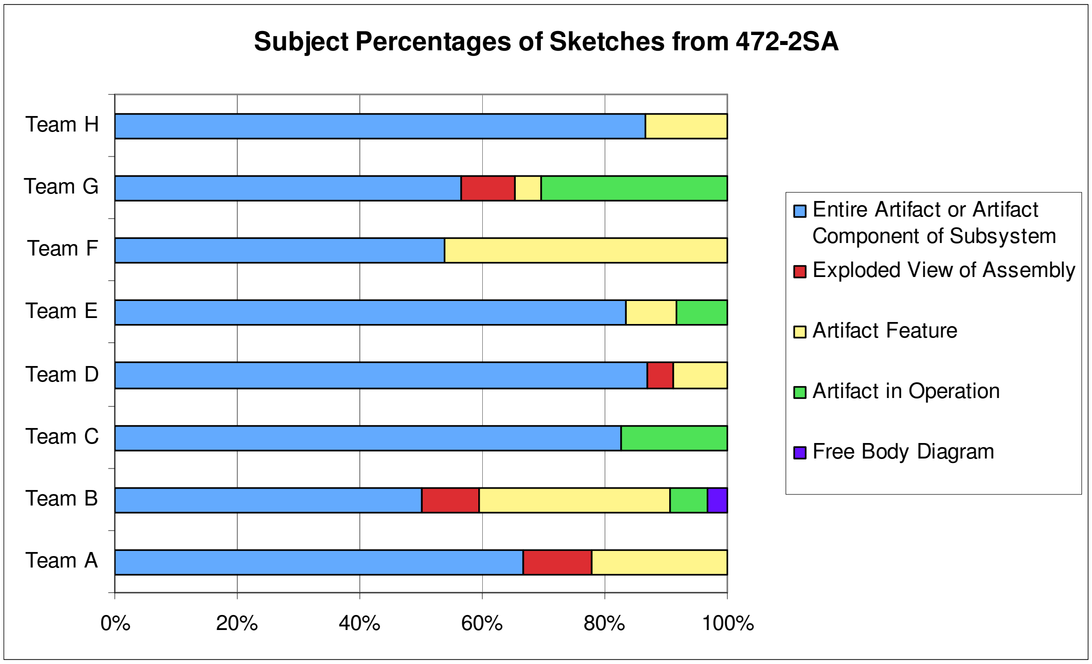


Figure 36: 472-2SA Subject Codes

ANOVA was performed on the percentage of sketch subject ratings per team within SAs. Table 33 displays the ANOVA subject results. The ANOVA states that the only significant difference between subject matter among SAs is that of the exploded view of assembly (F2). If the analysis of results was conducted by average sketches per team per member, the results would be skewed due to the fewer number of sketches within 472-2SA. Percentages allow to see the differences within SA by taking out such factors.

Table 33: Percentage of Subject Ratings per Team ANOVA

Comparison of Percentage of Subject Matter Ratings per Team

	Percentage over Teams			ANOVA Results		
	472-1SA	472-2PB	472-2SA			
No. of Teams	7	9	8	*F-Value*	*p-value*	*Differences*
F1	0.8927	0.8079	0.7082	1.04	0.37	
F2	0.00977	0	0.04191	4.57	0.022	Significant
F3	0.0641	0.0779	0.1679	1.99	0.161	
F4	0.03342	0.0483	0.07801	2.26	0.129	
F5	0	0.01587	0.00391	1.03	0.374	

5.2.4 Details of Sketches within Sketch Assignments

The new content-based coding scheme was applied to all of the sketches submitted within the three SAs. The content-based scheme permitted seeing how many times different types of detail occurred. The code of annotations (O) was added to the coding scheme for these three SAs. The prevalence of annotations (O) within the first few students' SAs coded intrigued the author. The annotations detail (O) is unique to this specific application of the new coding scheme.

The total numbers of each sketch detail within each SA are listed in Table 34. Within Table 35, the same data is shown except in percentages. From Table 34 and Table 35, an abundance (on average 90%) of the sketches included annotations (O). Dimensions (N) were used within 472-2 sketches but not at all within 472-1 sketches.

Table 34: Total Number of Details Coded per SA for all Assignment Submissions

	472-1SA	472-2PB	472-2SA
G. Part of A Multiple Subject Object	0	0	25
H. Motion Indications	14	21	60
I. Isometric	4	26	35
J. Set of Orthogonal Views	64	81	39
K. Part of a Set	278	206	100
L. Applied Forces	5	9	9
M. Multiple Views of 1 Object	0	0	31
N. Dimensions	0	66	16
O. Annotations	349	399	201
TOTAL NUMBER OF SKETCHES	*393*	*459*	*211*

Table 35: Percentages of Details Coded per SA Averaged over Assignment

	472-1SA	472-2PB	472-2SA
G. Part of A Multiple Subject Object	0.00	0.00	11.85
H. Motion Indications	3.56	4.58	28.44
I. Isometric	1.02	5.66	16.59
J. Set of Orthogonal Views	16.28	17.65	18.48
K. Part of a Set	70.74	44.88	47.39
L. Applied Forces	1.27	1.96	4.27
M. Multiple Views of 1 Object	0.00	0.00	14.69
N. Dimensions	0.00	14.38	7.58
O. Annotations	88.80	86.93	95.26

Table 34, Table 35, and Figure 37 indicate differences among the type of detail presents in the SAs. Figure 37 displays the data as percentage of sketches submitted to eliminate influence of raw numbers (since 472-2SA had about half the number of sketches as the other two SAs). Overall, 472-2SA submitted sketches included all detail types and mostly had higher percentages in each detail (except K: Part of a Set and N: Dimensions). This may be a result of the sketch lesson given before the assignment. The sketch lesson emphasized sketching as a tool and how it assists the design process. A reading on sketching in engineering design was given as an in-class assignment and discussed.[5] All SAs had about the same percentage of annotations (O). This is not surprising because each assignment required that sketches include annotations.

A major point within this data is that sketch quality with McGown and Yang is not obvious from detail data as seen in Figure 31. 472-1SA and 472-2SA had similar percentages of sketch skill levels (both McGown and Yang); however their data percentages of sketch details: Motion Indications (H), Isometric (I), and Part of a Set (K) vary significantly.

[5] The sketch lesson included a definition of sketching, various details that can be used to enhance sketches, pros and cons of sketching, and a class reading McCormick, D. (2007). "Seeing Mechanical." Mechanical Engineering, 35-36. was given which was discussed in class. The sketch lesson PowerPoint presentation is located in Appendix B.

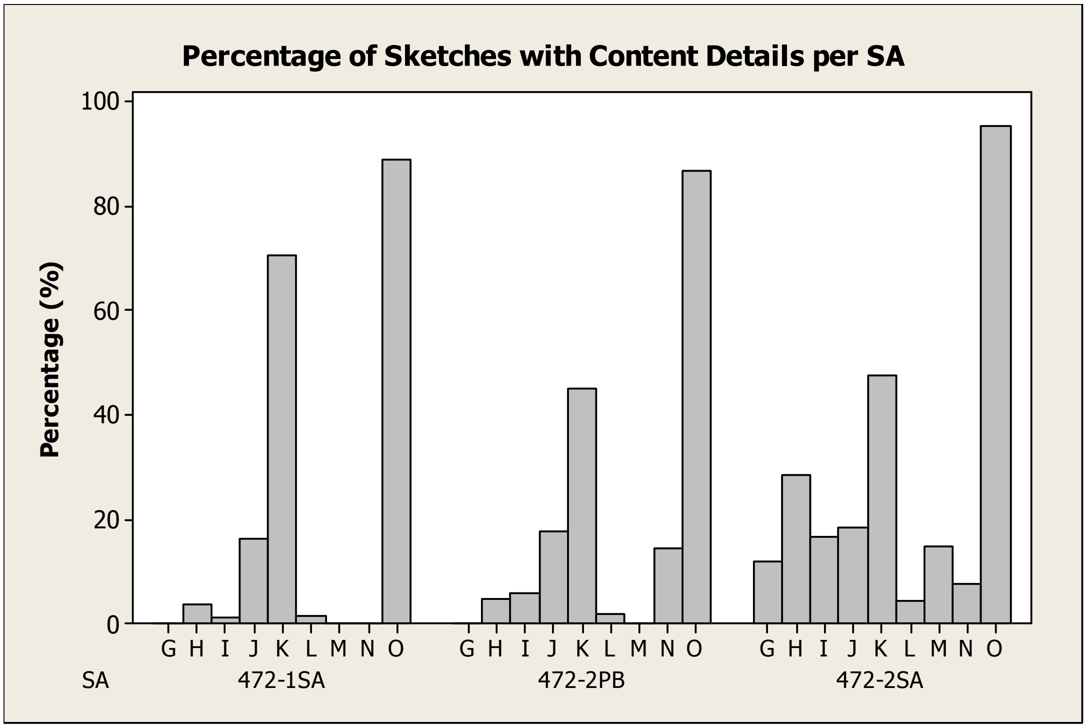


Figure 37: Percentages of Sketches with Content Details per SA

ANOVA was performed on the percentage of detail ratings per team. Table 36 displays all of the ANOVA results per detail code. The significant difference between details among SA include: motion indications (H), isometric (I), and multi-view objects (M). These three details are significant due to the fewer number of occurrences compared to the total number of sketches within 472-1SA and 472-2PB, while there is significantly higher percentages of these codes with 472-2SA.

Table 36: Percentage of Detail Ratings per Team ANOVA

Comparison of Percentage of Detail Ratings per Team

	Percentage over Teams			**ANOVA Results**		
	472-1SA	472-2PB	472-2SA			
No. of Teams	7	9	8	*F-Value*	*p-value*	*Differences*
G	0	0	0.1126	3.44	0.051	
H	0.3245	0.04598	0.28753	19.36	0	Significant
I	0.0106	0.0405	0.179	5.92	0.009	Significant
J	0.1578	0.1465	0.1847	0.08	0.926	
K	0.6503	0.4265	0.4669	2.34	0.121	
L	0.02215	0.01825	0.04976	1.19	0.324	
M	0	0	0.14162	10.25	0.001	Significant
N	0	0.1221	0.0692	2.7	0.09	
O	0.8892	0.8717	0.9583	0.9	0.423	

SAs had a high percentage of sketches being a part of a set (K). 472-1's part of a set (K) was slightly higher than that of both SAs of 472-2. 472-2SA had a higher percentage (28.44%) of motion indications (H) than that of 472-1SA (3.56%) and 472-2PB (4.58%).

The details within the sketches from all three SAs show:

- Multi-subject sketches (G) are only in 472-2SA. The SA may have limited this detail due to the assignment requiring a specific number of concepts. Most students put the separate concepts on separate sheets of paper. 472-2SA sketched more than one concept or multiple ideas on one page.
- Motion indications (H) are most frequent in 472-2SA. This may be a result of the students becoming more familiar with sketching, idealogging, and this specific assignment.
- Isometric (I) and orthogonal (J) views are within all three SAs. Isometric views (I) are less frequent than orthogonal views (J). Fewer isometric views are within 472-1SA and 472-2PB than 472-2SA.

- Part of a set (K) detail occurs more frequently in 472-1SA and 472-2PB than 472-2SA. This may be a result of the type of assignment, just as mentioned with the reason for multi-subject sketches (G).
- Applied forces (L) within sketched did not occur often in any of the SAs. However, applied forces occurred more often in 472-2SA. This may be a result of familiarity and ease with the assignment as mentioned about motion indications (H).
- Multi-views of one object (M) did not occur at all in 472-1SA or 472-2PB, but did occur some in 472-2SA. This may be a result of students' trouble sketching different views of objects.
- Dimensions (N) within sketches occurred in 472-2 but not 472-1. A decrease in occurrence of dimensions occurred from 472-2PB to 472-2SA. This result may show that students were grasping the concept of sketching rather than drawing or drafting.
- Annotations (O) are used within the majority of all sketches in SAs. This may be a result of the given assignment and students' low sketch skills make students elaborate with words rather than visuals.

5.3 Discussion of Sketch Assignment

The analysis of SAs revealed that the students within 472-1 submitted higher skilled sketches then did 472-2 within their first SAs (472-1SA and 472-1PB). 472-1SA was a part of the semester project with student chosen team while 472-2PB was a part of a two week introductory project with randomly assigned teams. 472-1 chose their teams and projects which resulted in more investment with the project and SA. 472-2 Paper Boat teams were not as invested due to the instructor given problem, short time frame, and randomly assigned teams.

A high percentage of sketches were of low quality according to McGown and Yang sketch coding schemes. Students sketched low quality sketches for the SAs which were all completed during concept generation. The number of sketches submitted for 472-2SA was about half of the number submitted for 472-2PB and 472-1SA. The content of their sketches was different from that of the other two SAs. Fewer sketches were needed because they contained more information as evidenced by higher incidence of details. As being the TA of this 472-2, many students felt they were behind and rushed on their semester project s compared to 472-1. As well, the 472-2 students had over two weeks of practice with their idealogs and their projects were more specific because many of the projects had external sponsors.

