AN ABSTRACT OF THE THESIS OF

Michael Koch for the degree of Master of Science in Mechanical Engineering presented on June 11, 2010.

Title: Utilizing Emergent Web-Based Software Tools as an Effective Method for Increasing Collaboration and Knowledge Sharing in Collocated Student Design Teams

Abstract approved:

Irem Y. Tumer

Over the last few decades, the methods and tools through which humans collaborate, share knowledge and generally communicate have been advancing at a rapid pace. Thanks mostly to advances in broadband internet, cheap data storage and fast microprocessors, humans now have the ability to work together in ways that even a couple decades ago were not even imaginable. From holding video conferences with clients in Europe and Germany to organizing a team of engineers operating in different cities, the way humans interact has entered an era where the lines between being in the same room and sitting thousands of miles away have been blurred. The implications of such technology have been and continue to become increasingly influential on how our society produces knowledge and creates innovation.

The field of engineering design has not been left out of such advances and continues to be directly affected by such shifts in economic and societal structures. As such, this defense will look at the overarching effects that internet-based collaboration and knowledge sharing is having on the economy, society and most importantly tech industries; the goal being to draw insight and conclusions from fundamental shifts in these areas and how they are applicable to engineering design and specifically design education. As part of this, two studies were completed on undergraduate students at Oregon State University and Humboldt State University to better understand the dynamics of collaboration and

knowledge sharing in the context of engineering design, and how it affects the overall process.

Utilizing Emergent Web-Based Software Tools as an Effective Method for Increasing Collaboration and Knowledge Sharing in Collocated Student Design Teams

by
Michael Koch

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Presented June 11, 2010
Commencement June 2011

Master of Science thesis of Michael Koch presented on June 11, 2010

APPROVED:

Major Professor, representing Mechanical Engineering

Head of the School of Mechanical, Industrial and Manufacturing Engineering

Dean of the Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Michael Koch, Author

ACKNOWLEDGEMENTS

First and foremost, I would like to thank my advisor, Dr Irem Tumer, for her support and help throughout the last couple years of research. It has been an excellent experience.

In terms of mentoring, numerous individuals have influenced my intellectual thought process including my good friends Richard Schulte, Vince Foley, Jordan Garcia, Nathan Jones and Jacob Kollen, who’s late night discussions during both undergrad and graduate school set me on a path that has led me to continually search for and question what I’m truly passionate about and how I can apply such skills for the betterment of humanity, and in many respects, formed the basis for much of this research; Dr. Marcin Jakubowski and Lonny Grafman for helping me realize that settling for the status quo of what engineering ‘should be’ is not enough if we are to turn around the world’s many problems; Dr. Robert Stone for allowing me to use his class as the test subjects for which most of this thesis is based off; Dr. Amit Prasad for further opening my eyes to the effects that technology and engineering have on society and that as an engineer, it is my duty to works towards a world that is more just; Dr. Denise Lach for further expanding my understanding of organizational theory and its effects on the engineering world as well as aiding me in this research; Joe Junker and the Energy Efficiency Center for supporting me financially throughout grad school; and to Lauren Babcock for being supportive and lending an ear throughout.

Finally, I would like to thank my family, Mom, Dad and Catherine, for their unending support throughout not only my Master’s work, but in life. Without their help, none of this would have been possible, and as such, I’m extremely grateful.

TABLE OF CONTENTS

Page

TABLE OF CONTENTS (Continued)

Page

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF TABLES

1 Introduction

Over the last few decades, the methods and tools through which humans collaborate, share knowledge and generally communicate have been advancing at a rapid pace. Thanks mostly to advances in broadband internet, cheap data storage and fast microprocessors, humans now have the ability to work together in ways that even a couple decades ago were not even imaginable. From holding video conferences with clients in Europe and Japan to organizing a team of engineers operating in different cities, the way humans interact has entered an era where the lines between being in the same room and sitting thousands of miles away have been blurred. The implications of such technology have been and continue to become increasingly influential on how our society produces knowledge and creates innovation [1],[2].

As such, the societal structure in which humans participate has evolved to a point where individuals in developed countries often must to be able to quickly access, interpret and utilize disparate pieces of knowledge in their daily lives and subsequently be able to relay that information to others. Often referred to as 'information societies', these social structures operate in sharp contrast to the agricultural and industrial economies prevalent in the 1800s and 1900s [3]. Whereas in the past, value was created by being able to produce some physical product, such as a crop or a manufactured item [4], many jobs today create value by dealing simply in the research, development and dissemination of knowledge. Individuals who operate in this realm are often referred to as ‘knowledge workers’ [5].

The field of engineering design has not been left out of such advances and continues to be directly affected by such shifts in economic and societal structures. However, in many respects, design and particularly design education has failed in adequately grasping how such technological shifts can and are affecting professional engineering and what are effective ways of transferring that knowledge to students in the classroom. Such education is of the utmost importance when considering the fast paced, rapidly changing and interconnected world that students are preparing to enter.

As such, the following thesis will look at the overarching effects that internet-based collaboration and knowledge sharing is having on the economy, society and most importantly tech industries; the goal being to draw insight and conclusions from fundamental shifts in these areas and how they are applicable to engineering design and specifically design education. In particular, there will be special focus on open source software development and the emergent ‘open source hardware’ realm, as both areas are operating at the cutting edge of web-based collaboration. From this background information, the motivation for the subsequent research will be outlined, focusing on the relevance to engineering design and how it was used to drive to the subsequent research. Following the Motivation section, two research papers will make up Chapters 3 and 4. The first, “The Effects of Open Innovation on Collaboration & Knowledge Sharing in Student Design Teams”, outlines research that looked at how students collaborated and shared knowledge in collocated student design teams. The second paper, titled “On the Utilization of Web-Based Collaboration Tools by Student Design Teams”, looks more at the use of specific tools, such as wikis and email, in the context of the engineering design process. Both papers took a broad look at how students performed such tasks in the classroom setting and how they felt about using particular methods and technology during that process. From these two papers, conclusions will be drawn on how engineering design education can best utilize the changes that are quickly becoming a part of everyday life for engineers and humans in general.

2 Background

Over the last couple decades, the wide adoption of the internet has sparked a fundamental transformation in how humans organize and communicate that is quickly permeating every aspect of the human social structure [6]. The following sections will survey specifically how economic production has changed and draw important parallels with the open source software movement and its effect on engineering design.

2.1 Commons-Based Peer Production

In the past couple centuries there have been two main modes of economic production occurring in the United States, these being firm production and market-based production. Firm production, as the name implies, is centered on a hierarchical organization, or firm, where the centralized decision-making process is run by supervisors who choose what the subordinates must produce [7]. Examples would include Microsoft producing the Vista operating system or Boeing creating the 787. Market-based production on the other hand works by placing prices on certain jobs, which in turn act as a way to attract individuals to those positions [1]. Paying entry-level engineers high wages to entice students to enter that field of study would be one familiar example. These two models often work hand-in-hand.

With the emergence of nearly ubiquitous internet and affordable computing power, a third mode of economic production has emerged known as “commons-based peer production”. This term, coined by Yochai Benkler, refers to a new paradigm that is distinctly different from the firm or the market. Commons-based peer production, or simply CBPP, is a system that draws from the knowledge and innovation of often geographically dispersed individuals to work on large, complex projects. These projects are generally internet-based, have little hierarchical organization and often no financial compensation [1].

The most visible form of CBPP is the open source software movement, or simply open source. Over the past couple decades, open source has proven to be hugely successful at developing complex and robust software packages through the contributions of volunteers all over the world. Some prominent examples include Apache web server, Linux OS and the Firefox internet browser . The following section will go more in depth into the open source development method and look at why and how it has been successful.

2.2 Open Source Software Development

In the last few decades, the open source design methodology has grown from an idea that was somewhat undefined to what many consider a paradigm shift that is threatening the closed systems that have existed for decades. As Eric Raymonds so puts it, “the open source model of operation and decision making allows concurrent input of different agendas, approaches and priorities, and differs from the more closed, centralized models of development [8].” This mode of design is in contrast to the more established institutional methods that were mentioned earlier.

An ‘open source design methodology’ is a relatively unstructured way of developing software packages or products. Simply put, open source software development is a process in which the source code is made available through the Internet and its modification, use and distribution is promoted as essential to the success of the product [9].

Similar to concurrent engineering, the design and implementation is performed in a highly parallel fashion [10] by individuals who may or may not be geographically dispersed. However, there are stark differences to more orthodox methods of economic production. Specifically, those involved are not directly compensated monetarily [11]. Contributors may join and leave whenever they feel like, and have no repercussions for such actions [12]. The source code, or the inner workings of the software, is then distributed openly with the final software product [11]. With this source code, others may start separate projects based on the code, also known as ‘forking’. Forking is a fairly common occurrence, and happens often, especially in more popular programs like Linux and Wiki software [12]. Openness has allowed for a more diverse dialogue to evolve around these projects, and is one of the keys to open source's success.

