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ASSESSING HOW DIGITAL DESIGN TOOLS AFFECT LEARNING OF ENGINEERING DESIGN CONCEPTS

Jacquelyn K. Stroble

School of Electrical Engineering and Computer Science
Oregon State University
Corvallis, OR, USA

Robert B. Stone

School of Mechanical, Industrial and Manufacturing
Engineering
Oregon State University
Corvallis, OR, USA

Steve E. Watkins

Department of Electrical and Computer Engineering
Missouri University of Science and Technology
Rolla, MO, USA

ABSTRACT

Engineering education has been evolving over the last few decades to include more engineering design courses in the curriculum or offer a new degree altogether that allows one to design a unique degree suited to his or her own interests and goals. These new engineering curricula produce engineers with strong backgrounds in fundamental engineering and design knowledge, which make them strong candidates for solving complex and multidisciplinary engineering problems. Many universities have embraced the need for multidisciplinary engineers and have developed interdisciplinary engineering design courses for many experience levels. Such courses build a foundation in engineering design through a unique series of lectures, real-world examples and projects, which utilize validated design tools and methodologies. This paper assesses the value of using design tools, web-based and downloadable, in undergraduate interdisciplinary design engineering courses. Six design tools are tested for their ability to increase the student's knowledge of six design concepts. Also, the tools are evaluated for ease of use and if the different digital formats affect their educational impact. It was found that most students valued all the design tools and that the tools reinforced all but one design concept well. Quotes from the open-ended portion of the survey demonstrate the acceptance of the design tools and a general understanding of the importance of engineering design. The design tools, design concepts course goals, survey questions and survey results are discussed.

INTRODUCTION

Early Engineering education is changing [1-7]. Not because new scientific discoveries have been made or because distance courses are now regular practice, but because the students have changed. Students currently entering college engineering curricula are familiar with several types of technology; they have probably had a computer with internet to use at home and regularly use mobile phones for a number of other uses besides talking to one another. The students of today are

“connected” and are quick to embrace technology, whether it is for personal use or in the classroom. Engineering education has struggled to keep pace with the capability of these new students and simultaneously incorporate new teaching practices to better prepare them for the jobs of tomorrow. Slowly, engineering education has been evolving to suite the uniqueness of these students at the individual level [8]. Methods include development of interdisciplinary, project-based engineering design courses for second and third year students, advanced capstone courses, undergraduate research, or the offering of a new degree altogether that allows one to design a degree suited to his or her own interests and goals. Broadbent and Cross anticipate, “an ambitious and exciting agenda for design education in the near future,” and believe that many changes will be established in the information age [9]. Of the design education changes they mention, accessible design education, further layering of design practice and the role of holistic sciences are evident in the current direction that standard undergraduate engineering curricula are taking [10]. This development prepares students to utilize the fundamental engineering and design knowledge in a practical setting.

The American Society of Engineering Education asked 13 engineering educators and researchers to address a particular aspect of the future of engineering education. The 2002 publication provides insightful comments on the topics of stimulating change, using technology to improve learning, research, outcome assessment, the organization of a university and the new educational paradigm [7]. In the report, Eschenbach elaborates on developing a curriculum that teaches students to: work in teams, both distant and local; appreciate how the differences in culture, gender, ethnicity, race, learning style, values and ethics contribute to problem solving; appreciate how engineering impacts society; and to even question the fundamental assumptions about the nature of engineering [7]. Such a curriculum would support Yokomoto's view of the future of engineering education. He states that as engineering problems become more complex and take on added

dimensions, the engineering student must become better at learning, working in teams, more creative and more skilled at engineering procedures [7]. The authors believe that engineering design provides a common meeting ground for all engineering disciplines and should be more prevalent in the engineering curricula, which would inherently promote many elements of Eschenbach's paradigm and Yokomoto's view. To accomplish a diverse engineering experience, technology must be employed. Felder foresees technology, "promot[ing] a deeper learning far better than traditional lecturing can possibly do" [7]. Richards points out that it takes time and effort to develop quality instructional materials for technology enhanced courses [7]. However, Richards, like Felder, foresees, "information technology can help us achieve [the] optimal conditions of teaching and learning" [7]. As engineering education becomes more "connected" and students are required to learn more soft skills, graduates will be strong candidates for solving multidisciplinary engineering problems, understand design challenges and be equipped to use tools of the trade.

This paper investigates the use of technology to support learning. A suite of six design tools was employed to facilitate learning of engineering design concepts and demonstrate how the design process is executed. The design tools are the Functional Basis, Function CAD, the design repository, concept generator version 1, MEMIC and a morphological matrix, which are a web-based or downloadable format. The Design Engineering Lab tools were developed with the intention of formalizing the concept generation phase in the design process.

RELATED WORK

Computer programs are utilized in courses across the engineering domain to facilitate learning of concepts and to simulate how the program would be utilized in a work environment. However, the use of technology by students in an engineering design course and how it affects the student's ability to learn is the focus of this section. Other researchers in the design community have put forth assessments of the effectiveness of a design information tool to aid novice designers through the conceptual design process, creativity related to the use of software tools and intellectual growth related to the use of design tools.

Okudan, *et al.* developed a design information support tool (DIST) to facilitate the conceptual design phase of the design process [11]. A study was undertaken with 16 groups, to assess the effectiveness of the DIST software; half of the groups used the software and half were a control group. A statistically significant difference existed between the students using the DIST and the control group. Students using the DIST spent less time gathering and analyzing data, and less time preparing reports and presentations [11]. A final assessment of the DIST features by the eight groups that used it revealed that, ">80% of the participants found the DIST interface to be at least moderately useful" [11]. The design tool is still under development, but initial data shows that students did benefit from using the software.