Chapter 6: Creation of Mechanical Engineering Visual Design Mediums Concept Inventory

Sketching seems to be used less and less within the engineering curriculum and during students' design projects. What students know about sketching, their motivation to sketch or not to sketch, and what medium they use instead of sketching are questions that are addressed by the Mechanical Engineering Visual Design Mediums Concept Inventory. The Concept Inventory was created by the author. Published literature on sketching and previous research informed and inspired the questions within the CI.

6.1 Research on Concept Inventories and their Use

Concept inventories are composed of multiple choice questions that are designed to test whether a person has the correct understanding of a specific set of concepts. The multiple choice format insures that the scoring will be objective. The answers include one correct response and other responses that represent incorrect concepts and common misconceptions about the question. This method of creating intentionally incorrect responses facilitates research about concepts and misconceptions, also commonly called distracters. The distracters are incorrect views believed to be commonly held by the test takers. Concept inventories are not the same as standardized tests. Concept inventories measure concept mastery and focus on uncovering of common misconceptions.

The first concept inventory to be widely publicized was the Force Concept Inventory (FCI) pioneered by David Hestenes, Malcolm Wells, and Gregg

Swackhamer (1992). The FCI was designed to assess student understanding of Newtonian force concepts. The FCI's questions cover six conceptual dimensions that are needed for the complete understanding of Newtonian Forces (Hestenes 1992). "The inventory data provide a clear, detailed picture of the problem of commonsense misconceptions in introductory physics." (p. 2, Hestenes 1992). The FCI is based on the "Mechanics Diagnostic" test that tests individual's general knowledge on physics principles. The FCI's goal is to improve upon the "Mechanics Diagnostic" test. The researchers have followed some students from undergraduate courses (with scores), then retested and observed their performance in a Mechanics class.

The FCI is often used for both instructional and research purposes. The FCI applications can be divided into three categories: diagnostic tool, evaluator of instruction, and a placement exam. Identifying, misconceptions of Newtonian forces is the major focus of the concept inventory (Hestenes 1992). A significant result from applying the FCI was that about 80% of students could state Newton's third law but less than 15% fully understood it (Hestenes 1998).

The FCI has been administered beyond Hestenes' research work with a wide range of students and at many institutions. The 30-item multiple choice FCI was administered in the beginning calculus-based physics classes at the University of Minnesota. The University of Minnesota has been using the FCI since 1993. On average, 850 students enroll in the introductory calculus-based physics course each fall. The FCI was administered as a voluntary and un-graded test during the first lab session of the course as a pre-test. The FCI was given in 1997 and 1998 as a part of the final exam and was graded. It was seen that there was no significant difference from those who took the FCI posttest with or without the pretest which means that seeing the test once before did not skew the results. The researchers correlated the FCI scores and individual's course performance (final grades). These correlations showed that the FCI is a good predictor of who will have success in the class (meaning high letter grades). It was found to not be a very good predictor for those with little success. From the data and analysis, it was found that the FCI should not be used as a placement exam. However, it is noted that the results of the FCI can and will be different at other institutions. Researchers also published notes on how to tell if students are not taking the FCI seriously: "refusing to take the test, drawing a picture on the Scantron answer sheet, answering all A's, B's, etc, leaving six or more blanks, and other patterns (such as ABCDE, EDCBA, AAAAA, BBBBB, etc) any place in their responses." (Hestenes 1998) The major conclusions of this work are good to keep in mind: the FCI is inappropriate for a placement exam; there are little differences in final grades when the FCI is taken for credit or not, and taking the pre-test does not effect post-test results (Henderson 2002).

Huffman and Heller express concern that the Force Concept Inventory does not actually measure force concepts because the questions are too loosely formed. With analysis, it was found that the FCI does test parts of concepts but not the entire concept. It is still recommended as a diagnostic exam as long as one keeps in mind that the central force concept is not focused on and that familiarity with context may be a large factor in test results. Much more research is needed with the amount of uncertainty from this specific study (Huffman 1995).

One researcher, McColluogh (2002), found that the FCI has a gender gap that favors males. In this research, the FCI was modified to eliminate most of the gender bias within it. The gender-oriented version of the FCI (GFCI) changes the context of the questions to be more female oriented while keeping the same physics and types of questions. In addition to the students taking the FCI, the students gave some demographic information: level of math preparation, number of high school math courses, and number of college level math courses. This preliminary study was unable to make any definite conclusions; some of their data points had very small numbers of participants. With the small amount of data, the study suggests that math background does not play a role in the gender gap (McColluogh 2002).

Lindell compared twelve concept inventories in physics and astronomy (2006). From this investigation, it was found that the definition and understanding of concept inventories varies with each instrument. Concept inventory methodologies are not standardized and sometimes not even thought through. It is strongly recommended to give a definition of the specific concept inventory and explain the concept inventory's methodology in order to aid in determining its appropriateness for other utilities (Lindell 2006).

Even though the FCI has not been shown to affect students' knowledge and performance, the FCI and concept inventories in general provide data on the students' knowledge base. If improvement is needed, more than administering the CI is necessary. The CI data reviewer must keep in mind that only very specific items of knowledge can be tested by the inventory, not entire concepts. It is difficult to test understanding of a complete or sophisticated concept with a multiple choice tool.

However, short answer questions can be included in the CI to obtain deeper and more detailed knowledge of the entire concept. The CI developed for this research will collect data on students' knowledge about sketching.

6.2 Development of Concept Inventory

The Mechanical Engineering Visual Design Mediums Concept Inventory was modeled after the Force Concept Inventory (FCI), one of the oldest, well-known and most validated concept inventories. The CI was created in the same manner as reported by the authors of the FCI. Key steps in the process were the creating of the list of concepts for testing and probable misconceptions.

The CI focuses on sketching and CAD as visual representation mediums in the design process. There are many more visual design mediums that are and can be a part of the Mechanical Engineering Design Process, including: drawing, drafting, photographs, hand gestures, graphic art, and so on. Sketching seems to be fading from the current design process and being replaced by the use of CAD programs. A widespread decrease in sketching skills may have effects on the design process and the success of future engineering disciplines. As the CI evolves, it can be expanded to include more visual design mediums.

The creation of the Draft CI began with sketching and CAD research. Every question in the CI (both Draft and Fall 2007 versions) has a literature reference, excluding two questions that were configured from the experience of the author and Dr. Linda Schmidt. The Draft CI differs slightly from the IRB approved CI. The Draft CI was administered for the sole purpose of seeing how students reacted to it and if certain questions were inappropriate in the context of student curriculum and research goals. An IRB was not obtained for the draft because none of the data would be reported.

The Draft CI was given to students enrolled in Machine Design, a Mechanical Engineering elective course during the summer of 2007. The students giggled at question number 1 due to its simplicity and obviousness. As can be seen in Figure 38, question number 1 of the draft CI asked students to label which picture was a sketch and which was a CAD drawing. For the upperclassmen in this specific course, the answers were obvious. However, freshman may not have had the same reaction and it may have taken some time to determine the answer, especially if the acronym “CAD” or Computer Aided Design drawing was unfamiliar to the test taker.

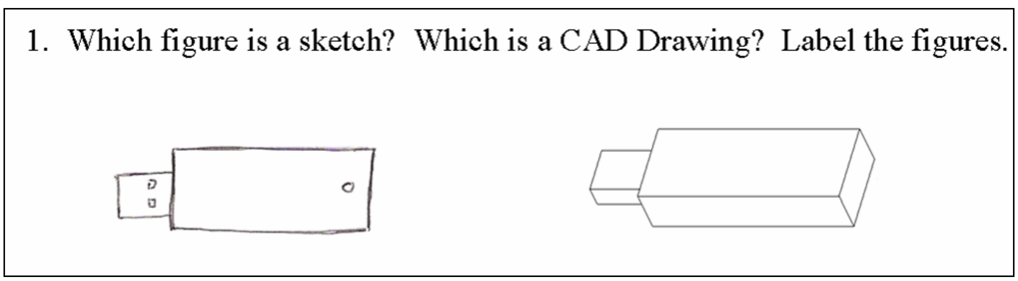


Figure 38: Draft CI Question 1

A decision was made to change the simple (and perhaps obvious) question number 1. Instead, the question was split into two short-answer questions asking for definitions as follows: “Define sketch” and “Define Computer Aided Design (CAD) drawing”. The open ended questions will require the students to think more deeply about sketching and CAD drawings. Figure 39 displays question 1 of the Fall 2007 CI which is the replacement for the draft CI question number 1 shown in Figure 38.

The integration of short answer questions allows for deeper thought to see if students understand the entirety of the concept.

1. a. Define sketch:

b. Define Computer Aided Design (CAD) drawing:

Figure 39: Fall 2007 CI Question 1

The questions relating to "sketch level of detail" were edited from the draft CI so that the level number was not referred to. Figure 40 displays the Draft CI sketch level question. The level number reference detracted from the validity of the CI because the level number was specific to McGown's (1998) sketch coding scheme work. Stating "Level 2" could mean anything without referring to McGown's sketch coding scheme. Even if McGown was referenced, only the people who know of that work would be able to relate to those specific level numbers. A more general question was created without reference to levels.

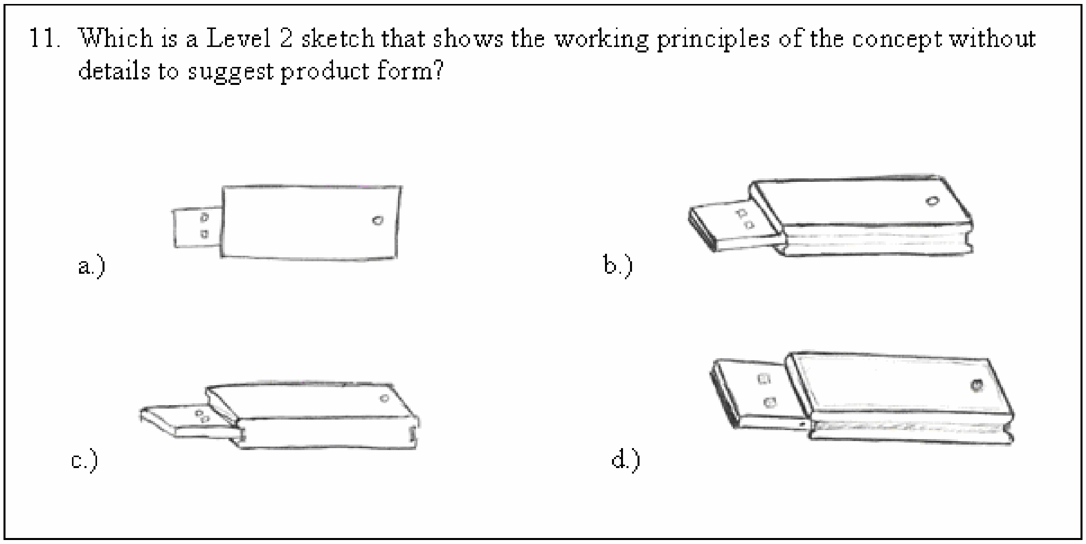


Figure 40: Draft CI Proper Sketch Use Question

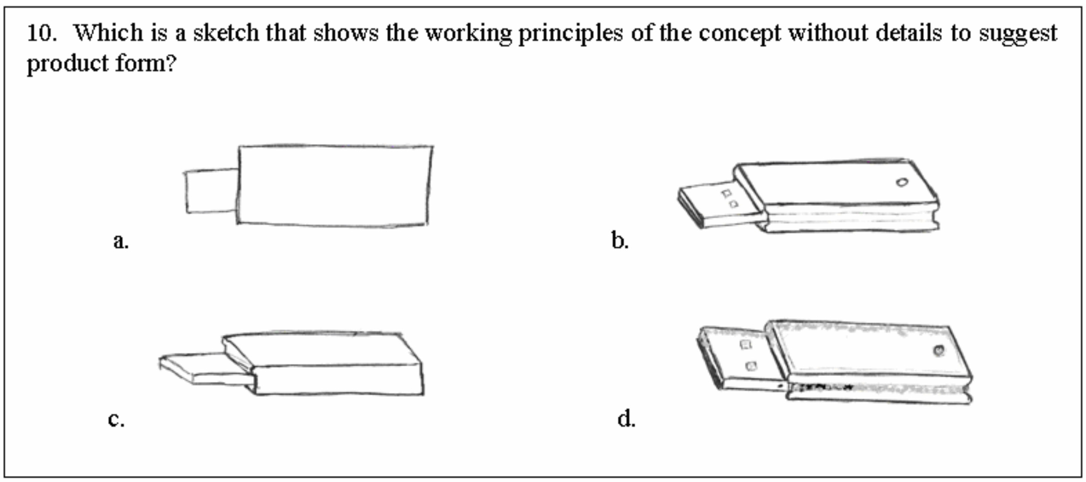


Figure 41: Fall 2007 CI Proper Sketch Use Question

Defining and labeling sketching concepts and misconceptions were necessary to produce the Fall 2007 CI version. All questions (except 11 and 17) have a literature reference indicating the correct answer. Question numbers 11 and 17 require some deeper thought with inferences and analogies. Question number 11 compares a picture with a sketch. The correct answer requires students to know that sketches are ambiguous while pictures are exact. Number 17 is a question that is related to McGown's sketch levels but asks the viewer to select an appropriate sketch for a purpose defined by one of McGown's sketch levels. The referenced and answer key Concept Inventory is in Appendix C. The CI that was administered to students without references and the answer key is in Appendix D and Appendix E.