Another way to visualize the design process is to use the analogy of the Cathedral and the Bazaar [8]. This model put forth by Eric Raymond has been used extensively to describe how open source design works. The Cathedral represents the firm, a highly organized, closed and hierarchical institution that has the task of producing a product such as software or airplanes. In modern terms, the Cathedral can be likened to corporations such as Microsoft or Boeing. The Bazaar on the other hand represents an organizational structure that is relatively flat and open where contributors have equal say and representation [8]. The visualization of a bazaar as a bustling area where people are presenting their ideas and agendas gives a good idea of how open source works [11]. These descriptions infer a general idea of why each system has had its successes and failures.

Part of the genius of open source is that large, complex projects such as Linux OS or Apache web server can be divided up into smaller tasks that a large group of volunteers can work on. By leveraging this large group, the amount of brainpower that is utilized is literally unmatched in the corporate setting [13]. Of course, there must be a well-defined review process to ensure that quality work is being submitted as well as to avoid the possibility of the code 'forking' [14]. Apache's success in using this method can be seen in the graph below which depicts web server market share from August 1995 to November 2008. Specifically, Microsoft versus Apache clearly shows the ability of the open source development methodology to compete against well established corporations [15].

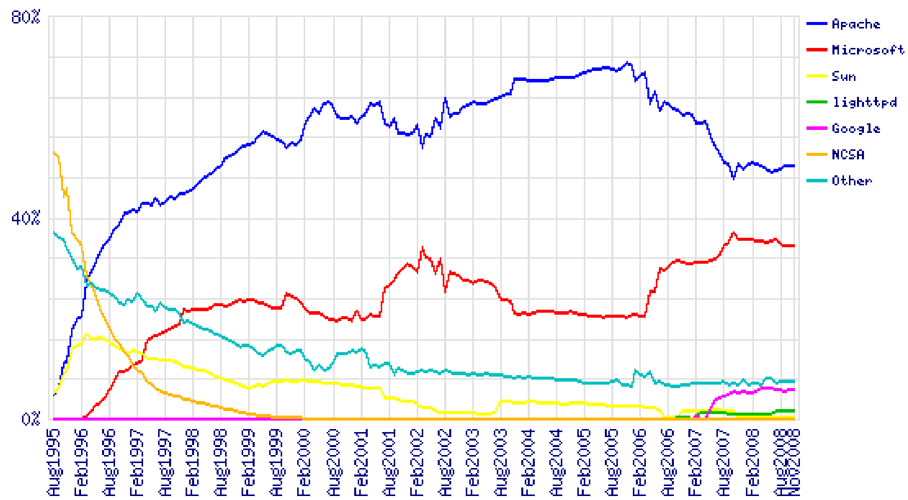

Figure 1 - Market Share for Top Servers Across All Domains August 1995 - November 2008 [16]

Similarly, the large group of volunteers allows for the application of Linus's Law, which states: "Given enough eyeballs, all bugs are shallow" [8]. What this means is that by leveraging this large network of contributors, any problems in the source code or design can be found and fixed. In the realm of software development, debugging can be a tedious job, especially when dealing with millions of lines of code. By creating an asymmetrical, distributed network, this task is significantly reduced due to the parallel nature of the work [11]. The same idea has been applied by Wikipedia, where information is reviewed and debated by users all over the world, hence creating a robust information database that is unrivaled in recent times [17].

Similarly, Charles Leadbeater points out that previous organizational models rely heavily on the idea that experts must be assembled in institutions to create products or innovation [18]. Example institutions include Microsoft, Stanford University or the NASA Jet Propulsion Laboratory [19]. The idea of open source flips this idea on its head, and relies not on an institution but rather a community of developers and contributors to create innovation motivated by things such as utility, pride and enjoyment. To many, this may seem perplexing, but makes perfect sense when looking back into history at how people organized around community needs or issues [1]. However, it should be noted that many large corporations, notably IBM and Sun Microsystems, are starting to contribute to the open source movement as a way of tapping into the huge resources the open source method provides [11].

In summary, open source software development is a development framework that is very different from the more established design methods. At its core, open source software development is an egalitarian, internet-based design process that looks to give each individual freedom over what they work on and how they approach design problems. The philosophy behind this process is important to its success and presents a challenge to the more established methods that have dominated organizations and institutions for decades. Because of open source's success, the next step seems to point towards broadening the methods used here into other fields, specifically engineering design. Is it possible to accomplish the same complex system design in the physical realm that open source has in the virtual realm? The following section will look at the current work being done in what is now being called open innovation and the sorts of successes and failures have been met in its relatively new existence.

2.3 Open Source Hardware & Open Design

In the spirit of open source software, such development models have been manifesting themselves in the mechanical and electrical engineering realms through what is known as 'Open Source Hardware' or 'Open Design'. Since these areas are still early in their development, the terminology has yet to be settled on. Generally, open source hardware refers to the actual products that are created (similar to the executable software file), while open design refers to the process of openly sharing design information through mostly web-based methods (similar to the development of raw source code).

The basic concept though is similar to open source software development in that designs are freely available to those that are interested in continuing work on a project. Currently, many of those operating in this realm are hobbyist or do-it-yourselfers working on projects that are relatively simple compared too many modern day engineering projects. Much of the focus has been around development of 3d printers and printed circuit boards. Below is a sampling of projects that have enjoyed popularity, and give a good overview of the type of products coming out of the open source hardware movement.

Project Title	Function	Developer
RepRap	3d printing	Dr. Adrian Bowyer University of Bath
Cupcake CNC	3d printing	Zach Smith, Bre Pettis, Adam Mayer MakerBot Industries
Arduino	Microcontroller	Arduino Software
BUG	Modular, wireless product development platform	Bug Labs

Table 1 – Example of Open Source Hardware Projects

2.4 Open Innovation

In a broader sense and more directly applicable to the world that engineering students will be entering upon graduation, such concepts of openness and willingness to collaborate have been permeating the world of traditional organizations, particularly the technology industry. Whereas in the past, research and development at engineering firms was performed in house and was generally closed to outsiders, companies and organizations are realizing that to be successful, the innovation process must include outside entities if they are to be successful [20]. The need for such collaboration stems from the need of corporations, universities and other organizations to be able to drive broad levels of innovation to compete and stay current in our rapidly changing world. In order to accomplish this, such entities must reach outside their organizational boundaries in order to gather expert advice they might not have access to locally, diversify their pool ideas through open communication or tap into resources that they simply do not have.

Pioneered by Henry Chesbrough, this shift in how the typical technology firm operates is generally known as “Open Innovation”, and is a concept that is quickly catching on in many realms.

Key to this concept is how the internet has changed the way companies and organizations look at knowledge. In the past, knowledge that was integral to a company’s success could be kept away from prying eyes and held onto until the organization was ready to use it. Today, this is no longer the case. To keep on the cutting edge, companies must be constantly innovating and coming up with new ideas. Holding onto what might be a successful business venture is no longer feasible, but rather must be spun off into a start-up or the intellectual property sold for a profit [20].

The basic idea of open innovation is depicted below with comparison to the closed innovation model. It can be seen that, as mentioned before, the closed innovation keeps ideas and innovation within the firm’s boundary.

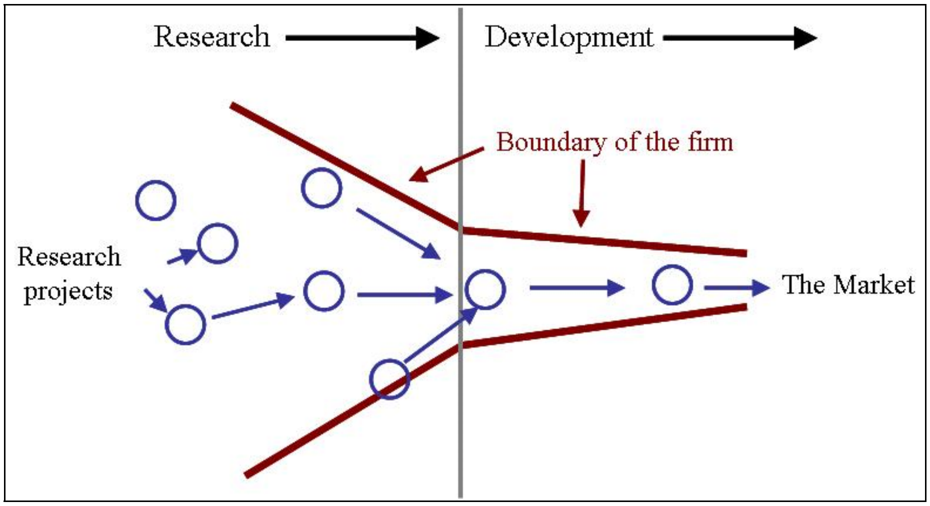

Figure 2 – The Closed Innovation Model for Industrial R&D [20]

Open innovation, on the other hand, looks for ways to utilize innovation of the firm to the greatest benefit possible, which often means reaching out to those that in the past might have been viewed solely as competitors.