A case study performed at the University of Queensland, Australia explored the importance of creativity in solving engineering problems in relation to the possible impact of software design tools [12]. The goal was to identify the presence or absence of barriers and enablers to the creative process, and the mechanisms by which it might be occurring. Robertson and Radcliffe proposed a model of creative problem solving in engineering design, which they predict their findings will follow. Tool for Embedding Systems Engineering in Small Teams, or TESS for short and a standard CAD package were the software tools used for investigating effects on creativity [12]. It was

found that the software led to enhanced visualization and communication for all which enabled the creative process. Conversely, students that had difficulty with abstract thinking (non analytical problem solving) demonstrated premature fixation, restricted thinking and bounded ideation at multiple points in the problem solving process. These findings are the mechanisms that inhibit creative design, but they were not a direct result of using design software. A psychological study would need to be performed to adequately identify the reasons for creative barriers and when they exactly happen. Overall, the findings and the creativity model reinforce each other.

Educators at Clemson University observed the effect of design tool use on a design team enrolled in design courses from sophomore to senior years. Miller, *et al.* propose using the information of the study to improve the delivery of design instruction, which will in turn improve the quality of graduates [13]. Design clarification, ideation, selection and refinement tools were lectured on and used in undergraduate design courses. Of the design tools utilized by the students, very few were considered meaningless or not applicable to their projects. It was found, however, that the ideation design tools were primarily utilized, suggesting that software tools increase creativity in design, which aligns with the Robertson and Radcliffe study. Furthermore, students expressed a higher percentage of beneficial uses of design software in a senior level course, compared to a lower level course, which means they feel the work was valuable to their education. "Based on the ratings of the student opinions of benefit, requirements, and lectures, it could be determined that requiring students to perform distinct design tasks in design courses does increase both their appreciation for the task, as well as their ability to execute it" [13].

The findings of the three research groups mentioned here, support that the proper use of technology in the classroom does facilitate knowledge transfer and learning of concepts.

EDUCATIONAL STUDY

This educational study was performed at Missouri University of Science and Technology (Missouri S&T), which is the former employer of the authors now at Oregon State University.

Fundamental engineering knowledge, no matter the discipline, does not change over time; however, the method in which the material is taught can evolve over time to utilize current technology. This idea is well demonstrated with the transition from chalkboard illustrations to overhead projector transparencies to computer projected slides. Utilizing a projector allows an instructor to show animations, images with rich color and detail, movies, etc., which cannot be provided using an analog overhead projector. There is a caveat. With new technology come new complications in the learning process [7, 14]. Thus, it is important to assess the students' knowledge transfer and be aware of the concepts learned and unlearned when using new technology in the classroom. In this educational study, we examine how digital design tools affect the learning of important engineering design concepts in two interdisciplinary engineering design courses.

Mathematical software has eliminated the engineer from spending too much time calculating an answer, which allows more "time to concentrate on the genuinely demanding intellectual parts of the problem solving process" [15]. Digital design tools have the same effect; a designer can focus on meeting customer expectations without worrying about component compatibility, high rate of failure or design optimization. Although, the underlying concepts must be taught and

understood so the tools can be trusted [10]. Furthermore, educators must not forget, “the primary principle holds [that] the learning theory must be preeminent in and consideration of the using technology in learning” [16]. Assessing the digital design tools used in Missouri S&T interdisciplinary engineering design courses allows one to gauge whether the learning theory was presented as a distinguishable learning objective. With that knowledge, the course and use of design tools in the course can be updated to better reflect the course learning objectives.

We hypothesize that the digital design tools increase the students’ knowledge of engineering design concepts, thereby reinforcing their learning. To assess the design tools’ ability to reinforce design concepts and the overall notion of functionality, we chose to give a survey at the end of the course. The survey was given to students in the month of December that took a design course during the Fall semester of 2008. The survey length was two pages with eleven questions; the questions were a mix of yes/no, rate on a scale of 1-5 and open-ended questions. From the survey, we hope to discover if the students:

- learn design concepts while using the design tools;
- increase their knowledge of engineering design;
- value the design tools;
- note any difficulty in using the design tools; and
- identify which design tool contributed most to their learning of the design concepts.

The two interdisciplinary engineering courses are described in the first subsection, followed by a subsection that introduces and describes each of the digital design tools. A third subsection introduces and describes the surveyed design concepts as taught in the interdisciplinary engineering design courses.

Design Courses

Missouri S&T has embraced the need for multidisciplinary engineers by developing interdisciplinary design courses for many experience levels and a Bachelor’s level design certification. The interdisciplinary engineering courses are for students interested in working in a new or emerging area that combines different fields of engineering or science. Students in the certification program build a foundation in engineering design through a unique series of courses, which utilize validated design tools and methodologies. However, students of any engineering or science discipline can take the interdisciplinary design courses as elective courses without pursuing the certification. Design representations and engineering design methodologies are the two courses utilizing digital design tools to teach and reinforce design concepts. The former was team taught by Dr. R. B. Stone and Dr. S. Orsborn and the later by Dr. R. B. Stone and Dr. S. Taki, in the Fall 2008 semester when the survey was given.

Design Representations

This course examines methods of representing objects including sketches, photography, computer generated drawings, solid modeling, and 3D physical representations. Emphasis is on appropriate selection of methods of representation for a given application. An individual project is required. Students enrolled in this course must be of sophomore standing. During the Fall 2008 semester, all students enrolled in the course were of sophomore standing.