An outline of hand-sketching and CAD concepts was organized from the appropriate reference literature (all described in Chapter 2). These concepts spanned the range and overall understanding of sketching and CAD deemed interesting for this work. The concepts paralleled with the research questions as well. Table 37 displays all of the concepts within the CI and the corresponding items (correct answers).

Table 37: Concepts in the CI

Sketching and CAD Concepts in the Inventory

		Inventory Item(s)
1. Sketching		
CS1	Thinking Tool	2B, 5B, 20B
CS2	Communication Tool	3D, 5B
CS3	Physical Memory	4A, 13B
CS4	Role of Creativity	6A, 18C, 20B
CS5	Place in Design Process	7C
CS6	Definition	8B, 9A, 11D, 18C
CS7	Sketch Levels	10A, 17B, 21C
CS8	Perception	6A, 12C
CS9	Interactive Process	3D, 5B, 13B
2. CAD		
CC1	Physical Memory	13A, 13B, 19D
CC2	Role of Creativity	15A
CC3	Place in Design Process	14C
CC4	Definition	18C
CC5	Fixation	16B

6.2.1 Sketching Concepts (CS) in Concept Inventory

The sketching concepts section (CS) exists to identify the many different roles and uses of sketching. Sketch is a thinking and communication tool (CS1 and CS2). Sketching acts as physical memory (CS3) and promotes creativity (CS4). Sketching is used the most within the concept generation phase of the design process (CS5). The correct definition (CS6) and quality and application of sketches (CS7) are concepts within the CI as well. The perception of sketching in engineering education (CS8) and interactive process (CS9) are also concepts focused on in the CI.

6.2.2 CAD Concepts (CC) in Concept Inventory

The CAD concepts (CC) include: how CAD acts as a physical memory (CC1), the role of creativity in CAD (CC2), the occurrence of CAD mainly within final design (CC3), the definition of CAD (CC4), and CAD promoting premature design fixation (CC5),

A listing of misconceptions was created as well. The misconceptions in the CI are the wrong answers (a.k.a. detractors). Incorrect answers from the draft CI were then altered to be more precise in describing common misconceptions. Just as Table 37 outlines concepts, Table 38 outlines the misconceptions within the CI.

Table 38: Misconceptions in CI

Taxonomy of Misconceptions Probed by CI

		Code	Misconception	Inventory Item
1. Sketching				
	Definition			
		S1	Sketching is equivalent to drawing	9C, 9D, 11C
		S2	Sketching is equivalent to CAD	5C, 8A, 9B, 11C
		S3	Only artistic	4C, 5D, 12B, 13C, 20C
		S4	Only educational	4D, 13D
		S5	CAD take the place	5C, 8A
		S6	Worth little or nothing	9D, 11A, 11B, 12B
	Tool (ST)			
		ST1	Hindrance to thinking	5C, 8D, 18B
		ST2	Hindrance to communication	2C, 8D, 18A
		ST3	Hindrance to creativity	2A, 2D, 18B
		ST4	Analysis aid/tool	3B, 3C, 6C, 18D, 20D
	Use (SU)			
		SU1	Assist in solely other stages in design process (not concept generation)	7A, 7B, 7C
		SU2	Rely only on sketching in design process	6D
		SU3	Leads to immediate solution	5A
		SU4	Assist in solely individual work	3A, 4B, 8C
		SU5	Incorrect application for specific sketch	10A, 10B, 10D
		SU6	Creativity has positive outlook from engineering education	12A, 12D
2. CAD				
	Definition			
		M1	Creative process	15D, 16A, 16D, 18B, 19A, 19B, 19C
	Tool			
		MT1	Presentation focused	15C, 18A
		MT2	Hindrance to documentation	15C, 18D
	Use			
		MU1	Assist in all of the design process	6B, 14D
		MU2	Assist in solely other stages in design process (not final design)	14A, 14B, 19B
		MU3	Rely only on CAD is design process	6B, 16C
		MU4	Assist in solely individual work	3A, 15B, 16D

6.2.3 Sketching Misconceptions (S, ST, SU) in Concept Inventory

Just as there are correct concepts of sketching and CAD, there are also misconceptions of sketching and CAD within the CI. Misconceptions of the definition of sketching (S) include: sketching is equivalent to drawing or CAD (S1, S2); sketching is only artistic or education oriented (S3, S4); CAD replaces sketching (S5); and sketching is worth little or nothing (S6). Misconceptions of sketching as a tool (ST) include: sketching is a hindrance to thinking (ST1), communication (ST2), and creativity (ST3); and sketching acts as an analysis aid or tool (ST4). Misconceptions of sketching use (SU) include: sketches assist solely in other design stages (except concept generation) (SU1); reliance on sketching completely (SU2); sketching leads to an immediate solution (SU3); sketching assists in individual work only (SU4); sketch is chosen for the wrong application (SU5); and creativity has a positive outlook from engineering education (SU6).

6.2.4 CAD Misconceptions (M, MT, MU) in Concept Inventory

Misconceptions of CAD include: the definition includes that CAD is a creative process (M1); CAD is solely presentation focused (MT1); CAD hinders documentation (MT2); CAD is the tool of choice for all of the design phases (MU1) or any of the other design phases excluding final design (MU2); CAD is relied on solely on the design process (MU3); and CAD assists only in individual work (MU4).

A small survey was included with the CI when administered. The survey collects demographic information while still keeping students' anonymity. The survey is in Appendix E. Information collected includes: year in school, courses taken, hours/week on sketching, hours/week on CAD, etc. This data will be helpful in analyzing how students answered questions of the CI. The draft CI included the draft Survey. The survey was created with the assistance of other recent surveys from our Design Research Team. The survey was made to be straight forward and easy to answer.

6.3 Validation of Concept Inventory

The validity of a concept inventory is based upon the probability that when a student selects the correct answer it is because they recognize it to be correct based on their knowledge of the topic. In other words, they can't just guess the correct answer. In the same way, a good CI will offer students false answers that match a misconception the student believes is correct. Usually evidence of validity comes from interviews with concept inventory takers. Since this CI is still within its first version, the analysis within this research is part of its validity. The draft CI assisted in fine-tuning the CI questions and laying out the taxonomies of concepts and misconceptions. Further research and implementation of the CI will allow for more formal validity testing.

6.4 Results and Analysis of Concept Inventory

The CI was administered in the classroom. Depending on the professor's preference the CI was administered during the beginning or end of the lecture. The author administered all of the CIs except for one which was ENME472, Section 0101 administered by Dr. Linda Schmidt. The administrator explained who they were and what the CI was in brief. The students were told that the CI was voluntary. The IRB consent form must be read, signed, and dated in order for the student to participate. The complete IRB approval and consent form is in Appendix F.

The CI was administered to various Mechanical Engineering classes and the general freshman engineering class. The CI was administered to 100, 200, 300, and 400-level classes to obtain data from each year of the curriculum. There are no Mechanical Engineering 100-level courses offered, so ENES100 filled the 100-level section. ENES100 is the first engineering (all disciplines of engineering) class students take and contains a semester-long design project. The 200 through 400-level students were all Mechanical Engineering Department. Table 39 displays the classes, sections, instructors of the classes, registered students, date CI was administered, and the number of CIs taken. 223 students took the CI during Fall 2007. A total of 344 students were registered in those same classes but due to some of the classes having low attendance and some students choosing not to take the CI, less than half of the registered students in the classes took the CI. Especially within the 400-level classes, many of the students were taking 414, 472, and 489X concurrently which results in lower number of participants. When the CI was administered, the students were told that if they had already taken the CI in another class then they could not take the CI again because this would skew the results.

Table 39: Fall 2007 CI Classes and Number of CIs Taken

Class	Section	Instructor	Number of Registered Students	Date Administered	Number of CI Taken
ENES100	302	Sheryl Erhman	32	11/19/2007	27
ENES100	401	George Syrmos	40	11/15/2007	31
ENME232	All	R. Radermacher	69	12/5/2007	27
ENME371	All	C. Thamire	60	11/12/2007	33
ENME414	101	Guangming Zhang	42	12/10/2007	24
ENME472	101	George Dieter	35	10/23/2007	33
ENME472	102	Rebecca Currano	36	10/18/2007	33
ENME489X	101	Rebecca Currano	30	10/23/2007	15
Totals			**344**		**223**

The answers to the CI were collected and recorded within an Excel database. Number 1 was a short answer question that was included in the Excel data base but analyzed with another software package called: HyperResearch.

The definitions of sketches and CAD drawings written by students were coded within HyperResearch. The frequency of words within definitions was calculated.

Table 40 displays selected coded words from the definition of sketch question number 1a. Table 41 displays selected coded words from the definition of CAD question number 1b. Within these tables, a subset of the coded words is displayed. The words within these tables were chosen because they occurred the most frequently within the definitions. Table 40 and Table 41 contain yellow highlighted cells that show the most used word within each course's CI. The bold numbers within certain cells are for those words occurring at least 30% of the time.

The most frequent word used to define "sketch" was "drawing" across all undergraduate years except for 472-2. 472-2 sketch definitions' most dominant word was "idea." The word of "drawing" was also a dominant word from 472-2 student responses. Rough and hand-drawn were dominant among other courses.

Table 41 shows that the most dominant words among CAD drawing definitions were: "computer" and "drawing." Question 1b was worded: "Define Computer Aided Design (CAD) drawing." The question contained both dominant words which indicates that most students did not take time to think critically and try not to define the concept with the concept.

The words 2-D and 3-D were within both sketch and CAD definitions. The CAD elective course (414) definitions most frequently used the terms 2-D and 3-D in sketching and CAD definitions as compared to the other course. "3-D" was the dominant term in ENME 414 student's CAD definition. The other courses did not use "3-D" nearly as much which signals that ENME 414 student's knowledge base is more specific about CAD.

Table 40: Word Frequency in CI's Number 1a Short Answer Sketch Question

Frequency of Words in CI's Number 1a Related to "Define a Sketch"

	100 0302	100 0401	232	371	414	472 0101	472 0102	489X
Drawing	16	22	18	17	14	24	21	9
Design	6	7	6	7	1	5	4	0
Object	7	8	3	5	1	5	1	0
Concept	3	1	3	9	3	9	9	2
Idea	1	2	1	8	4	10	25	7
Product	6	0	5	0	1	0	0	0
Rough	7	13	14	14	2	12	10	6
Preliminary	1	1	0	2	0	2	1	1
Quick	2	3	4	1	0	5	6	2
Simple	0	0	0	2	0	4	1	3
Hand-drawn	2	3	4	8	7	11	9	9
2d	2	7	0	3	6	1	3	0
3d	1	2	0	3	5	0	1	0
Communicate	0	0	0	1	3	2	8	4
TOTAL CIs	*27*	*31*	*27*	*33*	*24*	*33*	*33*	*15*

Table 41: Word Frequency in CI's Number 1b Short Answer Sketch Question

Frequency of Words in CI's Number 1b Related to "Define a CAD Drawing"

	100 0302	100 0401	232	371	414	472 0101	472 0102	489X
Drawing	9	10	14	12	18	18	19	8
Design	7	9	4	9	3	8	7	3
CAD	0	1	3	0	2	2	1	1
Program	3	6	8	3	4	3	9	2
Computer	14	16	18	20	9	19	14	8
Object	3	8	2	0	0	3	1	2
Detail	2	6	5	8	5	10	6	4
Dimension	7	4	5	8	3	9	10	2
Product	1	1	5	0	0	0	0	0
Model	4	3	5	6	5	2	3	1
Views	0	0	0	0	3	1	3	0
Software		2	1	7	2	6	4	0
2d	0	0	1	4	3	4	1	0
3d	7	8	2	7	18	6	8	2
sketch	8	11	2	7	0	2	2	2
TOTAL CIs	*27*	*31*	*27*	*33*	*24*	*33*	*33*	*15*

The students multiple choice responses (numbers 2 through 21) of the CI were calculated with 'if' statements to see if the answer for each question chosen was the correct concept or not. The grades of each of the students' CIs were calculated and listed in Appendix G. Table 42 displays the average grade on the CI per section. The section average grades range from 43.96% to 57.67%. The highest individual grade among the 223 students was 75% and the lowest individual grade was 15%.

Table 42: Fall 2007 CI Average Grade per Section

Sections	Average Grade (%)
100 0302	47.41
100 0401	44.35
232	51.30
371	51.67
414	43.96
472 0101	56.06
472 0102	55.30
489X	57.67

Table 42 allows comparisons to be made from freshman level (100) courses to senior (400-level) courses. The average grades are within a small range; however the 400-level courses had the highest grades, excluding ENME 414 which had the lowest grade. ENME414 is the CAD elective. ENME 414 having the lowest grade on the CI is appropriate since the influence and prevalence of CAD is extreme compared to the other courses in which the CI was administered.