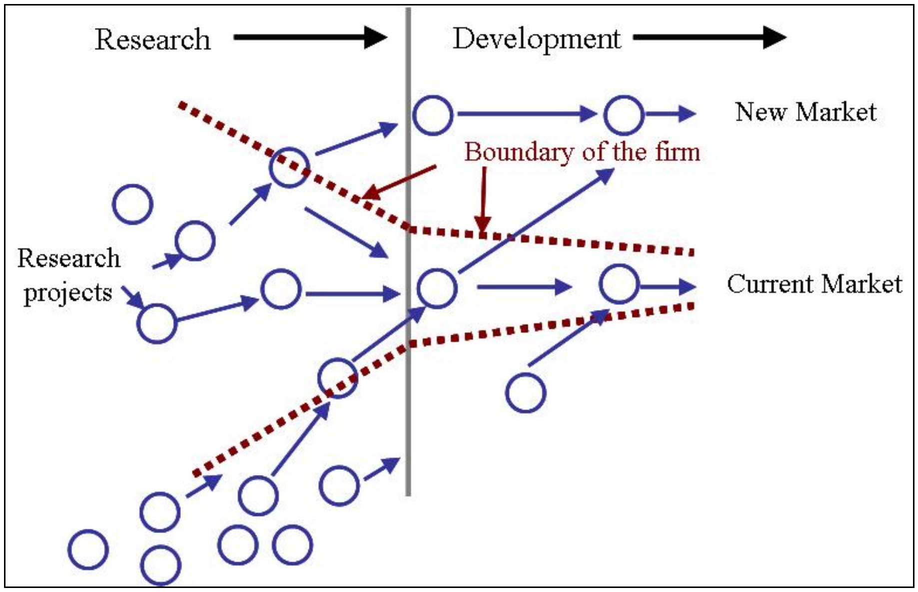

Figure 3 – The Open Innovation Model for Industrial R&D [20]

3 Effects on Engineering Design

So why are such changes important to the world of engineering design and education? As mentioned before, the fundamental way that humans are collaborating and communicating is changing at a rapid pace. Because of this, the rate at which innovation occurs is also increasing as access to information and knowledge increases by the day. These changes are fueled mostly by technological changes that have come in the form of web-based platforms and applications that allow for such communication to occur. Technologies like email, wikis, blogs and social networks are just a few examples of tools that are now being adopted to facilitate such knowledge transfer. As such, understanding how these emergent web-based methods of communication, collaboration and knowledge sharing can be used in the engineering design process is of utmost importance to ensuring that engineering design is able to most effectively take advantage of a shifting technological landscape.

Part of this is understanding the role and effectiveness of such tools in relation to the engineering design process. The following two chapters will focus on this topic, and how it specifically relates to engineering design education. The third chapter, "The Effects of Open innovation on Collaboration & Knowledge Sharing in Student Design Teams", looked mostly at students' perception of collaboration and knowledge sharing in relation to engineering design. This study was completed using students from Oregon State University. The fourth chapter, "On the Utilization of Web-Based Collaboration Tools by Student Design Teams", extended this research and looked specifically at the tools student used to collaborate and share knowledge. This study was completed using students from Oregon State University and Humboldt State University.

With both of these manuscripts, the goal was to understand how such changes translate to engineering design education, particularly in how students are taught to manage projects, collaborate and share knowledge and the tools they use to accomplish these tasks. In addition, a portal known as Open Pario was developed as part of this work as a way of implementing web-based collaboration tools in a controlled setting.

4 "The Effects of Open Innovation on Collaboration & Knowledge Sharing in Student Design Teams"

Michael D. Koch
Graduate Research Assistant
Department of Mechanical, Industrial and Manufacturing Engineering
Oregon State University
Corvallis, Oregon, USA
Email: kochm@engr.orst.edu

Richard J. Schulte
Program Coordinator
Open Design & Manufacturing Research Group
ReRooting Collaborative
Cleveland, Ohio, USA
Email: Richard.j.schulte@gmail.com

Irem Y. Tumer
Associate Professor
Department of Mechanical, Industrial and Manufacturing Engineering
Oregon State University
Corvallis, Oregon, USA
Email:irem.tumer@oregonstate.edu

Proceedings of the ASME 2010 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference
IDETC/CIE 2010
August 15-18, 2010, Montreal, Quebec, Canada

DETC2010-29008

4.1 Abstract

As the need to innovate more creatively and effectively becomes increasingly apparent in engineering design, powerful open design tools and practices have emerged that are allowing organizations and firms to tap an already vast pool of skills, knowledge and intellect to solve complex design problems. The need for engineering design educators to bring these new trends into the classroom continues to grow as the industry for which students are being prepared begins to revamp its design strategies and practices in the pursuit of more openly accessible information infrastructures. By conducting an experimental study of over 25 student design groups in an undergraduate design engineering class, our team was able to gauge the relevance and utility of collaboration and knowledge sharing between and within design groups. Specifically, issues and opportunities were identified to help bring engineering and design education in line with the increasingly networked and distributed professional engineering environment that students will be enter upon graduation.

Keywords

Collaboration, Knowledge Sharing, Open Innovation, Open Design, Web 2.0, Productivity, Design, Computer Supported Cooperative Work, Wiki, Design Education

4.2 Introduction

As seems to be the consensus across disciplines, new approaches to innovation are becoming ever more important in a fast paced, rapidly changing world. The ability for groups and teams to collaborate between organizations and entities in various scales and capacities has become increasingly necessary to enhance both distributed and co-located group coordination of design, planning and strategic processes. This emerging phenomenon is quickly becoming understood to be most powerful when groups reach outside their institutional boundaries to seek the knowledge and skills necessary to innovate [20].

More than ever, this is becoming the case in design engineering, a field in which the problems that need to be solved are increasingly complex, timelines necessitate rapid development and the ability to strategically innovate are both more difficult and more vital. Because of this, emerging tools and best practices for sharing information & knowledge have changed the way groups look at collaboration, both within their organization and with those they have partnered with [1],[21]. As such, the translation to engineering design education will be key in ensuring future engineers are prepared to interact in these emerging environments.

4.3 Background & Motivation

In the past few decades, the ability of engineers and teams to easily share information and collaborate on complex engineering projects within their organization has become commonplace. However, in recent years, industry, academia and other groups have seen an explosion in intra-organizational collaboration. This is due to many factors, such as the need for expert advice not found locally, lack of local resources and a growing diversification of ideas in hopes of increased innovation. These concepts, collectively known as "open innovation", were pioneered by Henry Chesbrough and grew out of the importance for technology and engineering companies to reach out of their specific design teams or organizations to drive broader levels of innovation [20]. An illustration of open innovation as it relates to corporate research and development is depicted in Figure 4. The diagram depicts how such practices can be used to broaden research and development capacity by crossing formal boundaries to drive innovation in the current market and to leverage that innovation to create opportunities in new markets. Chesbrough argues that such a framework is necessary for organizations to be successful in an economy where knowledge is readily accessible.

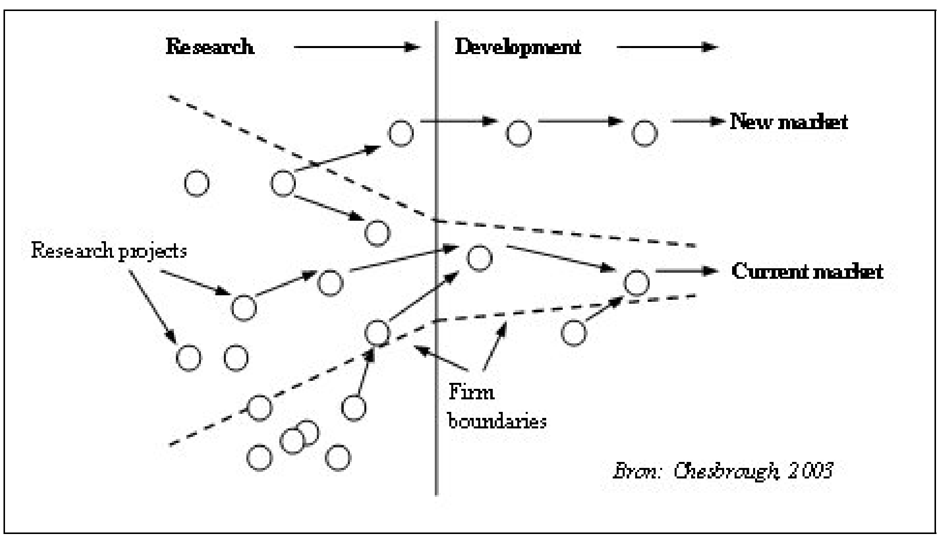

Figure 4 - Open Innovation in relation to corporate research & development [20]

Similarly, the rapidly growing success of Open Source Software has shown that innovation prospers in settings where knowledge is shared openly for others to build upon and contribute to [12],[22].

Due to these changes, how collaboration is performed has changed dramatically over the last decade. Beginning with basic communication technologies like email, to asynchronous methods like wikis and now the move to real-time web-based environments such as Google Wave, technology is quickly changing the logistics of collaboration [23]. Increasingly, project teams rarely meet face-to-face, but rather find effective ways to collaborate with their colleagues through emails, instant messaging, video conferencing and various web based collaboration tools.