Engineering Design Methodologies

This course examines structured engineering design theory and methodologies for conceptual design and redesign of products. Topical coverage includes customer needs gathering, functional modeling, engineering specifications creation (QFD), concept generation, selection and design embodiment. Team work/hands-on projects emphasized. Students enrolled in this course must be of at least junior standing. During the Fall 2008 semester, all students enrolled in the course were of senior standing.

Design Tools

The suite of six design tools assessed in the engineering education study were all developed in the Design Engineering Lab, which conducts research in the area of design theory and methodology [17]. Research work in the design theory and methodology area focuses on attempts to formalize the process of design. The Design Engineering Lab tools were developed with the intention of formalizing the concept generation phase in the design process. Table 1 lists the design tools and a brief summary of each one.

Stone, *et al.* developed a well-defined modeling language comprised of function and flow sets with definitions and examples, entitled the Functional Basis [18]. Here, a function represents an action being carried out, where as a flow represents what type of material, signal or energy that is performing the function. Hirtz, *et al.* later reconciled the Functional Basis and NIST developed taxonomy into its most current set of terms [19]. There exist eight classes of functions and three classes of flows, both having an increase in specification at the secondary and tertiary levels. There are 24 tertiary functions, each with a set of correspondent terms to aid the designer in choosing the correct function. Similarly, there are 22 tertiary flows, with certain ones having correspondent terms. The reconciled Functional Basis is utilized for developing hierarchical functional models, which describe the core functionality of products and processes in domain independent function and flow terms.

The function CAD software is a downloadable application for creating digital versions of functional models, with the library of Functional Basis functions and flows [17]. With the software, blocks of any shape and size can be created and linked. The digital models can be used with other design tools, for sharing information or quickly generating several iterations of a model. Function CAD is available for the Mac OS X and Windows platforms.

The Design Repository is a database of design information for representing, archiving and searching of product design knowledge, in support of engineering design activities [17]. Directly, the repository has transformed a disparate set of heterogeneous product design knowledge into a single knowledge base, offering extended capability for current product data management applications. The design repository, which includes descriptive product information such as functionality, component physical parameters, manufacturing processes, failure, and component connectivity, now contains detailed design knowledge on over 113 consumer products and 17 biological phenomena. To support automated conceptual design efforts, the repository system offers many options for generating function-component matrices (FCMs) and design structure matrices (DSMs), morphological matrices, as well as, knowledge search and navigation. The repository system, available on the web, reaches designers and researchers worldwide.

Concept generator software has been an ongoing research topic, which resulted in two versions. Both versions of the concept generator software are based on an algorithm that utilizes the Functional Basis and the design repository to generate and rank viable conceptual design variants [20,21]. The output is closely related to a morphological matrix; however, the software is intelligent and removes components from the remaining choices as incompatible components are chosen. This type of tool is intended for use during the early stages of design to produce numerous feasible concepts utilizing engineering component relationships as found in the design repository. Both tools are of the downloadable format and provide a list of possible solutions to each function of the functional model. The difference between the two versions is one allows the user to upload an entire functional model where the other prompts the user to manually enter one function structure or chain at a time. Concept generator v1 and MEMIC (v2) are java based applications, which work on both the Mac OS X and Windows platforms.

Table 1: Summary of Design Tools

Design Tool	Description
Functional Basis	A well-defined modeling language comprised of function and flow sets at the class, secondary, tertiary levels and correspondent terms.
Design Repository	A knowledge base to represent, archive and search product design information.
Function CAD	An application for the visual and digital representation of functional models.
Concept Generator version 1	Generate concept variants one function structure at a time using FCM/DSM data generated by the design repository.
MEMIC	Generate concept variants to an entire functional model using FCM/DSM data generated by the design repository.
Morpho-logical Matrix	A matrix listing many solutions to indicated functions, generated by the design repository.

Design Concepts

In the interdisciplinary design courses, several engineering design concepts are taught as described by the class descriptions in a previous section. The key topics introduced to students are product design, functionality and abstraction, customer needs, function based design methods and a general overview of what is engineering design. Several in class examples consisting of past success stories and interactive research, are presented to demonstrate to the students how design tools are used to develop an engineering design, and more importantly, when they are used in the design process. Table 2 lists the design concepts and a brief summary of each one.

Product design is an activity that spans the design space. In the clarification phase, customer needs are gathered and subsequently transformed into engineering requirements or design objectives [22]. The conceptual design phase attempts to formulate many design variants that obey engineering principles and achieve the customer’s requirements. All of the variants are evaluated to choose the best one or the top designs, which are utilized for a new finalized concept. The design embodiment phase involves the application of components and form to the conceptual design, such that it can be physically realized.

Mock-ups and prototypes follow embodiment and are used for validation of the product’s feel, appearance, functionality, usability and other metrics, before the product is chosen for production and marketing. Throughout the product design process, abstractions about the product are commonly used to generate creative solutions to ordinary functions [23]. Furthermore, abstractions lead to analogies, which also result in creative solutions to design problems [22]. A key aspect of product design is closely following the design objectives throughout the product design process, such that the desired functionality is achieved; the product does what it was intended to do [22-24]. Product design, abstraction, and functionality are closely linked to customer needs.

Function-based design methods and product functionality go hand-in-hand. One is a set of methods devoted to achieving a well thought out engineering design from the perspective of function and the latter is concerned with describing what the product must accomplish regardless of form. Typically, function-based design methods are followed in the early design phases so the designer is not persuaded towards a particular component, form or material before the concept is finalized. The five concepts mentioned already in this section contribute to the overall notion of engineering design. Dym and Little summarize engineering design very well, “Engineering design is the [systematic], thoughtful development and testing of characteristics of new objects that have a particular configuration or perform some desired function(s) that meets our aims without violating any specific limitations [25].”