ANOVA was performed on students' CI grades by class and grade-level. Figure 42 and Figure 43 display the ANOVA results by class and grade-level, respectively. The grades analyzed both ways are significantly different. The classes and grade-levels are from different populations which can be easily seen in the figures below.

One-way ANOVA: Grade per Student versus Classes

```
Source    DF     SS   MS     F      P
Classes    7   5042  720  5.86  0.000
Error    215  26446  123
Total    222  31488

S = 11.09   R-Sq = 16.01%   R-Sq(adj) = 13.28%


                            Individual 95% CIs For Mean Based on
                            Pooled StDev
Level     N   Mean  StDev  ----+---------+---------+---------+-----
100.302   27  47.41  10.50        (------*------)
100.401   31  44.35  10.93   (------*-----)
232       27  51.30  12.98              (------*-------)
371       33  51.67  11.16                (-----*-----)
414       24  43.96  11.70  (------*-------)
472 0101  33  56.06  10.14                       (-----*------)
472 0102  33  55.30   9.51                      (-----*------)
489       15  57.67  12.80                       (---------*---------)
                            ----+---------+---------+---------+-----
                             42.0      48.0      54.0      60.0

Pooled StDev = 11.09
```

Figure 42: CI Grade per Students versus Classes ANOVA

One-way ANOVA: Grade per Student versus Grade-Levels

```
Source          DF     SS  MS     F      P
Grade-Levels     3   2144  715  5.33  0.001
Error          219  29344  134
Total          222  31488

S = 11.58   R-Sq = 6.81%   R-Sq(adj) = 5.53%


                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level    N   Mean  StDev  ---------+---------+---------+---------+-
100     58  45.78  10.75  (---------*-------)
200     27  51.30  12.98              (------------*-----------)
300     33  51.67  11.16                (-----------*----------)
400    105  53.29  11.76                          (-----*------)
                          ---------+---------+---------+---------+-
                               45.5      49.0      52.5      56.0

Pooled StDev = 11.58
```

Figure 43: CI Grade per Student versus Grade-Levels ANOVA

Table 43 and Table 44 display the percentages of each multiple choice question answer by the course grade level of students tested. The percentage score for the correct concepts (correct answers) are highlighted in bold. For each question, if a misconception (wrong answer) was chosen more often than the correct answer, the percentage is highlighted in red. Questions 5, 7, 8, 19, and 21 have majority percentages of correct answers. Questions 6, 10, 11, 12, 14, 17, 19 and 20 had one misconception choice that had a higher percentage of answers than that of the correct answer. The codes of concepts and misconceptions are listed in Table 37 and Table 38.

Table 43: Percentages by Year from Fall 2007 CI Results, Numbers 2-12

Concepts / Misconceptions	Number of CI	Answers	100	2XX	3XX	4XX
ST3	2	a	2	0	6	2
CS1		**b**	**38**	**56**	**72**	**65**
ST2		c	26	22	19	19
ST3		d	34	22	3	15
SU4, CU4	3	a	2	4	3	5
ST4		b	16	27	24	28
ST4		c	14	15	18	19
CS2, CS9		**d**	**68**	**54**	**55**	**48**
CS3	4	**a**	**56**	**59**	**67**	**53**
SU4		b	4	0	3	3
S3		c	21	30	18	25
S4		d	19	11	12	19
SU3	5	a	2	0	0	1
CS1, CS2, CS9		**b**	**84**	**82**	**82**	**85**
S2, S5, ST1		c	5	4	3	2
S3		d	9	14	15	12
CS4, CS8	6	**a**	**15**	**15**	**19**	**23**
CU1, CU3		b	25	41	19	16
ST4		c	24	26	26	37
SU2		d	36	19	35	24
SU1	7	a	2	0	0	0
SU1		b	5	4	0	3
CS5		**c**	**60**	**78**	**94**	**91**
SU1		d	33	19	6	6
S2, S5	8	a	25	7	6	5
CS6		**b**	**70**	**78**	**76**	**87**
SU4		c	5	15	18	6
ST1, ST2		d	0	0	0	3
CS6	9	**a**	**53**	**59**	**61**	**52**
S2		b	7	4	3	1
S1		c	33	30	27	44
S1, S36		d	7	7	9	3
CS7	10	**a**	**19**	**21**	**18**	**12**
SU5		b	9	7	27	17
SU5		c	71	61	48	65
SU5		d	2	11	6	6
S6	11	a	2	4	0	3
S6		b	24	15	15	17
S1, S2		c	45	44	58	52
CS6		**d**	**29**	**37**	**27**	**28**
SU6	12	a	46	29	33	32
S3, S6		b	4	29	24	19
CS8		**c**	**30**	**39**	**39**	**30**
SU6		d	21	4	3	18

Table 44: Percentages by Year from Fall 3007 CI Results, Numbers 13-21

Concepts / Misconceptions	Number of CI	Answers	100	2XX	3XX	4XX
CC1	13	a	12	4	15	10
CS3, CS9, CC1		b	56	52	52	54
S3		c	7	4	3	7
S4		d	25	41	30	29
CU2	14	a	5	4	3	5
CU2		b	3	0	9	4
CC3		c	7	15	23	34
CU1		d	84	81	66	57
CC2	15	a	59	63	64	71
CU4		b	10	19	12	13
CT1, CT2		c	27	15	24	13
C1		d	3	4	0	2
C1	16	a	15	7	25	10
CC5		b	42	48	50	66
C1		c	27	30	16	16
CU3		d	15	15	9	8
SU5	17	a	0	4	0	0
CS7		b	17	33	9	11
SU5		c	78	59	88	88
SU5		d	5	4	3	1
ST2, CT1	18	a	54	46	38	41
ST1, ST3, C1		b	14	4	6	2
CS4, CS6, CC4		c	32	46	56	56
ST4, CT2		d	0	4	0	1
C1	19	a	12	7	12	10
C1, CU2		b	4	0	6	2
C1		c	7	4	0	4
CC1		d	77	89	82	84
SU2	20	a	54	74	70	65
CS1, CS4		b	21	7	6	24
S3		c	21	15	24	8
ST4, SU3		d	4	4	0	3
SU5	21	a	0	0	0	0
SU5		b	0	0	0	2
CS7		c	88	89	88	90
SU5		d	13	11	12	9

The questions with the majority percentage of misconceptions are shown in Table 45. The major apparent misconception that students have concerns the application of sketches (SU). The most detailed sketches from the multiple choices in questions 10 and 17 were thought to be the appropriate choice. In fact, the correct answer was a sketch with less detail, leaving room for ambiguity.

Table 45 shows that a popular misconception was that sketches are appropriately used throughout the entire desire process (SU2). For questions 6 and

20, the misconception that sketches are appropriately used in the entire design process (SU2) occurred more than the concept of sketches roles of creativity (CS4), thinking (CS1) and perception (CS8).

Other major misconceptions included: sketches are equivalent to drawings (S1), sketches are equivalent to CAD (S2) and creativity seen as a positive from engineering education (SU6). The short answer definition of sketches (number 1a) in the CI showed that many students define sketches as drawings. This result in question 11 re-emphasizes the sketch equal to a drawing misconception (S1). The misconception that sketches are equivalent to CAD drawings (S2) may be a result of many factors including: the idea that sketches need to be detailed like drawings and the CAD-type programs that call work-ups as sketches or have sketch in the title of the programs, such as “Google Sketch-Up.”

Many 100 and 400-level students thought creativity is positively received in engineering education – more than subject mastery (SU6). This may be due to the 100-level class being the engineering introduction course that allows more freedom in students’ designs. 400-level students are also exposed to more creative classes, including the Ambidextrous Thinking Mechanical Engineering design course that promotes creativity and sketching which was first taught in Fall 2007. The 200 and 300-level courses are more structured and analytical due to the class curriculum and objectives; these are more required standard classes, while 400-levels are electives and capstone design.

Table 45: Summary of CI Questions with Higher Percentage of a Misconception than a Concept

		ENME Course Level Students				
Question	Correct Answer	100	200	300	400	Concept or Misconception
6	X	15.25	14.81	19.35	23.15	Sketches' Role of Creativity and Perception
		25.42	***40.74***	19.35	15.74	***CAD's Used in Entire Design Process***
		23.73	25.93	25.81	37.04	Sketches as an Analysis Tool
		35.59	18.52	**35.48**	**24.07**	**Sketches Used in Entire Design Process**
10	X	18.97	21.43	18.18	12.38	Correct Application for Specific Sketch
		8.62	7.14	27.27	17.14	Incorrect Application for Specific Sketch
		70.69	**60.71**	**48.48**	**64.76**	**Incorrect Application for Specific Sketch**
		1.72	10.71	6.06	5.71	Incorrect Application for Specific Sketch
11		1.82	3.70	0.00	2.94	Sketches Worth Little or Nothing
		23.64	14.81	15.15	16.67	Sketches Worth Little or Nothing
		45.45	**44.44**	**57.58**	**51.96**	**Sketches Equivalent to Drawing and/or CAD**
	X	29.09	37.04	27.27	28.43	Sketch Ambiguity Allows for More Meaning
12		***45.61***	28.57	33.33	***32.11***	***Creativity Seen Positively from Engineering Education***
		3.51	28.57	24.24	19.27	Sketches are Only Artistic and Worth Little
	X	29.82	39.29	39.39	30.28	Creativity Undervalued in Engineering Education
		21.05	3.57	3.03	18.35	Creativity Seen Positively from Engineering Education
14		5.17	3.70	2.86	4.63	CAD Assist in Other Design Stages excluding Final Design
		3.45	0.00	8.57	3.70	CAD Assist in Other Design Stages excluding Final Design
	X	6.90	14.81	22.86	34.26	CAD in Final Design
		84.48	**81.48**	**65.71**	**57.41**	**CAD's Used in Entire Design Process**
17		0.00	3.70	0.00	0.00	Incorrect Application for Specific Sketch
	X	17.24	33.33	9.09	10.68	Correct Application for Specific Sketch
		77.59	**59.26**	**87.88**	**88.35**	**Incorrect Application for Specific Sketch**
		5.17	3.70	3.03	0.97	Incorrect Application for Specific Sketch
20		**54.39**	**74.07**	**69.70**	**65.14**	**Sketches Used in Entire Design Process**
	X	21.05	7.41	6.06	23.85	Sketches as Thinking and Creative Tools
		21.05	14.81	24.24	8.26	Sketches are Only Artistic
		3.51	3.70	0.00	2.75	Sketches as an Analysis Tool and Lead to an Immediate Solution

ANOVA was conducted on answer 12A to see if the answers were from the same population. The 12A percentages across grade-levels have a p-value of 0.415. This states that that there are no significant differences between grade levels and answers to 12A, as expected.

The data from all CI questions was further studied by determining the incidence of a series of answers that reflect the same misconception. For example, the concept of sketching as a thinking tool (CS1) was present in answers: 2B, 5B, and 20B. If CS1 was mastered completely all three concept answers would be chosen by each individual who took the CI. Table 46 lists the percentages of students in each class that answered the corresponding questions correctly.