As these practices become more widespread in the workplace, the need for engineering design educators to bring these trends into the classroom continues to grow as the industry for which students are being prepared begins to reassess its design strategies and practices [24-26]. The need for students to thoroughly understand how to use such tools, be able to interact in virtual settings and collaborate effectively with others is integral to a student's professional development [27],[28]. Wikis, forums and related tools as well as using distributed teams in engineering education environments have been investigated in the research literature [29-32]. Specifically, the utilization of wikis in engineering design education has garnered the most attention, and been met with favorable reviews [29],[30],[33]. The specifics on how to effectively utilize such tools and the advantages of their use in the classroom is slowly becoming well researched and documented, though widespread adoption of such methods and tools in educational settings has yet to be seen.

Taking a closer look at the use of certain collaboration tools will be crucial in investigating their appropriateness for design teams. However, the following research addresses a broader inquiry into how the interaction both within design teams and between them is influenced by student preferences, the many tools available and the various collaborative approaches and methods used. The following paper will first discuss the structure and nature of the engineering design course that was researched, followed by the methodology and experimental design that was applied to the test subjects. Finally, the results will be presented and interpreted through their relationship to engineering design education.

4.3.1 Open Pario Development

In addition to understanding collaboration and knowledge sharing, an important segment of this research was to test the use of Open Pario in a design engineering education environment. Open Pario is a web-based project management system developed and maintained at OSU, but originally designed for software engineers. It includes features such as project-based wikis, task and time tracking, Gantt charts, blogs, file repositories and forums [22]. In Figure 5, a screenshot showing the introductory page to Open Pario is shown. From this page, the user can login, view recent blog news, start a project and see which projects have been recently added. The software is based on Redmine, an open source software package [34], with modifications made to make it better suited for engineering design and education.

Since its inception, Open Pario has received a great deal of attention. Currently, the site is being used by engineers collaborating on projects at several universities as well as on private projects with users distributed throughout the United States, Mexico, Germany, Russia and several other countries. Most of the projects are operating in the open source hardware realm, a movement with the basic premise of openly sharing design information such as CAD drawings to drive broader levels of collaboration, mostly outside of the traditional organizational structure. The idea is to emulate the success of open source software in the engineering world.

Studies such as these can be very useful in developing strategies to adapt it to collaborative engineering design. As such, this paper seeks to find methods and practices students already used to collaborate within and between groups in a co-located setting. The end goal of our study was to determine how Open Pario can be better tailored to fit the needs of the end-user population, with features such as design repositories, integration with desktop software and other web applications as well as social networking platforms.

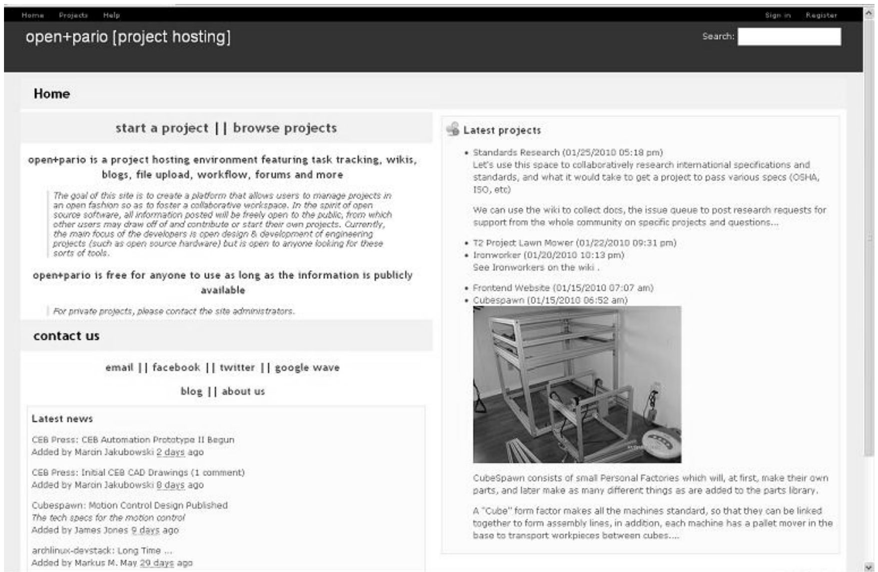

Figure 5 – The home page for the OpenPario.net Collaboration Platform

The Open Pario site (www.OpenPario.net) is available for use by anyone, and in particular, can be an easy method of introducing the use of such tools and project management methods to engineering design students.

4.4 Methodology

In order to explore how students currently collaborate and share knowledge and how this can be enhanced in the future, several main questions or topics were used as guides to drive the subsequent research.

- What are the students' perceptions of knowledge sharing and group collaboration in relation to class projects?
- What methods do student teams use to collaborate, share knowledge and complete class projects?
- What barriers exist to keep groups and individuals from collaborating?
- How does greater access to other groups' information affect the engineering design process?

To better understand these ideas, IRB-approved research was conducted on a group of students in a project-based engineering design course (ME 382). Twenty-seven teams of junior-level mechanical and industrial engineering students were tasked with designing, building and testing an Autonomous Material Sorter as defined by the 2010 ASME Design Competition [35]. The goal of the competition was to develop a product capable of accurately sorting common recyclable materials, namely ferrous and non-ferrous metals, plastics and glass into distinct waste containers. This project was to be finished in a 7-week time period, and was the final project for the course. Project teams were formed by dividing the 100 students into 3-4 person groups, creating 27 teams total. These project teams were then placed into 1 of 4 lab periods (Labs A-D).

To facilitate collaboration, there were a number of methods available to students. For this project, the class was introduced first to the use of wikis as a tool for document preparation and file storage, as assignments (i.e., memos and reports) were to be entered directly into the wiki (Word and PDF documents were not acceptable). In addition, the project managements tools found at OpenPario.net were introduced. The students were instructed on how to use both of these tools during the course of the design project component. However, the wiki received most of the focus as it was the method students were required to use when submitting assignments. In addition, meetings were required on a weekly basis through class, lab and outside of school. Shop time was also made available for students to work on their projects during lab or outside of class.

Over the course of the term, these students were observed in several manners. First, computer software was used to track their usage of various web tools. Second, a series of individual and group interviews were conducted to gain detailed qualitative information regarding their methods of collaboration, knowledge sharing and communication. Finally, the information from these interviews was used to drive the development of a survey which was used to gather quantitative data on similar topics found in the interview. These methods are detailed in the following sections.

The overarching goal was to better understand how collaboration within and between student design groups occurs, students' perception of collaboration and methods that were used as well as the issues and opportunities afforded by increased intra-group collaboration in the classroom.

4.4.1 Experimental Design

In order to answer the questions posed earlier regarding collaboration and knowledge sharing, the experimental design needed to take into account traditional comparison techniques [36]. As such, the class was divided into control and experiment groups based on labs. This was chosen in a random fashion, though with only 4 labs to choose from, randomization was not terribly relevant. Also, project teams could not be randomly assigned to certain treatment groups, as it would have been logistically very difficult, as well as mixing treatment groups within labs would have created interactions between teams that were unwanted.

Labs A and D made up the control group. They were required to use the wiki for submitting project assignments and had the option of using the wiki as a collaboration tool. The information they uploaded and added to the site was only accessible to students in their own project team, effectively making it siloed. Labs B and C made up the experiment group. These students were also required to use the wiki for uploading assignments, however they were able to view content uploaded and added by the other project teams in Labs B and C. Additionally, the experiment group was introduced to a set of project management tools found at OpenPario.net. As on the wiki, the students could see each other's uploaded information on Open Pario. Due to the nature of the division, the unit of analysis for this experiment is the project team.

In order to understand how these particular students shared knowledge and collaborated with their classmates as well as the influence of the provided tools, two different methods of data collection data were employed, namely surveys and interviews. Tracking usage of the web tools was attempted, but issues arose that kept us from using this data. Details on these problems will be discussed later.

4.4.2 Group and Individual Interviews

In order to obtain qualitative data on how students collaborate, shared knowledge and used the provided tools, a series of interviews was deemed the most effective method to gather such information based on the literature [37], as well as from expert recommendations [38].

These interviews were held with individual students and focus groups, and were selected utilizing a random sampling technique [39]. A total of 32 students were interviewed; 12 being individual interviews, 4 project team focus groups and 2 treatment groups with randomized students. Even after random sampling, each of the 4 labs was represented in some fashion. These interviews were semi-formal in structure with questions focused on collaboration, knowledge sharing, project management and the tools they used to accomplish these tasks. The interviews for both individuals and groups were similar, with questions such as the following asked:

- How did your group work to accomplish tasks? What methods were employed to facilitate this work?
- What tools did your team use to collaborate on the project? What was most efficient?
- Did your group collaborate or share knowledge with other groups? Why or why not?
- What experience do you have using web-based tools like wikis? Like/Dislike?

From here, the questions diverged for the experiment and control groups. The experiment group was probed further regarding their ability to openly see other group's work and how such access changed the dynamics of the class. As such, interviews with students in the experiment group tended to last longer as there were additional topics to cover.

The goal was to use these interviews, which were qualitative in nature, to drive the design of the surveys, which were quantitative in nature, discussed below. These interviews were incredibly insightful and allowed us to see more of the nuanced factors that came into play in student engineering design.