Table 2: Summary of Design Concepts [22-25]

Design Concept	Description
Product Design	A systematic activity that involves iterative conceptual, evaluation, embodiment, and validation design phases.
Product Functionality	The purpose or intentional use of a product; what it is to do.
Product Abstraction	The general idea of a product’s functionality without considering form.
Customer Needs	Requirements, objectives and constraints that define the design problem from an user perspective.
Function Based Design Methods	Product design methods that focus on solving functional requirements in the conceptual design phase before considering components or form.
Engineering Design	The discipline of engineering that studies the science of design.

EDUCATIONAL SURVEY

The survey to assess the educational value of digital design tools used in the Missouri S&T interdisciplinary design courses is comprised of yes/no, rate on a scale of 1-5 and open-ended questions. The set of yes/no questions is intended to, in general, understand the design tool experience of each student prior to the course and whether the course increased their engineering design knowledge. Three questions asked the students to rate the design tools’ ability to reinforce the design concepts, which was strongest as conveying the notion of functionality and if the format of the tool impacted learning. The final four questions are open ended, allowing the students to express their likes,

dislikes and concerns about the design tools and the interdisciplinary design course. In addition to survey questions, all students taking the survey were also asked to provide demographic data, such as gender, major, year and design course number. The following subsections present the survey questions as given in the survey and their purpose.

Choice Questions

The survey began with two yes/no questions to obtain a background of each student's design tool knowledge. The first set of yes/no questions assesses the level of experience of each student prior to the course with each of the design tools. A second set of yes/no questions assesses the general level of understanding of the design concepts after completing the course. With the design tools all in digital format and explained briefly in class, the idea of a tutorial was assessed and which format would have been best. The yes/no questions as they appeared on the survey are:

- Before taking this class, have you used any of the following design tools:
 - The Functional Basis?
 - The Design Repository?
 - Function CAD?
 - Concept generation software version 1?
 - Memic - Concept generator version 2?
 - A Morphological matrix?
- After taking this **course** was your understanding of the following concepts increased:
 - Product design?
 - Product functionality?
 - Product abstraction?
 - Customer needs?
 - Function based design methodologies?
 - Engineering design?
- Would a tutorial have been helpful for these design tools?
If Yes, in what format?
Video, Manual, Interactive example or Personal training

Next, the students were asked to rate many aspects of the design tools on a scale of 1-5 (a Likert scale). First, the objective was to examine the strength of the design tools' ability to reinforce major design concepts presented throughout the design course. Second, learning the overall notion of functionality was addressed; this is important since the interdisciplinary design courses teach many design methods, but focus on function-based design. Third, we were curious to know if format makes a difference when learning design concepts. Three of the design tools are only available as a downloadable program with the other three being web-based. Finally, disregarding knowledge transfer, the students were asked to rate the design tools by ease of use. Each question of this type was presented followed by the rating scale and the list of design concepts or design tools that are to be rated. The first three had a Likert scale with the following assigned numbers: 1 – Disagree; 2 - Slightly disagree; 3 - No change; 4 - slightly agree; 5 – Agree. The ease of use question had the following scale: 1 - Easiest; 2 - Easy; 3 - moderately easy; 4 - moderately hard; 5 - Hard; 6 - Hardest. The rating questions as they appeared on the survey are:

- Did the design tools used in this course help you to better understand the following concepts:
 - Product design?
 - Product functionality?
 - Product abstraction?
 - Customer needs?

- Function based design methodologies?
- Engineering design?
- Rate how the following tools helped you to understand functionality - the purpose or intentional use of a component, product or process:
 - The Functional Basis?
 - The Design Repository?
 - Function CAD?
 - Concept generation software version 1?
 - Memic - Concept generator version 2?
 - A Morphological matrix?
- Rate the following based on how the information format influenced your learning of engineering design methods and concepts:
 - Web-based design tools?
 - Stand alone (downloadable) design tools?
- Rate the design tools in the order of 1 to 6 on ease of use. (Only choose each numerical value once)
 - The Functional Basis?
 - The Design Repository?
 - Function CAD?
 - Concept generation software version 1?
 - Memic - Concept generator version 2?
 - A Morphological matrix?

Open-ended Questions

The purpose of the open-ended questions was to gain feedback not explicitly asked for in the other questions. For instance, we expected to receive specific comments regarding the integration of all tools into one, or aspects of a design tool that just did not make sense to the user. Overall, the first two open-ended questions conjured many insightful responses and the third question elicited a common response from most. Majority of students did not answer the final open-ended question. The open-ended questions, in the order they appeared on the survey are:

- What was the most valuable aspect of using the design tools?
 - What was the most valuable aspect of this design course?
 - What other information or changes would you suggest to improve the design tools?
- Use the rest of this space to add any additional comments.

DISCUSSION

In this section, we discuss the survey results and gain insight on how digital design tools affect learning of engineering design concepts. Nine students were enrolled in the engineering design methodologies course and 21 students were enrolled in the design representation course. Out of the 30 students, 25 students were surveyed. The results to the seven choice questions for all students are provided first, followed by comparisons between seniors and sophomores. After the data is presented and discussed, key answers to the open-ended questions are presented and examined.