Table 46: Percentages of Correlated CI Concept Answers

Percentages of CI Concept Answers

	CI Items Answered Correctly	100 0302	100 0401	232	371	414	472 0101	472 0102	489X
CS1	*CS1 (2B, 5B, 20B)*	11.1	0.0	7.4	6.1	8.3	12.1	15.2	13.3
	CS1 (2B, 5B)	**33.3**	22.6	**48.1**	**54.5**	**41.7**	**54.5**	**69.7**	**46.7**
	CS1 (2B, 20B)	14.8	0.0	7.4	6.1	16.7	12.1	15.2	13.3
	CS1 (5B, 20B)	**25.9**	9.7	7.4	6.1	25.0	15.2	**27.3**	13.3
CS2	*CS2 & CS9 (3D, 5B)*	**63.0**	**51.6**	**40.7**	**42.4**	**25.0**	**54.5**	**42.4**	**33.3**
CS3	*CS3 (4A , 13B)*	**25.9**	**35.5**	**25.9**	**36.4**	12.5	**33.3**	24.2	**33.3**
CS4	*CS4 (6A, 18C, 20B)*	0.0	0.0	0.0	0.0	0.0	3.0	3.0	6.7
	CS4 (6A, 18C)	7.4	6.5	3.7	9.1	0.0	18.2	12.1	**26.7**
	CS4: (6A, 20B)	0.0	0.0	0.0	0.0	4.2	6.1	6.1	6.7
	CS4 (18C, 20B)	3.7	9.7	3.7	3.0	16.7	12.1	21.2	13.3
CS6	*CS6 (8B, 9A, 11D, 18C)*	7.4	0.0	7.4	6.1	0.0	0.0	6.1	**26.7**
	CS6 (8B, 9A, 11D)	11.1	3.2	14.8	12.1	0.0	3.0	18.2	**26.7**
	CS6 (8B, 11D, 18C)	7.4	3.2	11.1	12.1	8.3	6.1	24.2	**26.7**
	CS6 (9A, 11D, 18C)	11.1	0.0	11.1	12.1	0.0	0.0	6.1	**33.3**
	CS6 (8B, 9A)	**37.0**	**38.7**	**51.9**	**48.5**	**29.2**	**51.5**	**45.5**	**73.3**
	CS6 (8B, 11D)	11.1	12.9	**25.9**	21.2	8.3	15.2	**39.4**	**26.7**
	CS6 (8B, 18C)	**29.6**	16.1	**37.0**	**42.4**	**25.0**	**54.5**	**51.5**	**66.7**
	CS6 (9A, 11D)	22.2	6.5	18.5	18.2	0.0	3.0	18.2	**33.3**
	CS6 (9A ,18C)	22.2	6.5	25.9	**36.4**	4.2	**36.4**	24.2	**80.0**
	CS6 (11D, 18C)	14.8	6.5	22.2	18.2	8.3	9.1	24.2	**33.3**
CS7	*CS7 (10A, 17B, 21C)*	3.7	0.0	11.1	3.0	0.0	3.0	3.0	0.0
	CS7 (10A, 17B)	3.7	0.0	11.1	3.0	0.0	3.0	3.0	0.0
	CS7 (10A, 21C)	22.2	12.9	22.2	18.2	0.0	6.1	21.2	20.0
	CS7 (17B, 21C)	18.5	12.9	**33.3**	6.1	12.5	12.1	6.1	6.7
CS8	*CS8 (6A, 12C)*	7.4	3.2	0.0	6.1	4.2	6.1	3.0	0.0
CS9	*CS9 (3D, 5B, 13B)*	**37.0**	**29.0**	**25.9**	24.2	16.7	**27.3**	18.2	20.0
	CS9 (3D, 13B)	44.4	**38.7**	**29.6**	**33.3**	**33.3**	**27.3**	18.2	**26.7**
	CS9 (5B, 13B)	**55.6**	**41.9**	**48.1**	**39.4**	**41.7**	**48.5**	**42.4**	**46.7**
CC1	*CC1(13A, 19D)*	11.1	9.7	3.7	12.1	8.3	9.1	9.1	0.0
	CC1(13B, 19D)	**40.7**	**45.2**	**48.1**	**45.5**	**45.8**	**48.5**	**42.4**	**53.3**

From Table 46, the highest percentage of mastered concepts within each class are highlighted in yellow. Any answer combinations earning a response rate above 24.9% are highlighted in bold print. The concepts mastered as indicated by the highest percentage of combined responses are: definitions of sketching as a communication tool (CS2) and that CAD serves as a physical memory (CC1). Classes ENME 414 and ENME 489X (both Mechanical Engineering electives) posted percentages lower than that of the other courses on selecting the concept that sketching can be used as a communication tool (CS2). As ENME 414 is a CAD course, the mastery of this concept about sketching is not surprising. However, that

ENME 489X students failed to master this concept is interesting. The expectation was that 472-2 and 489X would have more correct conceptual knowledge on sketching than that of the other courses because of the integration and focus of sketching within the courses. Within 489X, students were required to use sketching more as a thinking tool. It must also be noted that 15 students of 489X took the CI and the other half of the class already took the CI in 472-1. So 472-1's results for the CI are skewed due to many of the students taking 489X concurrently. Not as many 472-2 students were in 489X as compared to 472-1.

The complete mastery of the definitions of a sketch concept was difficult for most classes. However, it can clearly be seen that 489X had a higher percentage of students understand the concept within all questions where the concept of the sketch definition (CS6) was present.

Concepts that were rarely achieved were the sketch skill appropriateness (CS7) and perception of sketching (CS8). This was noted earlier in Table 45 and is reconfirmed with this correlated data. Sketching's role in creativity (CS4) was mastered rarely. 26.7% (4 students) in 489X answered 2 of the three CS4 questions correctly. This was the highest percentage among the concept of sketching and creativity.

Concepts of sketching's role of as physical memory (CS3) and sketching as an interactive process (CS9) were mastered by a third of the students in general. Mastery of these two concepts is significantly lower in classes: ENME414 and 472-2. Within ENME 414 this is expected due to the large CAD influence. The results with 472-2 are peculiar though. 472-2 had a sketch lesson while 472-1 did not. However, the only obvious explanatory factor within this mix of students is that 15 students of 472-1 were also taking 489X while only 4 students in 472-2 were in 489X.

A major issue with this data is the co-enrollment of 400-level students in multiple 400-level classes. Ideally, the CI would have been administered to 489X first and then to 472, so that the samples of students within classes were purer.

The survey attached to the CI asked students for their preference of sketching over CAD or vice versa. Table 47 shows the number of students' preferences within each course among: sketches, CAD, both, neither, or no response (NR). Most students prefer to sketch and use CAD. Even within the CAD course (ENME414), 15 out of 24 students prefer both. Interestingly, the only course that had no students who preferred sketching was ENME 414. As well, the only course that had no students who preferred CAD was ENME 489X, the creativity and sketching class.

Table 47: Students' Preferences of Sketching and CAD

Sketch or CAD Preferences Among CI Takers

	100 0302	100 0401	232	371	414	472 0101	472 0102	489X
Sketch	8	6	7	11	0	10	10	8
CAD	5	6	2	9	7	5	6	0
Both	6	12	17	11	15	17	16	6
Neither	2	6	1	2	0	1	1	1
NR	6	1	0	0	2	0	0	0
Total CIs Taken	*27*	*31*	*27*	*33*	*24*	*33*	*33*	*15*

Data on the average amount of time students spend on sketching and CAD per week was also obtained from the CI survey. Table 48 displays the average hours per week a student reports for sketching or uses CAD. The hours per week using CAD is higher among all classes except a section of the introduction engineering course (100 0302) and Ambidextrous Thinking (489X). The smallest difference between use of CAD and sketching is from this section of the introduction engineering course (100

0302) which implies that both sketching and CAD are used in this course's section almost equally. The largest difference between use of CAD and sketching is from the CAD course (ENME414) where students use CAD 4.30 hours per week and sketch 1.41 hours per week.

Table 48: Student Average Hours per Week Spent on Sketching and CAD

	Average Hours/Week	
	Sketching	CAD
100 0302	1.94	1.60
100 0401	0.74	1.85
232	1.28	2.54
371	0.85	1.27
414	1.41	4.30
472 0101	2.06	3.21
472 0102	1.77	3.30
489X	2.05	1.00

ANOVA was conducted on the average hours per week of sketching and CAD-use versus course-levels. Figure 44 and Figure 45 display the results of ANOVA on sketching and CAD, respectively, versus grade-levels. Both analyses state that the grade-level differences are not significant. The average hours per week of sketching and CAD use across grade-levels are within the same population.

One-way ANOVA: Sketching versus Grade-Levels

```
Source        DF     SS     MS     F      P
Grade-Levels   3  0.942  0.314  1.27  0.398
Error          4  0.992  0.248
Total          7  1.934

S = 0.4979   R-Sq = 48.72%   R-Sq(adj) = 10.26%


                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level  N    Mean   StDev  -------+---------+---------+---------+--
100    2  1.3394  0.8453              (-----------*-----------)
200    1  1.2800       *        (----------------*----------------)
300    1  0.8485       *  (----------------*----------------)
400    4  1.8236  0.3040                       (--------*-------)
                          -------+---------+---------+---------+--
                               0.00      0.80      1.60      2.40

Pooled StDev = 0.4979
```

Figure 44: Hours per Week Sketching versus Grade-Level ANOVA

One-way ANOVA: CAD versus Grade-Levels

```
Source        DF    SS    MS     F      P
Grade-Levels   3  3.42  1.14  0.78  0.564
Error          4  5.86  1.46
Total          7  9.28

S = 1.210   R-Sq = 36.85%   R-Sq(adj) = 0.00%


                        Individual 95% CIs For Mean Based on Pooled StDev
Level  N   Mean  StDev     +---------+---------+---------+---------
100    2  1.729  0.177            (-----------*-----------)
200    1  2.542      *           (----------------*----------------)
300    1  1.273      *     (---------------*----------------)
400    4  2.954  1.394                     (--------*-------)
                           +---------+---------+---------+---------
                        -2.0       0.0       2.0       4.0

Pooled StDev = 1.210
```

Figure 45: Hours per Week Using CAD versus Grade-Level ANOVA

6.5 Discussion of Concept Inventory Results

The CI provided much detail on what students understand about sketching and CAD in the Mechanical Engineering design process. Students across all classes and grade-levels performed poorly on the CI with an average of 50.9%. Analysis of the individual questions allowed for further details on students' sketching and CAD knowledge.

Mechanical engineering students showed that they mostly knew what sketching was by defining it in a short answer question and multiple choice questions. The short answer definition questions showed that most students defined sketching as a "drawing" and often described a sketch as "rough." The short answer definition of a CAD drawing included the words: "computer," "design," and "drawing" the most. These definitions indicate limited understanding of the concepts. As well, a lack of critical thinking by students may be occurring.

From the multiple choice questions within the CI, the most mastered concepts were the use of sketches as external physical memory and sketching as a tool for an interactive process. The most common misconceptions included: the incorrect application of sketching in the design process, the belief that CAD and sketches are used in the entire design process and creativity is seen positively from an engineering education viewpoint (to the point of overriding the need for subject mastery).

The CI survey provided data on students' preference between sketching and CAD and the self-reported hours per week students sketch and use CAD. The results among preferences and amount of time spent on sketching and CAD shows that most students spend more time on CAD yet they report that they prefer both sketching and CAD.

Clearly, the data collected by the concept inventory can be analyzed in many more ways. This chapter explored the most obvious trends in the data. Much more can be done.

Chapter 7: Conclusions and Implications

Researchers have shown that the Mechanical Engineering design process is improved by the intentional use of sketching. The lack of sketching by engineering students must be due to ignorance of this fact. To increase students' awareness of the benefits of sketching, it is necessary to assess their current attitudes and use of sketching. The work presented here contributes to this goal.

7.1 Conclusions

From this research, many conclusions can be made about sketching in Mechanical Engineering design. The research questions were addressed and answered. The research questions included:

1) Do mechanical engineering students sketch? Do they know what sketching is?
2) What are their current sketching skills and sketching knowledge levels and are these adequate for engineering design?
3) Why do mechanical engineering students sketch? How do they use their sketches?

From this research, it is concluded that mechanical engineering students rarely sketch unless required to do so. The Concept Inventory results indicate that students have a limited understanding of sketches, the proper use of sketches during design, the role of sketches related to CAD drawings, and when sketching is appropriate to use. The students generally believe that CAD drawing is superior to sketching and the two can be used-interchangeably. Nevertheless, students use and prefer CAD to sketching. The students have no idea of the cognitive benefits provided by sketching. For example, students do not realize sketching aids creativity.

The CI's survey question on student preference of tools sketching or CAD was inconclusive. Further research needs to be conducted on comments about sketching, e.g.: "It's easy, it's quick." Students will sketch when required to by their instructor. The use and purposes of students' sketches are bounded by sketch assignments and final reports within this research.

There is overwhelming evidence that the sketching skills of the students are poor. The question of whether or not students' sketching skills are adequate is open. The low quality sketches did not stop students from progressing and succeeding in their projects. The new content-based sketch coding scheme proved better at discriminating among the sketches. This occurred because the proposed coding scheme was based on the features of sketches. A significant finding was that the sketch lesson changed the type of sketches produced, the number of sketches produced by the students, and increased the number of details within sketches. This may mean that the students were sketching more effectively but this is only a preliminary conjecture.

7.2 Contributions

This thesis provides contributions in both the analysis of sketches done by engineering students and the creation of analysis tools. The specific contributions of this thesis are the following:

1) A method for analyzing sketch assignments was demonstrated.

2) A method of analyzing visual representations in capstone final reports was presented. This seems to be the first of its kind in its literature.
3) The New Content-Based Sketch Coding Scheme was created and implemented within capstone reports and sketch assignments.
4) The Mechanical Engineering Visual Design Mediums Concept Inventory was created and administered. This CI is the first within the Mechanical Engineering Design field.

7.3 Future Work

The research work begun in this thesis is the foundation for many years of interesting study. The initial research plan in Table 1 included investigation into the sketching habits of professional engineers and engineering faculty using the CI and survey.

The content-based coding scheme does not focus on sketch quality (i.e. how artistic the image is). The McGown and Yang quality-based coding schemes were used in conjunction with the new content-based sketch coding scheme within this research. However, further refinement on the new content-based sketch coding scheme is needed to include quality levels and other details that may be missing from this current version.

The CI can be applied to future semesters of students. The CI was not administered in Spring 2008 due to the fact that most of the same students would be taking the CI. The CI can be applied to the Fall 2008 semester to obtain new 100-grade level data and to see if within a year there were changes in performance among the upper classmen. The CI can also be applied at other institutions as well as to professionals and professors. The CI has a lot of potential for future research.