As an incentive to participate, students were given extra credit as an alternative to an extra credit assignment. However, our team found it rather difficult at times to convince students to do the interviews, as many of the students were busy as is. In the end, 44 students were contacted about interviewing, with 32 showing for the final interview.

4.4.3 Surveys

The surveys were designed after careful analysis of the interview recordings to ensure that they asked questions pertinent to the needs and activities of the students. The answers in the scales, in multi-choice questions and other questions reflected as many of the common interview responses as possible. Again, the motivation for using such tools is well documented in the literature, and a de facto standard for gaining insight into human activities [37].

The survey was divided into 3 sections: Collaboration, Knowledge Sharing and Tools. The section Collaboration section focused on questions regarding how effective the student felt his/her group was at topics related to group collaboration, project management and group dynamics. The Knowledge Sharing section focused on the perceived advantages of project teams sharing knowledge within and between groups, and if they participated in such activities. Finally, the Tools section asked questions regarding how effective the provided tools were, how often they were used and if the student would use them in the future.

These surveys were administered during the final design competition, in which students attempted to meet a set of criteria for the function of their projects. Extra credit was used to incentivize taking the survey with great success. Also, paper surveys were used as we felt it would be easier to get students to take a survey that was in front of them, rather then emailing them an electronic survey in hopes that they would fill it out. The resulting data was entered and stored using LimeSurvey, an open source tool for developing and administering surveys. Out of about 125 students, 118 took the survey, providing a dataset very representative of the class.

4.4.4 Statistical Analysis Methods

In order to evaluate the statistical difference between the experiment and control groups, basic two sample t-tests were run through the R statistical package [39]. As such, p-values found in the following results section that are below 0.05 show significant statistical difference between the test groups. Additionally, the alpha values recorded are a measurement of the reliability of a set of survey questions. In our case, this referred to a set of Likert scale questions. An example of such would be, "How effective was your group at completing assigned tasks" with a response being on a scale from 1-5. To measure this, we again used R, but this time with Cronbach's analysis using the "psych" package, an extension to the R environment. Cronbach's analysis is one established method for measuring such reliability [40],[41].

4.5 Results

After analyzing the results and looking for statistical differences between the control and experiment groups, it was found that in many dimensions, there was little difference in how the control and experiment groups operated. As detailed in the Computer Supported Cooperative Work (CSCW) literature, this can be attributed to the groups being in a collocated setting, meaning much of the collaboration and knowledge sharing is done in a face-to-face manner, as opposed to solely through the internet [23]. There are, however, several marked and significant differences between the two groups detailed below.

4.5.1 Specifics

Overall, when students were asked about how they perceived collaboration and knowledge sharing in the context of engineering design projects, it was viewed favorably. In regards to the effects of collaboration and knowledge sharing on engineering design, around 70% felt it provided a greater pool of ideas and inspiration and a diversity of approaches to problem solving. Another 19% considered it a good way to reduce workload, while a quarter viewed plagiarism as a potential issue when collaborating between groups. These responses are displayed graphically in Figure 6.

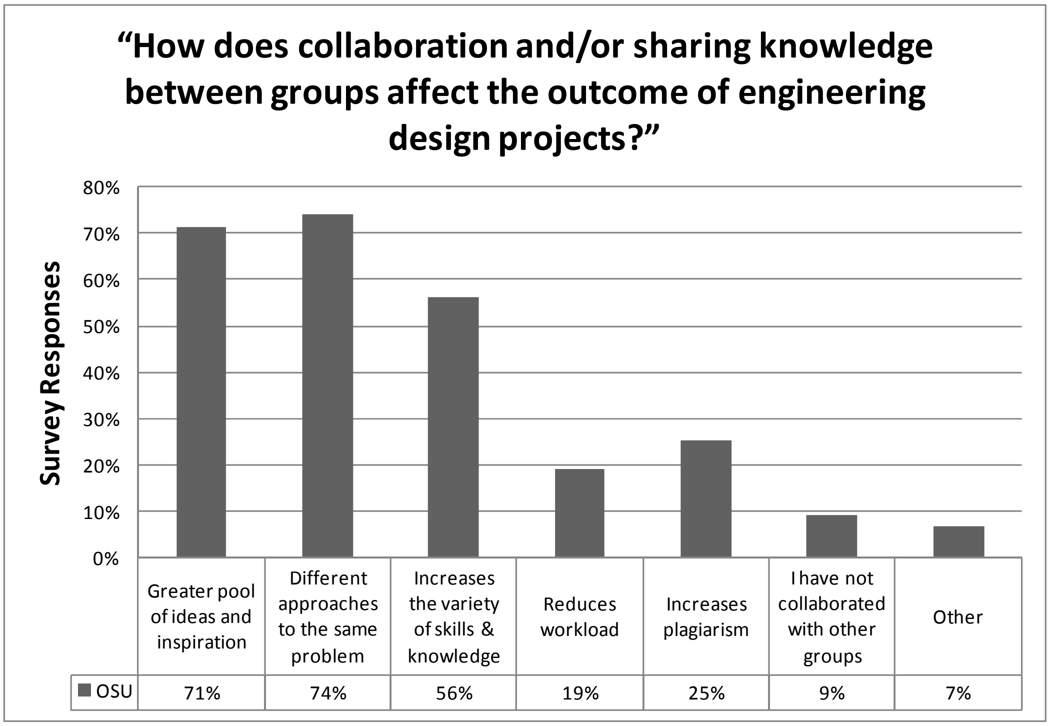

Figure 6 – Responses regarding perceived effects of between group collaboration and/or sharing knowledge on engineering design project outcome

In a specific group interview, one project team felt they had been cheated when they saw their design being built by another team without their permission. Though this was one of the only times such concerns arose during the study, it is a significant problem that must be addressed.

There were several important differences between and within the control and experiment groups. Teams from the experiment group that heavily used OpenPario (3+ times per week) found their teams to be more effective at design collaboration and sharing information both between and within groups when compared with those that did not utilize the optional tool (p=0.001,0.018,0.015, alpha>0.8). The responses from the groups that heavily used Open Pario are depicted in Figure 7, with the horizontal axis representing an individual group. The graph's legend represents the seven topics students were surveyed on regarding their group's effectiveness in the following areas:

- Sharing information between groups
- Sharing information within the group
- Design collaboration
- Meeting project & class deadlines
- Face to face communication
- Following through on tasks
- Designating and managing tasks

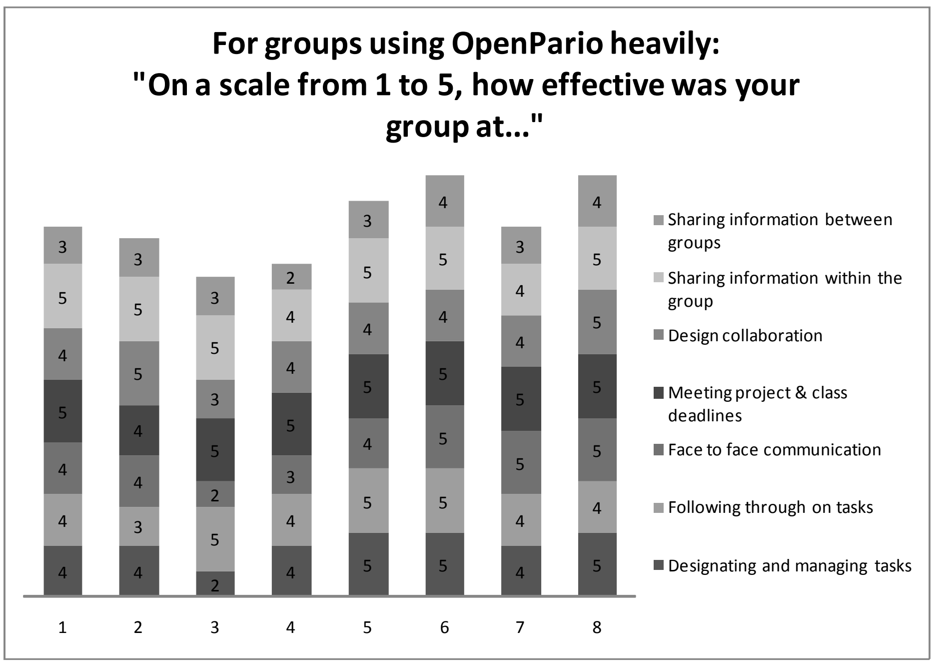

Figure 7 – Responses from 8 groups who used Open Pario heavily and how effective they were at specific group tasks

Answers were on a scale of 1-5, one being "Very Ineffective" and five being "Very Effective".

On the other hand, teams that heavily used the wiki did not feel that they were more effective in these three areas of collaboration (p=0.34,0.12,0.11).