Choice Question Analysis

As the numbers in Figure 1 suggest, over half of the students had not experienced the design tools before taking one of the two courses. The design repository and function CAD software were the only two with more yes responses, both of which, were developed by researchers in the Design Engineering Lab and are widely known on campus, which could explain their familiarity. Figure 2 demonstrates that overall, the course was successful at teaching design concepts. Students expressed

that the most valuable portion of the course was the, “integration of all design aspects”, “learning the tools needed to successfully design things” and that the course “introduced multiple design techniques.” Figure 2 also shows that the design concept of customer needs was less emphasized in the courses. This aligns with the data in Figure 3; the design tools were weak at helping the students to learn the concept of customer needs. Although, this finding is not surprising because the interdisciplinary design courses encourage students to develop a strong understanding of customer needs, requirements and constraints *before* conceptual design. Which leads to the notion of functionality - the purpose or intentional use of a component, product or process, and the data in Figure 4. Again, learning the concept of functionality is key in a design course and the design tools were positively viewed by the students in assisting them learn that concept. Those that disagreed with learning functionality through the use of the design tools are possibly not visual or hands-on learners. Understanding that students learn in different ways, the design tool format was addressed. Figure 5 shows that majority of students were affected by the format of the design tool and based on the numerous comments to open-ended question three of “better windows compatibility,” the web-based format is favored.