7.4 Recommendations for Teaching Engineering Design

The single most compelling recommendation from this thesis is that engineering students should be encouraged to sketch in their design activities. This can be accomplished with a specialty course like Ambidextrous Design (ENME 489X) taught by a visiting Ph.D. candidate during the 2008 academic year. Greater impact will be made by incorporating sketching activities into a required course with an established syllabus. The means to accomplish this is presented here.

To assist in this research, the author successfully completed the graduate course Cognitive Basis of Instruction (EDHD 692) with Dr. Guthrie, Professor of Human Development in College of Education. The title of the paper submitted for the course was "Mechanical Engineering Educational Intervention with Design Journals and Hand-Sketching Proposal." The paper is a manual for an instructional intervention implementing design journaling into the Mechanical Engineering Capstone Design course (ENME 472). The intervention was designed to implement sketching in the design course in a manner that improves student engagement in the design process.

The use of design journals and hand-sketching will be new activities to both students and instructors. Using these activities in a design course will be new to many instructors. This intervention will show instructors how to successfully integrate design journaling into the course. Instructors will integrate reflective exercises on the processes of journaling with emphasis on sketching. Design journaling and hand-sketching will be new activities to most of the students as well. Like the instructors, the students must also understand and accept the importance of documentation and hand-sketching for this intervention to be successful. The intervention will instruct students on how to use a design journal with particular emphasis on hand sketching. This is natural because sketching is the documentation and communication tool that is needed in the concept generation phase. The materials prepared for this intervention are summarized in Table 49.

Table 49: Intervention Materials

Students Materials	Design Journals					
Class Materials	Syllabus	Schedule	Design Journal Model	Concept Inventory		
Instructor Materials	Design Journal Intro	Sketch Activity	Design Journal Lecture	Sketching Lecture	Design Journal Rubric	Sketching Rubric

The design journaling intervention plan is modeled after a "5E" Lesson Plan. The 5Es are: Engagement, Exploration, Explanation, Extension, and Evaluation. The 5E lesson plan is commonly used in math and science classrooms for all ages. Research in the science classrooms has been conducted within the format of the 5E Lesson and has been successful (Rhea 2005). The Dimensions of Learning (DOL) and the 5Es are two tools that work well together. The DOL is a framework that is based on the five types of learning and that are essential to instruction (Marzano 2006). The five dimensions include: positive attitudes and perceptions about learning, acquiring and integrating knowledge, extending and refining knowledge, using knowledge meaningfully, and productive habits of mind (Marzano 2006). Each one of these dimensions supports each ‘E’ of the 5Es.

The instructional intervention was created with the 5E and DOL models. A table was created to best explain the intervention in a compact format. This allows instructors to get a quick overall view of the intervention. The Educational Intervention Plan in table format is located in Appendix H.

Appendices

Appendix A: Idealogs in team-based design IRB Application Approval

UNIVERSITY OF MARYLAND
INSTITUTIONAL REVIEW BOARD

2100 Blair Lee Building
College Park, Maryland 20742-5125
301.405.4212 TEL 301.314.1475 FAX
irb@deans.umd.edu
www.umresearch.umd.edu/IRB

October 11, 2007

MEMORANDUM
Application Approval Notification

To:	Dr. Linda Schmidt Rebecca Currano Ashley Grenier Department of Mechanical Engineering
From:	Roslyn Edson, M.S., CIP IRB Manager University of Maryland, College Park
Re:	**IRB Application Number:** # 07-0406 **Project Title:** "Idealogs in team-based design"
Approval Date:	October 11, 2007
Expiration Date:	October 11, 2008
Type of Application:	New Project
Type of Research:	Nonexempt
Type of Review For Application:	Expedited

The University of Maryland, College Park Institutional Review Board (IRB) approved your IRB application. The research was approved in accordance with 45 CFR 46, the Federal Policy for the Protection of Human Subjects, and the University's IRB policies and procedures. Please reference the above-cited IRB application number in any future communications with our office regarding this research.

Recruitment/Consent: For research requiring written informed consent, the IRB-approved and stamped informed consent document is enclosed. The IRB approval expiration date has been stamped on the informed consent document. Please keep copies of the consent forms used for this research for three years after the completion of the research.

Continuing Review: If you intend to continue to collect data from human subjects or to analyze private, identifiable data collected from human subjects, after the expiration date for this approval (indicated above), you must submit a renewal application to the IRB Office at least 30 days before the approval expiration date.

Modifications: Any changes to the approved protocol must be approved by the IRB before the change is implemented, except when a change is necessary to eliminate apparent immediate hazards to the subjects. If you would like to modify the approved protocol, please submit an addendum request to the IRB Office. The instructions for submitting a request are posted on the IRB web site at: http://www.umresearch.umd.edu/IRB/irb_Addendum%20Protocol.htm.

Unanticipated Problems Involving Risks: You must promptly report any unanticipated problems involving risks to subjects or others to the IRB Manager at 301-405-0678 or redson@umresearch.umd.edu.

Student Researchers: Unless otherwise requested, this IRB approval document was sent to the Principal Investigator (PI). The PI should pass on the approval document or a copy to the student researchers. This IRB approval document may be a requirement for student researchers applying for graduation. The IRB may not be able to provide copies of the approval documents if several years have passed since the date of the original approval.

Additional Information: Please contact the IRB Office at 301-405-4212 if you have any IRB-related questions or concerns.

CONSENT FORM

Project Title	***Idealogs in team-based design***
Why is this research being done?	*This is a research project being conducted by L. Schmidt, R. Currano, and A. Grenier at the University of Maryland, College Park. We are inviting you to participate in this research project because you are currently enrolled in a design class which requires the use of idealogs and/or design notebooks.* *The purpose of this research project is to study how idealog use, including methods, formats, technology, etc., influences student design activity in a project-based course environment. Our primary goal is to evaluate how idealogging techniques and practices can be changed or enhanced to better serve the needs of student designers, support them in performing design activities, and promote innovation in design.* *A secondary goal of this research is to evaluate the impact of a set of design methods on innovativeness in solutions and on overall satisfaction of sponsoring entities and/or independent project evaluators.*
What will I be asked to do?	*The procedures involve the use of 2 questionnaires (about 15 minutes each), 1 interview (about 30 minutes), records of human-computer interaction (such as web logs, online discussions, and emails you may choose to share), and portfolio assessment (a collection of your work from both in class and out of class) to capture different aspects of idealogging and design activity. If you decide to participate in this research, you will agree to the examination of all information gathered from these sources for research analysis.* *For the questionnaires and interviews, you may be asked to describe your goals and strategies, technologies and formats you use, methods you use, etc., in idealogging, and to periodically assess your needs, goals, and how the various aspects of your idealogging helps or hinders you in achieving your goals. You are free, but not in any way required, to revise your strategies at any time during the study. You may be asked to describe any revisions and any relevant factors influencing them. Researchers will document interviews, class presentations, and other observations by handwritten or typed notes, and/or by video recording.* *Any interviews will take place in EGL M0113, a private conference room, or possibly in another location of your choice. Your participation will last through the end of the current semester.*

Project Title	***Idealogs in team-based design***
What about confidentiality?	*We will do our best to keep your personal information confidential. To help protect your confidentiality, your identity and all personally-identifiable information collected will be kept confidential and accessed only by authorized researchers. All documented notes will be kept in a locked filing cabinet in EGL M0113 and/or password-protected computer files on the computers in EGL M0113, and will not be accessible to anyone not connected with the research project. The data files will be archived until they are no longer needed, at which time they will be destroyed.* *This research project may involve making videotapes of you during interviews and presentations to document these interviews for later review by researchers. These videotapes will only be accessible by authorized researchers. All videotapes will be kept in a locked filing cabinet in EGL M0113 and/or password protected computer files on the computers in EGL M0113. They will be archived until they are no longer needed, at which time they will be destroyed.* ___ *I agree to be videotaped during my participation in this study.* ___ *I do not agree to be videotaped during my participation in this study.* *If we write a report or article about this research project, your identity will be protected to the maximum extent possible. Your information may be shared with representatives of the University of Maryland, College Park or governmental authorities if you or someone else is in danger or if we are required to do so by law.* *In accordance with legal requirements and/or professional standards, we will disclose to the appropriate individuals and/or authorities information that comes to our attention concerning child abuse or neglect or potential harm to you or others.*
What are the risks of this research?	*There are no known risks associated with participating in this research project.*
What are the benefits of this research?	*This research is not designed to help you personally, but the results may help the investigator learn more about the use of idealogs in supporting design activity. We hope that, in the future, other people might benefit from this study through improved understanding of the role idealogs can play in suporting innovative design, and how they can be enhanced to better support innovation in design.*

Project Title	***Idealogs in team-based design***
Do I have to be in this research? May I stop participating at any time?	*Your participation in this research is completely voluntary. You may choose not to take part at all. If you decide to participate in this research, you may stop participating at any time. You have the right to refuse to answer particular questions. If you decide not to participate in this study or if you stop participating at any time, you will not be penalized or lose any benefits to which you otherwise qualify.* *Participation is not a course requirement. Your decision whether or not to participate will in no way affect your grades in this course. If you elect not to participate, you will still be required to do all of the course assignments and homework, but your work will not be included as data for analysis.*
What if I have questions?	*This research is being conducted by Rebecca Currano, department of Mechanical Engineering at the University of Maryland, College Park. If you have any questions about the research study itself, please contact Rebecca Currano at: 2181 Glenn L. Martin Hall, College Park, MD 20742, (301) 405-4518, currano@umd.edu* *If you have questions about your rights as a research subject or wish to report a research-related injury, please contact:* **Institutional Review Board Office, University of Maryland, College Park, Maryland, 20742;** **(e-mail) irb@deans.umd.edu; (telephone) 301-405-0678** *This research has been reviewed according to the University of Maryland, College Park IRB procedures for research involving human subjects.*

Project Title	***Idealogs in team-based design***	
Statement of Age of Subject and Consent	*Your signature indicates that:* *you are at least 18 years of age;,* *the research has been explained to you;* *your questions have been fully answered; and* *you freely and voluntarily choose to participate in this research project.*	
Signature and Date	**NAME OF SUBJECT**	
	SIGNATURE OF SUBJECT	
	DATE	

Appendix B: Fall 2007 Sketch Lesson PowerPoint Presentation

Sketching and Idealogs

Ashley Grenier
September 20, 2007

Outline

- Sketching Example Study
- Sketching Importance
- Sketching Reading
- Sketching Discussion
- Idealog Procedures

Importance of Sketching

Example Study:
45 mechanical engineering students were divided into 3 groups:

1.) First group had unlimited use of self-made sketches

2.) Second group was allowed to use sketches up to a certain stage; when stage was reached, the sketches were withdrawn from them

3.) Third group was not allowed to sketch at all.

Romer, 2003

Sketching Study Results

Solution Quality Ranking

1. Group One: unlimited sketching
2. Group Two: partial sketching
3. Group Three: no sketching

Fastest Time

1. Group Two & Three
2. Group One

Experienced Difficulty

Group One found it to be significantly less difficult than Group Three

Certainty of Correctness of Solution

No significant differences

Romer, 2003

Sketching Study

Subjects stated that sketching as an aid for:

- Analysis
- Short-term memory
- Communication
- Documentation

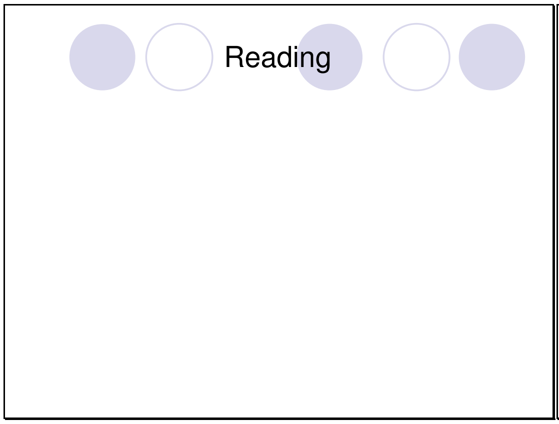
They added that sketching helped them to develop, test of their solutions, and identify errors.