The reasoning for this may lie in information gleaned from the interviews in that many students felt that while the wiki platform is a great tool for asynchronous collaborative text editing, a wiki's utility is limited when synchronous applications would be more effective (i.e., Google Docs). In other words, when students wanted to collaborate on the document simultaneously, they could not because the wiki only allows one editor to use it at a time. In this course, students were asked to use the wiki for things such as file upload and final document preparation. While the wiki is capable of such utility, there are other tools that can more efficiently perform such tasks. As such, Open Pario offered the ability for more organized file upload and task tracking, tools that allowed students to better organize their projects and in turn, collaborate to finish their tasks effectively.

In general, those who heavily used OpenPario and the wiki also found it to be a very effective tool for collaboration in general (p=1.495e-06, 2.370e-07). This is important, as it shows students were able to grasp the benefits of such methods to aid in the success of their own projects.

When asked directly about whether students shared project information with another group, over 53% replied that they had. Of those students who shared project information with other groups, the most common methods for sharing was during shop time, during class and lab, outside class and generally just face-to-face. This is graphed below in Figure 8. Students felt this was most effective, as opposed to looking at other groups' wikis because they could get quick answers and many groups had little issue with sharing. However, there were several groups that felt keeping their information private was the best choice and did so by manually removing outside team members from their OpenPario member page.

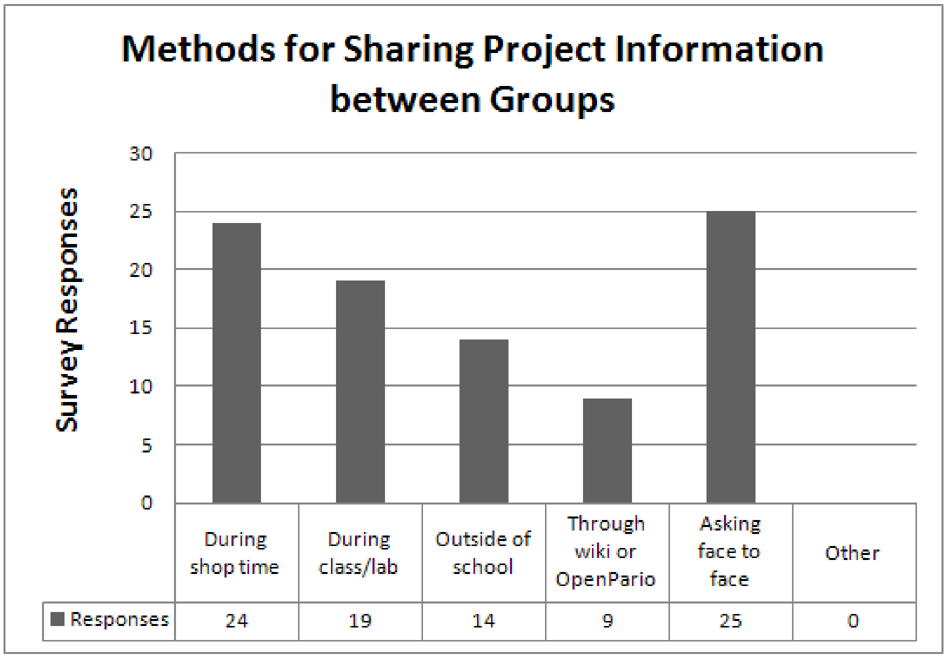

Figure 8 – Responses regarding "Methods for sharing project information"

Finally, when surveyed regarding perceived barriers to collaboration between groups, student's responses pointed to several key areas shown in Figure 9. The three main barriers were: lack of communication, lack of willingness to collaborate and lack of knowledge regarding class policy that allows collaboration between groups. In addition, several students pointed out in "Other" responses that the idea of competition for grades caused their groups not to collaborate.

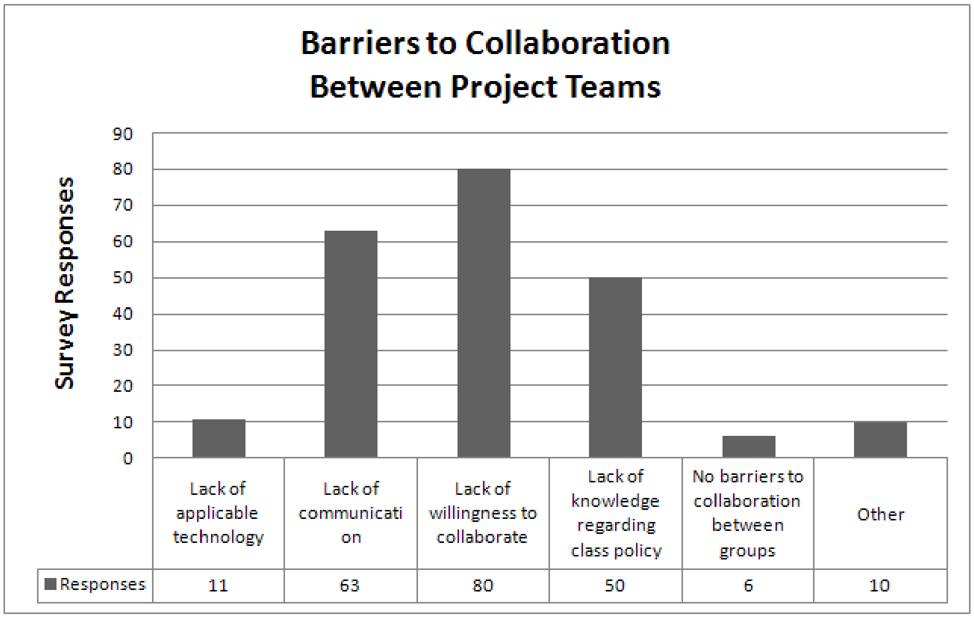

Figure 9 – Barriers to Collaboration between Project Teams

4.5.2 Future Iterations

There were several limitations to this study. The pool from which students were sampled was from one specific class at Oregon State University. In addition, the students were almost always collocated, so the conclusions on the effects of distributed design are minimal. For future iterations of this research, we are looking into conducting the study at multiple universities with project teams consisting of members from each school. This will allow for a more robust analysis of distributed design work in an educational setting and provide metrics and feedback on how such a project environment can be best structured to bring out the most in students' ingenuity, creativity and critical problem solving.

4.5.2.1 Social Network Analysis

Following consent from both the experiment and control groups, a data log of both the wiki and Open Pario was kept to gain insight into how the students utilized the various web base collaboration tools. This was done using an Apache server log for the wiki, and for Open Pario there was an extension to the Redmine architecture that kept a log of each clicked link which was tied to an arbitrary key for each user. The goal of collecting this data was to see exactly how the students used the websites and how the control and experiment groups interacted with the site differently. The basic concept is depicted in Figure 10 as data would show specifically which page users were visiting, and whether it was their own team's page or that of a different team that they were not part of.

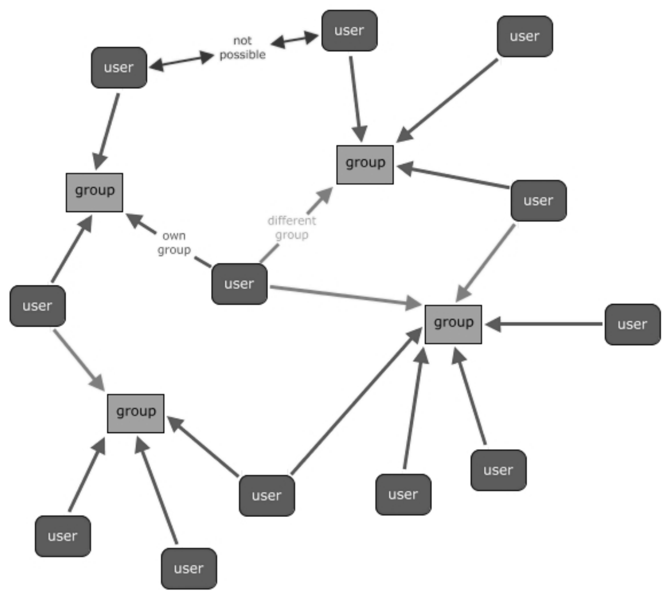

Figure 10 – Graphical depiction of Social Network Analysis of Student Use of the Wiki

This was to be analyzed using Social Network Analysis as a method of understanding these interactions in depth [42],[43]. Specifically, the statnet package in R, an open source statistical application, would run the analysis [44],[45]. The assumption was that teams from Labs B and C would take the opportunity to look at other project teams' pages as a way to help them develop their own project.

Issues arose late in the experiment that made this rather difficult. First, when collecting data, we did not limit data collected to only students in our research groups, but rather data was collected on all site users. This was true for both the wiki and Open

Pario, and was problematic as our datasets contained information that was irrelevant to our study. This was fixed through the use of Perl scripting. More importantly (and most detrimental), the usernames stored in the Apache log for the wiki were encrypted, obfuscating the usability of this dataset for any sort of Social Network Analysis. Similarly, the data for Open Pario did not allow for easy distinction of which group pages users were looking at. For future iterations of the study, these issues will be fixed and ensure that the data is output in a fashion that is usable, possibly even running it through a web-application for pre-analysis [46]. New data will be collected using Open Pario that will allow for proper analysis of site usage.