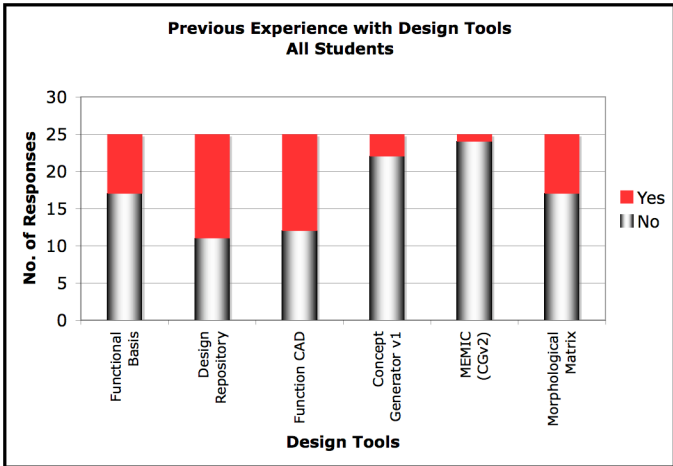


Figure 1: Question 1 Results

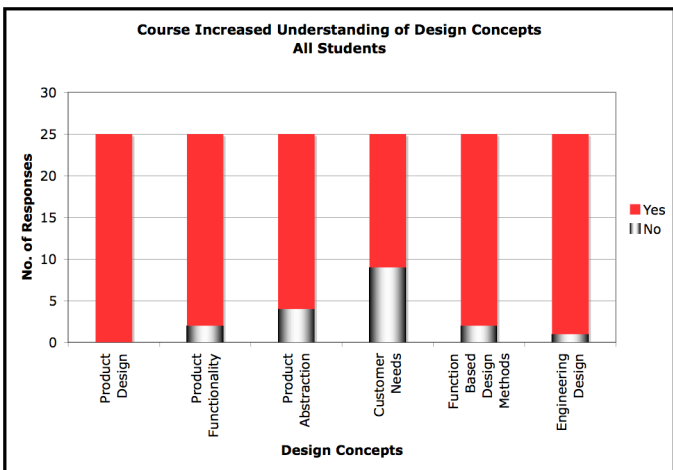


Figure 2: Question 2 Results

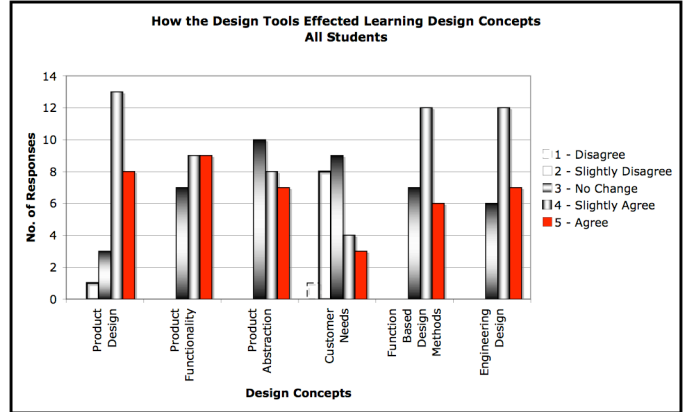


Figure 3: Question 3 Results

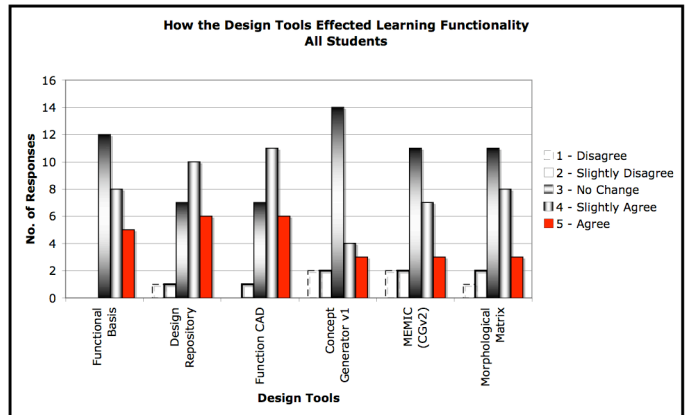


Figure 4: Question 4 Results

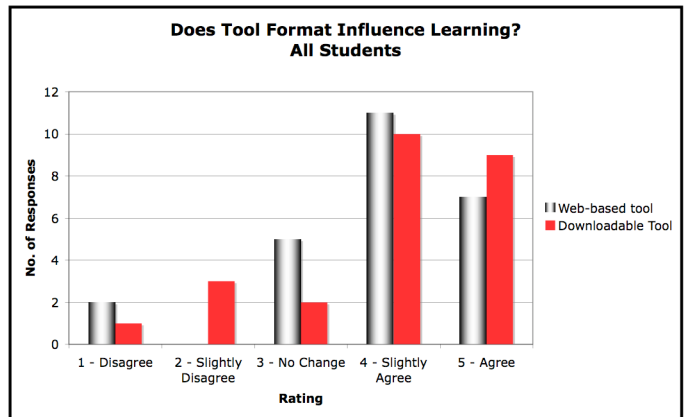


Figure 5: Question 5 Results

Tables 3-5 provide statistical mean, variance and standard deviation for the questions providing a Likert scale, which further support the analysis given in this section. Table 3 shows the statistical results of choice question 3 that asked the students to rate how well design tools added in learning the design concepts on a scale of 1-5. Table 4 shows the statistical results of choice question 4 that asked the students to rate how well design tools added in learning functionality on a scale of 1-5. Table 5 shows the statistical results of choice question 5 that asked the students to rate how the format type of the design tools affected their learning on a scale of 1-5.

Table 3: Statistical Results of Question 3

	Product Design	Product Functionality	Product Abstraction	Customer Needs	Function Based Design Methods	Engineering Design
Mean	4.12	4.08	3.84	3.00	3.96	4.04
Variance	0.61	0.66	0.64	1.17	0.54	0.54
Std. Dev.	0.78	0.81	0.80	1.08	0.73	0.73

Table 4: Statistical Results of Question 4

	Functional Basis	Design Repository	Function CAD	Concept Generator v1	MEMIC	Morphological Matrix
Mean	3.72	3.76	3.68	2.76	2.88	3.20
Variance	0.63	1.02	1.23	1.44	1.61	1.25
Std. Dev.	0.79	1.01	1.11	1.20	1.27	1.12

Table 5: Statistical Results of Question 5

	Web-Based Design Tools	Downloadable Design Tools
Mean	3.80	3.92
Variance	1.50	1.33
Std. Dev.	1.22	1.15

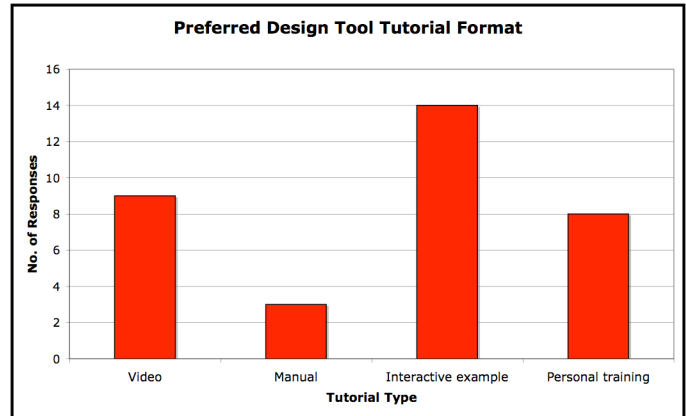


Figure 6: Question 6 Results

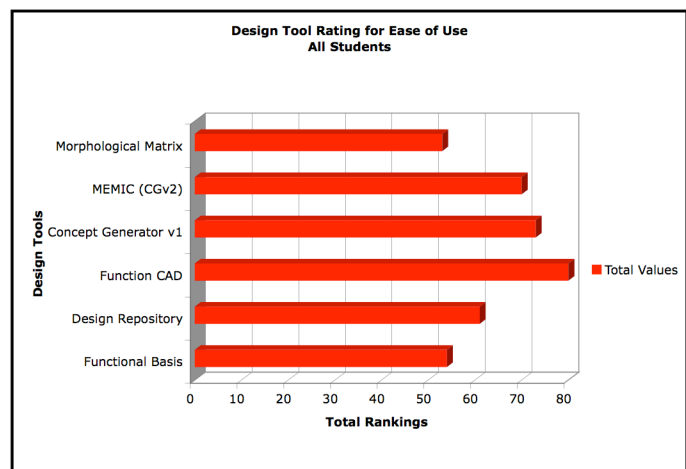


Figure 7: Question 7 Results – (shorter is easier)

Even though half of the design tools were of the preferred format, all but one student felt that a tutorial would have been helpful. Of the four tutorial formats listed in Figure 6, all formats but manual were preferred, with interactive example as the most popular choice. However, the students were tasked with using the design tools on their own, for homework and for class projects without a tutorial. As Figure 7 points out, Function CAD was voted the hardest design tool to use. This may be the case since it was of the unfavorable format, does not have a tutorial and is more stable in the Mac OS X platform. However, Function CAD has the biggest impact on learning functionality, as Figure 4 indicates. As one student puts it, “Function CAD was the most valuable.” We postulate that Function CAD had the same effect as the mathematical software (mentioned earlier) had during the problem solving process; when students create digital functional models they spend more time on the cognitive task rather than the spatial task of drawing the model. Therefore, more effort is placed on accurately describing a product’s functionally and students feel that the task is more valuable.

Out of the six design tools three were heavily emphasized in both design courses, the Functional Basis, design repository and Function CAD. The concept generator software and morphological matrices were discussed in both courses, but only those in engineering design methodologies actually used them. Therefore, looking at the survey data for the selected tools, we see that Function CAD and the design repository were the most valuable tools to all students. Figure 4 shows that half the students viewed the Functional Basis positively and the other half felt the tool was valuable, but did not encourage the design concepts. The data concerning the concept generator software and morphological matrices for the engineering design methodologies students was extracted from the data in Figure 4 and is presented in Figure 8. Students that were not experienced with the software indicated a 3-no change on the survey, which is reflected in Figure 4. Thus, we conclude that students using the concept generator software and morphological matrices found them to aid in learning design concepts. We speculate that MEMIC and morphological matrices had a higher rating since they are very similar and present principle solutions to all required functions simultaneously, rather than one function chain at a time as in the case of concept generator version 1.