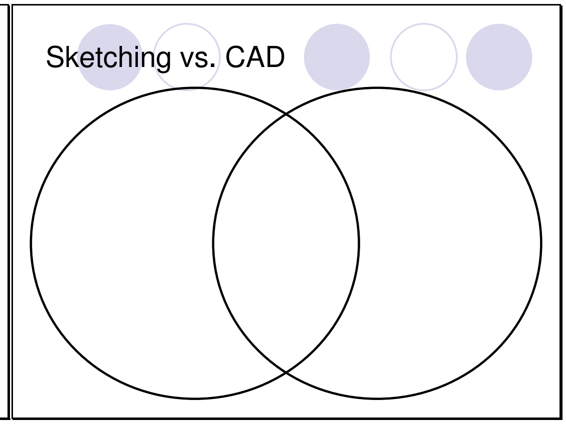
2/3 of the subjects agreed that the design problem could be solved without problems even without sketching

Romer, 2003

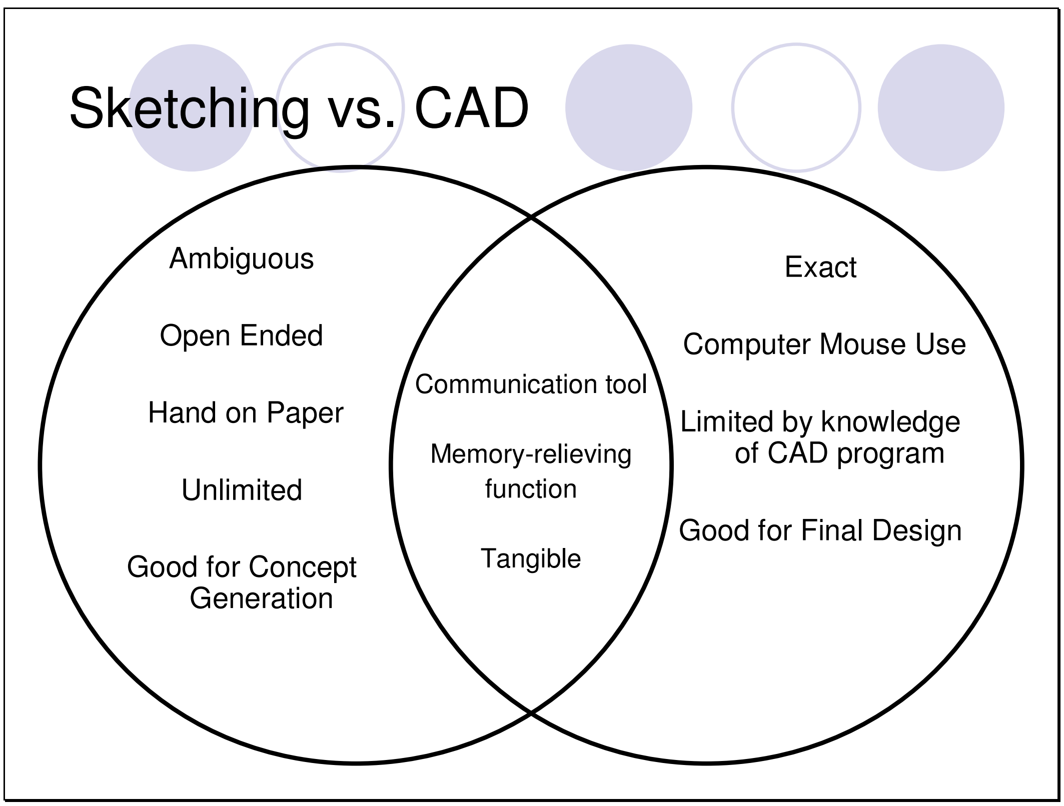
Sketching and Communication

- Sketching supports not only problem scoping and communication but every design activity as well.
- Communication with others
- Communication with self?
- Meta-cognitive tool





Reading:
McCormick, D. (2007). "Seeing Mechanical." Mechanical Engineering, 35-36.



Idealog Procedures

- Record the date in the upper left corner. Start each day on a new page.
- Record the start time for the activity on the left-hand side.
- Record a new start/end time every time you change activities. The difference between start and end times should represent total time spent on that activity (including journal writing).
- When you've finished the activity, record the end time the left-hand side.
- Use ink. *Do not erase.* Neatly cross through an error.
- Use consecutive pages.
- Record journal contents. This is your *individual* design journal, so record only your activities or group activities in which you participated.
- As a general rule, record: Who? What? Where? When? and Why?

Dr. Sobek, 2007, Design Journal Instructions

Idealog Guidelines

- Group Meeting: note attendees by name.
- Label entries (e.g., topic of discussion, captions on diagrams and sketches) to provide proper context for understanding the information that follows.
- Label sketches, drawings, and diagrams so you'll remember what they are three months from now.
- Avoid backfilling.
- Please do not staple items into your journal. Feel free, however, to tape things into your journal as long as they are fully contained and visible on one page (don't forget to label it!).
- If you do not work on your project for a stretch of several days, please note that in your journal so we don't think you're being lazy on the journal.
- If you change activities (e.g., switch from brainstorming to working on an AutoCAD drawing, or from group meeting to solo work), try to note the time.

Dr. Sobek, 2007, Design Journal Instructions

Idealog Reflection Ideas

If you just finished…	Ask yourself…
A meeting,	➢ What were the main outcomes of the meeting? ➢ Was the meeting productive, and why? ➢ What are/should be the next steps? ➢ Is the team heading in the right direction?
Brainstorming,	➢ Do we have a large enough set of ideas? ➢ Which ideas seem most feasible, and why? ➢ How could we have made the session better?
Analyzing data,	➢ What were the most important findings? ➢ What do the results mean? How should we apply them?
Designing (by hand or in CAD),	➢ What did I learn about the problem or solution possibilities? ➢ What problems did we resolve, and which still need to be addressed? ➢ How does this piece integrate with the whole?
An internet search,	➢ Do we have a complete picture? Are there other sources we should pursue? ➢ What key information did I find? Why it key? How does it help us achieve our objectives?

Dr. Sobek, 2007, Design Journal Instructions

Why keep an Idealog?

- Part of your grade!
- Place to put bits of information and track your work throughout the semester
- Excellent habit to have and keep throughout professional career
- It’s fun!

Dr. Sobek, 2007, Design Journal Instructions

References

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Cognitive Technologies Laboratory

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Schmidt, J, Schmidt, L., Lent, R. Collective Efficacy Beliefs in Student Work Teams: Relation to Self Efficacy, Cohesion, and Performance. Journal of Vocational Behavior 68 (2006) 73-84.

Appendix C: Answer Key and Literature References of the Mechanical Engineering Visual Design Mediums Concept Inventory and Survey

Mechanical Engineering Visual Design Mediums Concept Inventory and Survey

Directions: Answer the questions in the context of working in a Team Mechanical Engineering Design Project.

1. a. Define sketch:

____

____

b. Define Computer Aided Design (CAD) drawing:

____

____

2. Sketching can facilitate _________, but hinder _________. (Stacey et al. 1999)
   a. Learning; creativity
   b. Creative thinking; communication between designers
   c. Communication between designers; creative thinking
   d. The design process; creative thinking

3. Sketches and computer generated graphical representations of alternative designs, aid in the development of: (Rose 2005)
   a. Individual work.
   b. Trade-off decisions.
   c. Analytical design tools.
   d. Shared perceived concept.

4. Sketches serve as a kind of: (Goel 1995; Lawson 2002)
   a. External memory.
   b. Internal memory.
   c. Artistic expression.
   d. Educational tool.

5. In the mechanical engineering design process, sketching: (Stacey et al. 1999); (Rose 2005)
   a. Leads to an immediate solution.
   b. Assists the designer throughout the design process as a communication and thinking tool.
   c. Is not necessary in the design process because there are tools like CAD that can be used.
   d. Introduces the artistic side of design into the engineering design process.

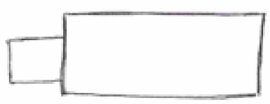
6. As mathematicians manipulate numbers and musicians manipulate notes, designers manipulate or decode: (Ferguson 1992; Lawson 2002)
   a. Visuals
   b. CAD drawings
   c. Mechanical processes
   d. Sketches

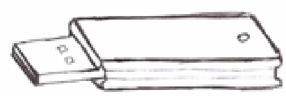
7. In which design stage is sketching used the most? (McGown 1998)
   a. Final Design.
   b. Product Refinement.
   c. Concept Generation.
   d. Prototyping.

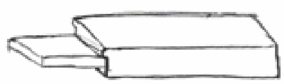
8. When expressing a specific design idea to another person, sketches are: (Stacey et al. 1999)
   a. Equal to a CAD drawing.
   b. Fast and ambiguous.
   c. An artistic expression.
   d. Slow and hinder the design process.

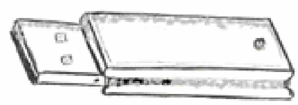
9. Concept generation sketches should be: (Kazerounian 2007)
   a. Ambiguous, leaving room for interpretation and change.
   b. Detailed and exact, much like CAD drawings.
   c. Detailed and neat, not always perfect though, the same as hand drawings.
   d. Rough Napkin/back of the envelope notes, thrown away after they are used.

10. Which is a sketch that shows the working principles of the concept without details to suggest product form? (McGown 1998)

a. 

b. 

c. 

d. 

11. If: "A picture is worth a thousand words," then a well-done sketch is worth:
    a. No words
    b. Fewer words
    c. The same amount of words
    d. More words

12. In engineering education, creativity is often: (Rebello 2004)
    a. Encouraged.
    b. Neglected.
    c. Under valued.
    d. Valued.

13. External symbol systems (like sketching and CAD drawings) and internal symbol systems (like visual thoughts and ideas) have: (Goel 1995)

   a. Visual equivalence.
   b. Representational equivalence.
   c. Emotional equivalence.
   d. Knowledge equivalence.

14. Computer Aided Design (CAD) programs aid in the design process in the stage(s) of: (Lawson 2002)

   a. Product Requirements
   b. Concept Generation
   c. Final Design
   d. All of the stages

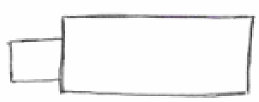
15. Most CAD tools are not focused on ________, but on _______. (Ullman 1990)

   a. Creativity; documentation
   b. Learning; work
   c. Documentation; presentation
   d. Work; creativity

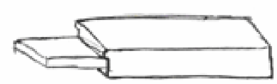
16. When a significant amount of detail and interconnectedness is built quickly into a CAD model, designers can become: (Robertson 2007)

   a. Creative.
   b. Fixated.
   c. CAD proficient.
   d. Open to new ideas.

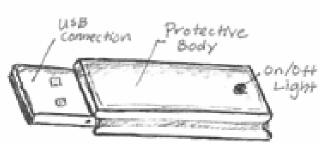
17. Which Thumb-drive sketch would aid you in conveying the general idea of the design to a bystander?



a.



b.



c.

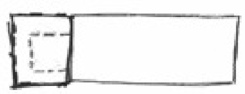
d. None. Sketches do not have enough detail, need a CAD drawing.

18. Sketching is _____ and CAD can be ______. (Robertson 2007; Stacey et al. 1999)
    a. Messy; exact and organized
    b. Constraining and prescriptive; boundless
    c. Boundless; constraining and prescriptive
    d. Exact and organized; messy

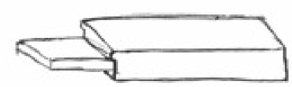
19. Design using CAD encourages: (Lawson 2002)
    a. Product characteristics.
    b. Alternative concept generation.
    c. Creative design ideas.
    d. Sophistication and details of designs.

20. Design using sketches encourages: (Stacey et al. 1999)
    a. Alternative concept generation.
    b. Self reflection and communication with one's self.
    c. Artistic expression.
    d. Sophistication and details of designs.

21. Which Thumb-drive sketch shows complete concept functionality? (McGown 1998)



a.



b.

c.

d. None. Sketches do not have enough detail, need a CAD drawing.

Appendix D: Mechanical Engineering Visual Design Mediums Concept Inventory

Mechanical Engineering Visual Design Mediums Concept Inventory and Survey

Directions: Answer the questions in the context of working in a Team Mechanical Engineering Design Project.

1. a. Define sketch:

____

____

b. Define Computer Aided Design (CAD) drawing:

____

____

2. Sketching can facilitate _________, but hinder _________.
   a. Learning; creativity
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   c. Communication between designers; creative thinking
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   a. Individual work.
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   c. Analytical design tools.
   d. Shared perceived concept.

4. Sketches serve as a kind of:
   a. External memory.
   b. Internal memory.
   c. Artistic expression.
   d. Educational tool.

5. In the mechanical engineering design process, sketching:
   a. Leads to an immediate solution.
   b. Assists the designer throughout the design process as a communication and thinking tool.
   c. Is not necessary in the design process because there are tools like CAD that can be used.
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6. As mathematicians manipulate numbers and musicians manipulate notes, designers manipulate or decode:
   a. Visuals
   b. CAD drawings
   c. Mechanical processes
   d. Sketches

7. In which design stage is sketching used the most?
   a. Final Design.
   b. Product Refinement.
   c. Concept Generation.
   d. Prototyping.

8. When expressing a specific design idea to another person, sketches are:
   a. Equal to a CAD drawing.
   b. Fast and ambiguous.
   c. An artistic expression.
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   a. Ambiguous, leaving room for interpretation and change.
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   d. Rough Napkin/back of the envelope notes, thrown away after they are used.

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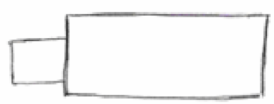
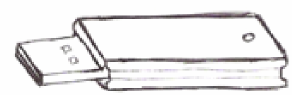
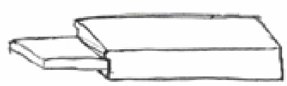
a. 

b. 

c. 

d. 