4.6 Discussion

Throughout, many students indicated in interviews and in the surveys that they would have enjoyed and benefited from a more collaborative project environment. However, various academic, technical, and logistical issues arose that caused intergroup collaboration to be deemphasized. Most of these concerned proper training and familiarity with tools, a class structure that facilitates and/or rewards intergroup collaboration and promoting a spirit of group collaboration.

To mitigate such issues, there are several key practices that should be considered to ensure that students are prepared to engage in a more open and collaborative environment.

A thorough and effective approach to training in the use of collaboration tools such as Open Pario or wikis is crucial for students to be able to effectively use these tools as well as grasp how they are useful to project management and engineering design. This should include in-depth documentation, demonstrative resources and other references for students and outside users to refer to when questions arise. If possible, this should be done in a lab setting, rather than in a lecture, so that examples and general usability of the tools can be explained in a more operational context.

Additionally, requiring students to use the tools in practical capacities to complete assignments is helpful. However, keeping the number of tools to a minimum is crucial, especially when those tools are unfamiliar to the student, are incompatible with commonly used commercial platforms or when software is not stable for academic use.

Also, one should seek out software that is interoperable with already prominent group collaboration tools, such as email, word processing and are intuitive in conjunction with non-software based approaches such as group meetings, in-lab collaboration, and other hands on settings. Bridging the gap between distributed knowledge sharing capacities and the efficiency and efficacy of co-locative collaboration will be crucial in ensuring that collaborative technology will effectively augment, not inhibit, the avenues through which students already effectively collaborate.

Providing academic guidelines related to intergroup collaboration and knowledge sharing, especially around plagiarism, must be clearly defined. As is the case in the classroom and in industry, many feel the need to keep their information closed or proprietary, when often it is more advantageous to share that information and gain feedback from others. Making sure students understand such ideas is critical to breaking down barriers that hinder collaboration and innovation.

As such, clarification over what constitutes sharing knowledge and what constitutes plagiarism must be clearly defined. The point of sharing knowledge is to foster more intuitive ideas, stemming from a wider pool of knowledge, intellect, and perspective. However, when it goes beyond inspiration and borrowing ideas with consent, students begin to tread much more blurred territory.   Overall, about 25% of the students felt that intergroup collaboration could increase plagiarism, indicating that it was a significant concern that might not only have led to less students being forthcoming about their progress and approaches, but at the same time less willing to take inspiration from others for fear of academic reprimand.

Indeed, one might want to address the curricula itself and see where more opportunities can emerge to promote intergroup collaboration among students. Promoting such a spirit of intergroup collaboration among students, and actively seeking pathways towards more integrated design environments is key for building an atmosphere that promotes open collaboration. As seen in the results, those groups that did take advantage of the provided tools found themselves more effective at collaborating and sharing knowledge in general. However, the number of groups that did take advantage of such opportunities were minimal. To mitigate this, barriers discussed previously should be addressed more thoroughly with students to ensure that a collaborative and open environment emerges in the future.

As a solution to this, we have been asked to develop a protocol for the use of collaborative software tools for engineering design course applications. We hope that by extending this protocol to professors and providing the appropriate educational and referential materials, our colleagues will have the tools to be more effective in engaging their engineering design students in a more open and collaborative project setting. To aid in this, the previous experiment will be run in varying capacities at Humboldt State University to further hone understanding of such topics and their relation to engineering design.

4.7 Conclusion

As the world quickly becomes more interconnected and teams more distributed, the ability of students to effectively collaborate, share knowledge and do so in web-based environments is critical to both their education as well as to the sustainability of the engineering field. Drawing parallels with the future of open innovation in engineering design and the results discussed above, it becomes apparent that the need for integration of such principles into design education is critical in advancing innovation in engineering design. In the end though, more open and collaborative methods will not only benefit engineering, but will allow for increased efficiency and productivity as the ability to share information becomes easier by the day.

4.8 Future Work

In order to advance the understanding of collaboration and knowledge sharing in engineering design, particularly in design education, the next step will be running a similar experiment with a class of distributed design teams. This is important as the dynamics of distributed teams controls for face-to-face interactions, and limits a number of traditional tools that are available to the collocated team (i.e. whiteboards, meetings, etc). Similarly, our team will be compiling a paper regarding more specific uses of emergent web-based tools and how they are pertinent to engineering design, both in academic and non-academic settings. As such, the ability of such tools capture this knowledge and make it usable for future users is of utmost importance. Taking cues from software development, our team is looking at the use of distributed files repositories such as Git as an advanced method of archiving and sharing knowledge for future use [47].

Additionally, to better understand the dynamics of how such teams operate, a survey geared towards open source hardware teams is being organized to gauge how engineering teams found outside of traditional organizations operate, collaborate on projects and what tools they use to accomplish such tasks. As part of this, more robust data collection methods will be used to collect information on how teams operate in such web-based environments.

Finally, developing protocol for use of wikis and OpenPario in the classroom, as well as training materials, will be important in conveying why such tools are important to engineering design and how they can most effectively be used.

4.9 Acknowledgements

Our team would like to thank the following for their help and support: National Science Foundation, Award Number 0742698 for financial support; Daniel Smith of BioPUG for help with processing the server logs; Dr. Denise Lach for her help in designing the interviews and surveys; Dr. Robert Stone for allowing us to run these experiments on the ME382 class; Kerry Poppa and Anthony Nix for setting up the wiki for the different treatment groups, and also gathering server log data for us; Yousef Alhashemi for installing, maintaining and modifying the Open Pario site, as well as developing the modules needed to collect site usage information.

"On the Utilization of Web-Based Collaboration Tools By Student Design Teams"

Michael D. Koch
Graduate Research Assistant
Department of Mechanical, Industrial and Manufacturing Engineering
Oregon State University
Corvallis, Oregon, USA
Email: kochm@engr.orst.edu

Lonny Grafman
Instructor
Department of Environmental Resources Engineering
Humboldt State University
Arcata, California, USA
lonny@humboldt.edu

Irem Y. Tumer
Associate Professor
Department of Mechanical, Industrial and Manufacturing Engineering
Oregon State University
Corvallis, Oregon, USA
Email:irem.tumer@oregonstate.edu

Richard J. Schulte
Program Coordinator
Open Design & Manufacturing Research Group
ReRooting Collaborative
Cleveland, Ohio, USA
Email: Richard.j.schulte@gmail.com

Proceedings of the ASME 2010 International Mechanical Engineering Congress & Exposition
IMECE 2010
November 12-18, 2010, Vancouver, British Columbia, Canada

IMECE2010-39207

5.1 Abstract

Over the last couple decades, the engineering world has seen a steady increase in collaboration and knowledge sharing through predominantly web-based means. Facilitated by a growing number of tools that allow for data and knowledge to be easily transferred, the technological landscape that organizations operate in is completely different than even a couple years ago. Specifically for engineering design, mainstream tools such as email, forums and wikis have been researched in both a professional sense as well as in design education. The following paper looks to build off these studies by identifying and studying the wide range of tools that engineering students utilize on their own accord to collaborate and progress towards finishing a design project. Specifically, mechanical and industrial engineering students enrolled in introductory design courses at Oregon State University and Humboldt State University were observed, interviewed and surveyed regarding these topics. The following will outline the findings from this study, with hopes that this work can help others in the design education field better understand and make better use of the tools that students prefer to use. Also, as the next generation of engineers moves onto professional careers, the ability of engineering firms to understand how the younger generation collaborates and communicates will be important in shaping how engineering firms efficiently utilize new web-based tools in engineering design.

Keywords

Collaboration, Knowledge Sharing, Computer Supported Cooperative Work, Design Education, Wiki,

5.2 Introduction

In the past couple years, the internet has become increasingly pervasive in the daily lives of students and engineers as a method of communicating, collaborating and sharing information in various realms. Whether it is sending files and meeting updates through email or using advanced tools like distributed repositories to remotely edit project files, the internet has exploded as the predominant medium for successfully working on and completing engineering projects, both in the classroom and in the workplace. Based on recent studies [48], this trend does not show any signs of slowing down and with the increasing adoption of smartphones and mobile internet, such technologies are becoming ever more ubiquitous.

As such, the integration and utilization of such tools into all aspects of design engineering education is important for preparing students for careers that increasingly rely on such tools throughout the entire engineering design process. The following paper will look at the use of such web-based collaboration tools as they relate to engineering design education. Specifically, a comprehensive study was performed on a junior-level design course at Oregon State University and on a sophomore-level design course at Humboldt State University. Both classes were tasked with finishing and building a design by the end of the academic term while using various web-based methods to collaborate on and share knowledge to complete the project.

5.3 Background & Motivation

Currently, much of the research regarding the use of web-based tools in engineering education has focused predominately on the use of a specific tool (i.e., wikis, forums) and how students utilized said tool in the design process. Wikis, a web-based asynchronous authoring environment that allows users to create and edit documents online [49-51],[32],[30], garnered significant attention in the research literature. Specifically, McGaughey and Michalek found wikis to be helpful in course management as well as enhancing student interaction for a number of reasons. These included their ability to be customized, easily accesible, have a low-learning curve, capture knowledege, log activity, amongst other features [29]. However, as noted by Minocha and Thomas, many wikis are not as intuitive to users as desktop tools such as Microsft Word may be [33]. This is an important point to consider no matter what tool is being introduced to the classroom because if students spend most of their time struggling with buggy or unfamiliar software, the learning experience can be significantly hindered.