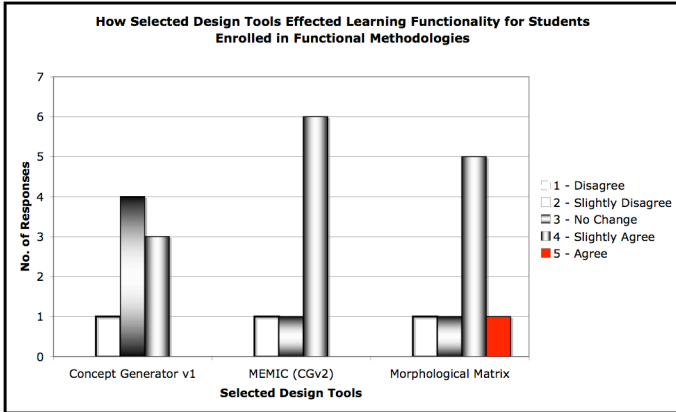


Figure 8: Rating of Selected Design Tools for Junior Level Course

The final aspect investigated in regards to all students is the impact prior experience had on the survey responses. Roughly half of the students surveyed reported prior experience with the design repository. Figure 9 compares the responses to survey Question 3 for 14 design repository experienced students (left column) to the 11 non-experienced students (right column). Since there is a difference of three between the experienced and non-experienced groups, the data normalized to a scale of 100% to easily compare the results. The experienced students consistently gave equal or slightly lower ratings except for the concept of product abstraction. Abstraction is a difficult concept to grasp and their prior experience and exposure may have been the reason the experienced students felt they learned it when using the digital design tools. However, majority of responses by both groups of students were positive with the discrepancy between the two groups being very small. We deduce that prior experience did not negatively affect learning the design concepts, but we suspect that prior experience saved time during the learning exercises.

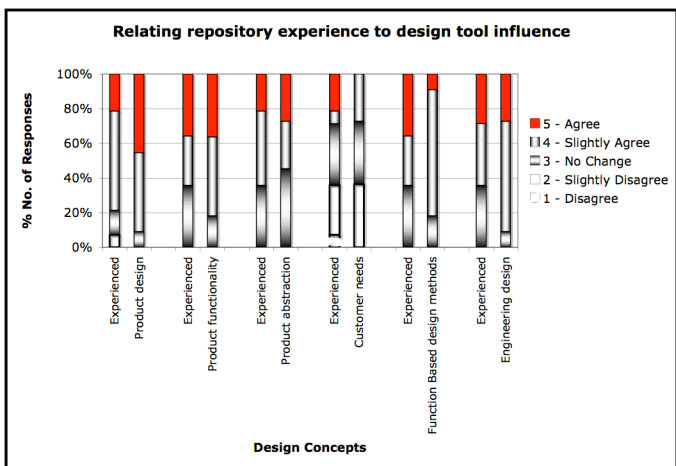


Figure 9: How Prior Knowledge of the Design Repository Influenced Survey Results

Seniors VS. Sophomores Analysis

As one might expect, the seniors had more responses of *yes* to previous experience with the digital design tools than the sophomores, except for the Function CAD software (Figure 10). The design tools were added to the lesson plan for the design courses for one academic

year before the Fall 2008 semester. It is possible that the open-source Function CAD software was shared or talked about among friends during a previous semester, which lead to its familiarity. It is interesting to see that the seniors had more knowledge of the Functional Basis and both groups shared the knowledge of the repository. The data in Figure 11 tells us that the same amount of seniors and sophomores struggled with the product abstraction concept, sophomores had a harder time with customer needs and both groups learned all other concepts. These results lead us to believe that that regardless of educational level, the learning outcome is the same when using the design tools. Software allows mastery of concepts at the student's pace and results in the same level of understanding.