11. If: "A picture is worth a thousand words," then a well-done sketch is worth:
    a. No words
    b. Fewer words
    c. The same amount of words
    d. More words

12. In engineering education, creativity is often:
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14. Computer Aided Design (CAD) programs aid in the design process in the stage(s) of:
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   d. All of the stages

15. Most CAD tools are not focused on ________, but on _______.
   a. Creativity; documentation
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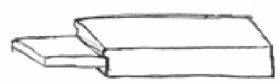
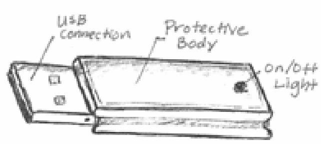
   c. Documentation; presentation
   d. Work; creativity

16. When a significant amount of detail and interconnectedness is built quickly into a CAD model, designers can become:
   a. Creative.
   b. Fixated.
   c. CAD proficient.
   d. Open to new ideas.

17. Which Thumb-drive sketch would aid you in conveying the general idea of the design to a bystander?

a. 

b. 

c. 

d. None. Sketches do not have enough detail, need a CAD drawing.

18. Sketching is _____ and CAD can be ______.
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19. Design using CAD encourages:
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    d. Sophistication and details of designs.

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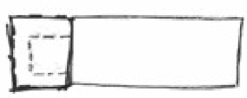
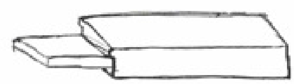
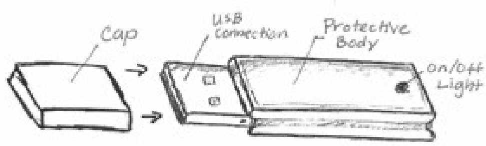
21. Which Thumb-drive sketch shows complete concept functionality?



A.



b.



c.

d. None. Sketches do not have enough detail, need a CAD drawing.

Appendix E: Mechanical Engineering Visual Design Mediums Survey

- Circle your current year: Freshman Sophomore Junior Senior

  Other: ___________________

- List the Mechanical Engineering Design courses taken to date or currently in:

Check if Taken	Courses
	ENME371: Product Engineering and Manufacturing
	ENME472: Integrated Product and Process Development
	ENME400: Machine Design
	ENME414: Computer-Aided Design

- Have you taken any Sketching/Drawing classes in high school and/or college? If yes, please name and explain.

- Have you taken any Computer Aided Design (CAD) classes (i.e. ProEngineer, SolidWorks in high school and/or college? If yes, please name and explain.

- I sketch _______ hours/week on average for a team design project.

- I used CAD _______ hours/week on average for a team design project.

- When working on a design project, what do you prefer to do: sketch, use CAD, both, neither, or something else? Explain.

- What are the percentages of CAD Drawings, Photos, and Hand Sketches on average in a final team design report?

____%	CAD Drawings
____%	Photographs
____%	Hand Sketches
____%	Other: ___________________________

- Any comments or suggestions:

<u>*Appendix F: Mechanical Engineering Visual Design Mediums Concept Inventory and Survey IRB Application Approval*</u>

UNIVERSITY OF
MARYLAND
INSTITUTIONAL REVIEW BOARD

2100 Blair Lee Building
College Park, Maryland 20742-5125
301.405.4212 TEL 301.314.1475 FAX
irb@deans.umd.edu
www.umresearch.umd.edu/IRB

October 11, 2007

<u>MEMORANDUM</u>
Application Approval Notification

To:	Dr. Linda Schmidt Ashley Grenier Department of Mechanical Engineering
From:	Roslyn Edson, M.S., CIP IRB Manager University of Maryland, College Park
Re:	**IRB Application Number:** <u>07-0437</u> **Project Title:** "Mechanical Engineering Visual Design Mediums Concept Inventory and Survey"
Approval Date:	October 11, 2007
Expiration Date:	October 11, 2008
Type of Application:	New Project
Type of Research:	Nonexempt
Type of Review For Application:	Expedited

The University of Maryland, College Park Institutional Review Board (IRB) approved your IRB application. The research was approved in accordance with 45 CFR 46, the Federal Policy for the Protection of Human Subjects, and the University's IRB policies and procedures. Please reference the above-cited IRB application number in any future communications with our office regarding this research.

Recruitment/Consent: For research requiring written informed consent, the IRB-approved and stamped informed consent document is enclosed. The IRB approval expiration date has been stamped on the informed consent document. Please keep copies of the consent forms used for this research for three years after the completion of the research.

Continuing Review: If you intend to continue to collect data from human subjects or to analyze private, identifiable data collected from human subjects, after the expiration date for this approval (indicated above), you must submit a renewal application to the IRB Office at least 30 days before the approval expiration date.

Modifications: Any changes to the approved protocol must be approved by the IRB before the change is implemented, except when a change is necessary to eliminate apparent immediate hazards to the subjects. If you would like to modify the approved protocol, please submit an addendum request to the IRB Office. The instructions for submitting a request are posted on the IRB web site at: http://www.umresearch.umd.edu/IRB/irb_Addendum%20Protocol.htm.

Unanticipated Problems Involving Risks: You must promptly report any unanticipated problems involving risks to subjects or others to the IRB Manager at 301-405-0678 or rodson@umresearch.umd.edu. *(continued)*

Student Researchers: Unless otherwise requested, this IRB approval document was sent to the Principal Investigator (PI). The PI should pass on the approval document or a copy to the student researchers. This IRB approval document may be a requirement for student researchers applying for graduation. The IRB may not be able to provide copies of the approval documents if several years have passed since the date of the original approval.

Additional Information: Please contact the IRB Office at 301-405-4212 if you have any IRB-related questions or concerns.

2

Informed Consent Form

Mechanical Engineering Visual Design Mediums Concept Inventory and Survey

This is a research project being conducted by Dr. Linda Schmidt and Ashley Grenier in the Department of Mechanical Engineering at the University of Maryland, College Park. We are inviting you to participate in this research because you have experienced working on engineering project teams. ***The purpose of this research is to examine engineering students' and professionals' conceptual understanding of visual design mediums.***

The procedures involve taking a multiple-choice question Concept Inventory with one short answer question and a brief survey on sketching and Computer Aided Design tools as used in design projects. Your Concept Inventory answers and Survey responses will be kept for analysis. Only study researchers will have access to the files and data that will be stored in EGL M0113. At the completion of the study (no later than May 2009) the files will be destroyed. The total time for instrument completion is approximately 20 minutes.

The Concept Inventory and Survey are anonymous and will not contain information that may personally identify you. Do not identify yourself in the instrument; there is no need to write your name on the Concept Inventory or Survey. In publications on results only group data and exemplar survey comments will be reported.

There are no known risks to you that will result from participation in this study. The research is not designed to assist you personally, but to aid the investigators in learning more about Mechanical Engineering Visual Design Mediums. Your participation is voluntary. You are welcome to ask questions and to withdraw from participation at anytime without penalty.

Your signature indicates that: you are at least 18 years of age; the research has been explained to you; your questions have been answered; and you freely and voluntarily choose to participate in this research project.

For more information contact: Ashley Grenier, Department of Mechanical Engineering, algrenier@gmail.com or Dr. Linda C. Schmidt, Department of Mechanical Engineering, 0162 Martin Hall, 301-405-0417, lschmidt@umd.edu.

IRB APPROVED
EXPIRES ON
UNIVERSITY OF MARYLAND
COLLEGE PARK

NAME OF PARTICIPANT:______________________________

SIGNATURE:____________________________________

DATE:____

If you have any questions about your rights as a research subject or wish to report a research-related injury, please contact: **Institutional Review Board Office, University of Maryland, College Park, Maryland, 20742; (email) irb@deans.umd.edu; (telephone) 301-405-0678**

This research has been reviewed according to the University of Maryland, College Park IRB procedures for research involving human subjects.

Appendix G: Fall 2007 CI Individual Grades by Class

Student	100 0302	100 0401	232	371	414	472 0101	472 0102	489X
1	60	40	55	65	75	50	55	70
2	50	35	55	45	55	60	55	40
3	40	40	40	50	50	60	60	70
4	45	40	50	45	40	55	75	50
5	45	35	55	70	40	55	60	65
6	75	45	30	50	40	55	40	60
7	35	40	55	50	60	55	45	35
8	55	45	45	45	40	55	35	40
9	40	15	65	65	40	40	60	55
10	30	60	70	50	40	85	55	65
11	55	25	45	65	55	65	65	60
12	35	45	70	20	35	55	60	70
13	50	60	60	50	45	50	70	75
14	40	40	55	55	50	50	55	45
15	55	45	60	70	35	60	45	65
16	50	60	50	65	35	65	40	
17	45	55	10	50	55	55	50	
18	45	50	55	35	45	50	50	
19	45	35	60	70	35	60	45	
20	60	60	45	40	45	70	60	
21	40	50	35	40	45	35	65	
22	45	45	55	50	30	45	55	
23	60	50	60	45	50	65	60	
24	50	40	60	40	15	60	55	
25	25	25	60	60		35	50	
26	50	60	50	50		50	55	
27	55	40	35	45		55	65	
28		45		55		55	50	
29		55		50		70	70	
30		50		65		45	60	
31		45		55		65	55	
32				45		55	40	
33				50		65	65	
Average	*47.4074*	*44.3548*	*51.2963*	*51.6667*	*43.9583*	*56.0606*	*55.3030*	*57.6667*

Appendix H: Educational Intervention Plan

ENME472 Educational Intervention Plan in Table Format

5E Components	Activities	Details	Outcomes	Time and Duration	DOL	Instructional Action/ Cognitive Processes
Engagement	Design Journal Intro	Instructor: Introduce course, syllabus, basics of design journal requirement. Students: What is a design journal? How do I think I will use it? What do I think about design journals?	Individually students write their thoughts then talk with a neighbor	First Day of Class- 10 to 15 minutes	Positive Attitudes and Perceptions	Direct Instruction/ Reflection and Inference
	Sketch Activity	Students: Draw a bicycle from memory. Draw your hand holding a key.	Students reflect with neighbor on sketching and their individual sketch ability. Reflect on the differences between sketching from memory and from something that is in front of you. Share thoughts with class.	First Day of Class- 10 to 15 minutes		Direct Instruction/ Reflection and Inference
Exploration	Pre-Test Mechanical Engineering Visual Design Mediums Concept Inventory and Survey	Instructors: Give a brief explanation of the concept inventory (CI). The CI is a multiple choice quiz to see what students' conceptual understanding on sketching and CAD is currently. A small survey is attached to the Concept Inventory to obtain demographic data. Explain that this will be given as a pre-test and a post-test to see individual's progress. The grades of the pre and post will be given at the end of the semester.	Instructor: Score the CI and keep the individuals' grades until the end of the semester.	Second Day of Class- 15 to 20 minutes	Acquiring and Integrating Knowledge	Assessment
	Design Journal Model	Instructor: Show model design journal to students. Copy sections of model design journal from different aspects of the process for student.	Individually students write their thoughts then talk with a neighbor	Second Day of Class- 10 to 15 minutes		Modeling/ Reflecting
	Sketching Scaffolding and Modeling	Instructor: Example sketches from model design journal, other engineering sketches, and mechanical drawings	Students: Discuss and reflect with partners and class.	Second Day of Class- 10 to 15 minutes		Scaffolding and Modeling/ Reflecting

ENME472 Educational Intervention Plan in Table Format (Continued)

Explanation	Design Journal Lecture	Instructor: Explain the importance of documentation and how to do so with the design journal. Explain expectations of design journal usage. Students: Receive research article on journal documentation for homework.	Students: Read article and write a short summary and reflection (250 words) on the article.	Third Day of Class- 45 minute lecture	Extending and Refining Knowledge	Direct Instruction/ Inferencing and Assessment
	Sketching Lecture	Instructor: Explain the importance of sketching. Explain the differences between sketching and CAD, their pros and cons. Engage the students to begin sketching with lines, to boxes, 3-D boxes and so on while the instructor models this. If possible have an art teacher go through sketching exercises if the current instructor does not have those sketching skills. Students: Receive research article on journal documentation for homework.	Students: Read article and write a short summary and reflection (250 words) on the article.	Fourth Day of Class- 45 minute lecture		Direct Instruction/ Inferencing and Assessment
Extension	Design Journal Submissions	Students: Instructed to use their individual design journals as they have learned to do in class and submit to instructor.		Every other week beginning the fifth day of class for the semester	Using Knowledge Meaningfully	Independent Work
	Sketching Assignments	Students: Assigned to sketch 4 concepts according to a specific sketch level (McGown, 1998).		Every month beginning the fifth day of class for the semester		Independent Work
Evaluation	Design Journal Rubric	Instructor: Grade Design Journal work based on rubric.		Feedback will be returned within a week of due date.	Productive Habits of Mind	Assessment
	Sketching Rubric	Instructor: Grade sketches based on rubric and sketch level.		Feedback will be returned within a week of due date.		Assessment
	Post-Test Mechanical Engineering Visual Design Mediums Concept Inventory and Survey	Instructor: Remind students that they took this in the beginning of the semester as a pre-test and will now be taking it as a post test/ They will receive both pre and post test scores.	Instructor: Grade post test and make comparisons with pre and post scores.	Second to last day of class: 15 to 20 minutes		Assessment

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