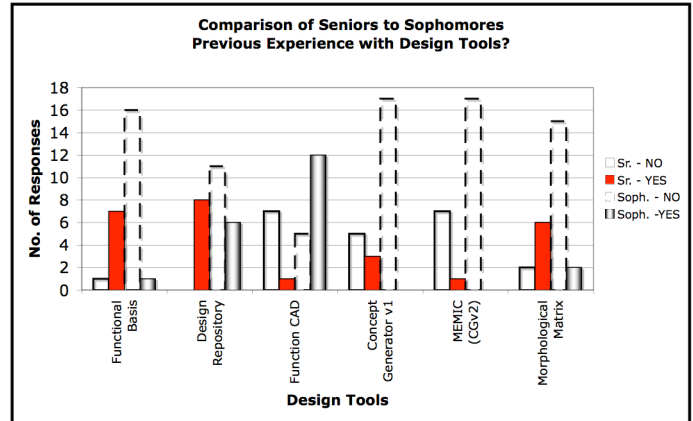


Figure 10: Question 1 - Senior to Sophomore Comparison

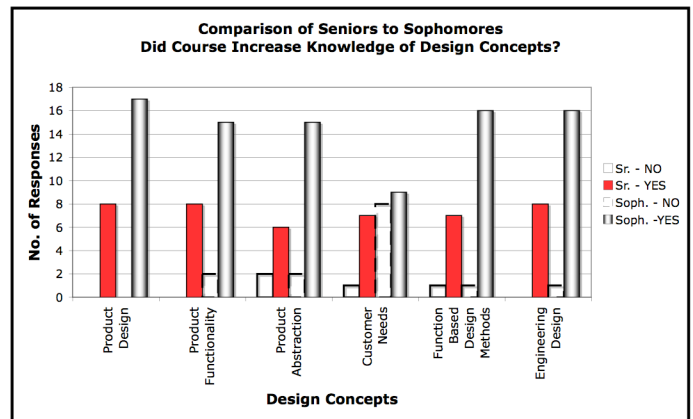


Figure 11: Question 2 - Senior to Sophomore Comparison

Finally, design tool ease of use is examined for both groups. As mentioned before, overall Function CAD was ranked as the hardest to use design tool, which is demonstrated in Figure 12. Looking at which tool is the easiest to use, the two groups differ. Seniors felt the design repository was the easiest to use, followed by a tie between the Functional Basis and a morphological matrix, where as, sophomores felt the Functional Basis and a morphological matrix were the easiest to use. Sophomores have less engineering experience than seniors, which could possibly contribute to these results. The younger students may not spend much time thinking through multiple design scenarios, rather, they use the Functional Basis definitions to choose suitable functions and flows for a functional model or morphological matrix

and don't look back. They may not be worried about what they do not know and feel their first choice is the best choice.

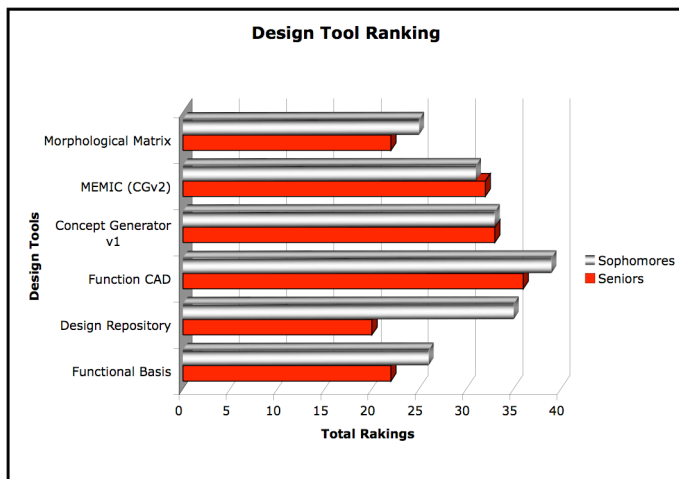


Figure 12: Question 7 - Senior to Sophomore Comparison

Open-ended Question Analysis

The open-ended questions yielded many useful comments for improving the design tools and design courses. The students overall really enjoyed the visual aspect of the design process and how the design tools can organize the conceptual data. Many students were unfamiliar with digital design tools before enrolling in the design course, and commented on not having to do calculations, generating immediate output or not losing data since they had a digital copy. Comments regarding the most valuable aspect of the design tools worth noting are:

- “Helped abstract the problem and prevent premature solutions.”
- “They saved a lot of time when it came to concept generation based off of the functional model. Function CAD took longer to use than manually drawing a model, but when it integrates with MEMIC, it’s worth it.”
- “Being able to see slight changes and how they effect the project design.”
- “Organization of thoughts and products.”

In regards to the course and what was most valuable, the students gave enthusiastic comments. Again, many expressed that they enjoyed the visualization aspects of design, such as sketching, modeling, design representation and making a portfolio. Comments about the course worth noting are:

- “I think it helped me think outside the box.”
- “Creativity and ingenuity.”
- “Learning how to represent designs in an easily understandable manner.”
- “The drawing portion. One must be able to convey ones idea visually.”
- “Learning the tools needed to successfully design things.”

As with all beta software, it is not perfect. The majority of suggestions for improving the design tools dealt with program integration, compatibility and stability. The downloadable software were created using open source methods and then ported to the Mac OS X and

Windows platforms. The windows version of the design tools had the most complications and the students requested better compatibility with Windows. Comments about design tool improvement worth noting are:

- “Better integration of tools.”
- “Make all applications web and server based.”
- “Tutorials.”
- “More help in learning the software. A slower paced class possibly.”

CONCLUSIONS

This paper assessed the value of using design tools, developed by researchers of the Design Engineering Lab, in two undergraduate interdisciplinary design engineering courses. Six design tools were tested for their ability to increase the student’s knowledge of six design concepts: Product design, product functionality, product abstraction, customer needs, function based design methods and engineering design. The tools were also evaluated for ease of use and if the tool format type affected their educational impact. Three formats were used for the survey questions: yes/no, Likert scale (rating) and open-ended. It should be noted that the sample size is small, however, we were able to identify the following trends. The majority of students in both interdisciplinary design courses, taught by different instructors, valued all six design tools and felt that the tools reinforced all but the design concept of customer needs well. We believe the design tool software allows mastery of concepts at the student’s pace and results in the same level of understanding, no matter the initial level of engineering experience. Furthermore, when students use the digital design tools they spend more time focusing on the cognitive tasks rather than the spatial layout tasks. Based on the student ratings, it could be determined that requiring students to perform design tasks with specific design software in design courses does increase both their appreciation for the task, as well as their ability to execute it. Future assessments of this nature should include: (1) an assessment of instructor teaching style to better understand how the students are influenced when learning design concepts and using digital design tools in a course; (2) a larger sample size; and (3) multiples sections of the same design course for data comparison.

The educational aspect of the survey involved assessing the digital design tools used in interdisciplinary engineering design courses to gauge whether the learning theory was presented as a distinguishable learning objective. With that knowledge, the course and use of design tools in the course can be updated to better reflect the course learning objectives. We believe that the students are “learning by doing” and that the overall positive response to the survey questions supports that belief. However, the compatibility, stability and integration of the downloadable design tools were a noted concern by the students and should be addressed. Stability issues aside, the design tools offer a dynamic learning experience, which could only be matched by industry experience.

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