In addition to wikis, the use of forums as a method for collaboration and communication has also been covered in the research literature [52],[53]. Mostly being used in distributed settings, forums are extremely useful for facilitating discussions between students and faculty as well as cataloging information for future use. This can be advantageous as it allows students to communicate in a peer-to-peer fashion that is transparent, allowing other students to learn from each other and gain insight that might otherwise be missed when a student goes directly to a professor or other student for help.

In addition to these tools, the research literature does touch on the use of other emergent and disruptive technologies. Tools such as Google Groups and Documents, web-based project management tools like Basecamp, amongst others have been utilized in the classroom to aid in increasing collaboration, communication and knowledge sharing in the classroom [49],[31],[54],[55],[50].

While this research is useful, it is limited in that students utilize a wide-array of methods and avenues for collaborating on projects [56], and as such, past research can overemphasize the useful characteristics of a particular tool and how they relate to the design process. In order to mitigate such issues and take a broader look at the use of technology in the design process, the following research looked not only at the web-based tools provided to the students, but also delved into what students chose to use on their own accord. By taking this route, a more complete understanding of the tools and methods that students prefer to use in collocated settings to collaborate and share knowledge is reached.

As such, this paper builds off previous work by Koch, Schulte and Tumer that focused on collaboration and knowledge sharing in collocated student design teams [56]. Specifically, students at Oregon State were interviewed and surveyed regarding how effective their group was in regards to collaboration, the advantages of increasing intergroup collaboration, what barriers may exist to hinder such collaboration as well as the degree to which they collaborated with other groups. With this in mind, the following paper extends this previous work by looking at the second half of the interviews and surveys which focused more directly on the tools and methods that students utilized throughout the collaborative design process.

Below, we will attempt to outline the current state of the art for these tools and how design engineers can use these tools. The latter was accomplished by providing specific tools to undergraduate students in design classes and observing how each tool was used.

5.3.1 Open Pario Development

As part of this research, the team at Oregon State University has been developing a web-based platform to promote collaboration and knowledge sharing amongst engineers, particularly in the classroom. Drawing inspiration from the open source software movement and sites like SourceForge and GitHub [57],[58],[47], the original idea for this site, now known as Open Pario and found at www.openpario.net, was outlined in a previous paper by Koch and Tumer [22]. As that paper points out, there are several key features that such platforms need to be successful in promoting web-based collaboration amongst both collocated and distributed individuals and teams. As such, Open Pario allows users to start, organize, manage and collaborate on complex projects. Additional features include the following:

- Multiple project support
- Flexible role based access control
- Flexible issue tracking system
- Gantt chart and calendar
- News, document & file management
- Feeds & email notifications
- Per project wiki
- Per project forums
- Time tracking
- Custom fields for issues, time-entries, projects and users

The system is based on Redmine [34], a project management web application that was originally geared towards the software development sector. However, the core tools have proven to be powerful and highly useful in relation to project collaboration in the engineering world. Currently, the site has over 200 registered users and hosts over 110 projects with collaborators from a diverse background of experience, culture and location. In the realm of higher education, several universities are currently using the site in some form. Both Humboldt State University and Oregon State University are the focus of this particular study. In addition, students at Georgia Tech have taken up the site for use in graduate research in engineering and manufacturing policy.

In terms of groups operating outside traditional organizations in a more distributed and open fashion, several groups have began utilizing the powerful features of Open Pario for their development purposes. A sampling of such groups is outlined in Table 2.

Organization /Project	Focus	Users
Open Source Ecology	Open development of products for use in agricultural settings	10+
Appropedia	Design and planning for appropriate technology wiki	10+
Cubespawn	Small Personal Factories which make their own parts, and later make parts from the SKDB library	7
Lathe	Designing a Sliding Head Style CNC Lathe that is affordable, reproducible, modular, open source and non-intrusive	2
Energize Corvallis	Enabling neighborhoods to become energy independent	10+
Algae Photobioreactor	Design, build, and operate an open source algae photobioreactor to produce, market and sell bulk food-grade Haematococcus Pluvialis	2

Table 2 – Sample of groups using OpenPario for open design projects

As the use of Open Pario expands both within academic and professional settings, the Open Pario team plans to expand accordingly. Over the coming year, more replete resources on how to use the site in the classroom will be developed to help educators take advantage of the advanced features available in a method that is suitable to their teaching style. Additionally, we plan to expand use into more traditional and professional settings to help increase the collaboration points between seasoned engineers, students and hobbyists.

5.4 Methodology

In order to explore how students utilize web-based collaboration tools throughout the design process, several main questions were addressed to drive the subsequent research:

- How often were web-based tools used throughout the project?
- Were such tools and methods effective in promoting collaboration?
- In what capacity were such tools utilized?
- What past experience did the students have using such tools?
- Will students seek out the use of such tools in the future?

To delve into these questions, two studies were performed with undergraduate students enrolled in introductory engineering design courses, summarized in Table 3.

	Oregon State University	Humboldt State University
Professor	Dr. Rob Stone	Lonny Grafman
Course	ME 382	Engr 215
Grade Level	Junior	Sophomore
Projects	Autonomous Material Sorter	-Energy education boxes for K-12 -Design and improve upon structures in Haiti
Partners	ASME	-Redwood Coast Energy Authority -World Shelters
Teams	27 teams	9 – RCEA 6 – World Shelters 15 - Total

Table 3 – Information regarding student design teams in this study

The first study took place in Fall 2009 at Oregon State University in Corvallis, Oregon. The subjects studied consisted of junior level mechanical and industrial engineering students enrolled in ME 382, a project-based engineering design course. Twenty-seven teams were tasked with designing, building and testing an Autonomous Material Sorter as defined by the 2010 ASME Design Competition [35]. The goal of the project was to create a device that could accurately sort common recyclable materials, namely ferrous and non-ferrous metals, plastics and glass. Teams had a 7-week window in which to finish the project. Teams were created by dividing individuals into 3-4 person groups, creating 27 teams, then placing these teams into specific labs.

The second study took place in Winter 2010 at Humboldt State University in Arcata, California. The subjects consisted of sophomore level engineering students enrolled in Engr 215, also a project-based engineering design course [59]. The course was similar in structure to the Oregon State class, having a total of 15 teams. Nine of these teams were tasked with working with the Redwood Coast Energy Authority to develop energy education boxes to be used in K-12 schools. Topics focused on energy conservation, renewable energy and climate change. The remaining six groups worked to design and improve upon structures for humanitarian needs, specifically in Haiti. Projects focused on using appropriate technology to develop simple yet robust solutions for housing in developing nations.

To facilitate collaboration between the students, there were a number of methods available to the students. In both studies, similar tools were used with a few minor differences. At Oregon State University, students were first introduced to the use of wikis for project management, including file upload and document preparation. Once they were familiar with this, students were briefly trained on the use of Open Pario; however its use was optional for the students. As such, the wiki received the most attention as it was the required method for turning in assignments. Additionally, students had access to Blackboard, though in terms of a platform for collaboration, it was not utilized. At Humboldt State University, the Open Pario platform was introduced first to the students and was used most heavily for organizing and planning projects, uploading files and basic collaboration between group members. Later in the term, the students were asked to use the Appropedia.org wiki to formally document their projects. Appropedia runs on MediaWiki, the same web-application that Wikipedia is based on. In addition, students at HSU used Moodle, an open source Virtual Learning Environment [60], as a way to perform tasks similar to what Open Pario and the class wiki accomplished. This platform had been in place before Open Pario was introduced and was utilized primarily for checking assignments.

For the Oregon State University group, students were observed in several manners. First, computer software was used to track how students used the Open Pario website. Second, individual and group interviews were held to delve into how students collaborate, shared knowledge and utilized web-based tools to accomplish these means. Finally, a survey was administered to gather more quantitative data. For the Humboldt State University group, a similar survey was administered towards the end of the semester with minor changes that are discussed later.

When comparing the courses at both universities, the main method for collaboration and knowledge sharing between students at Oregon State was through the class wiki, while at Humboldt State it was through Open Pario. This will be an important consideration when analyzing how students used the tools later in this paper.

5.4.1 Experimental Design

In order to answer the questions posed earlier, the Oregon State University group was divided into a control and experiment group based on labs. Labs A and D made up the control group, and were required to submit assignments through the wiki with the option of using it as a collaboration tool. The content that they added to the wiki was not viewable by the other students. Labs B and C made up the experiment group and were also required to upload assignments via the wiki. In addition, these labs were introduced to Open Pario as a collaboration tool, with any content being uploaded to the wiki or

Open Pario being viewable by the others in Labs B and C. As such, the project team was the unit of analysis for this experiment.

The study at Humboldt State University was not divided into control and experiment groups. Rather, all students in the course were introduced to Open Pario, Moodle and Appropedia as methods of collaboration and knowledge sharing. There was no separation between project teams based on which tools they used besides those that arose naturally out of the student's preferences.

As such, the two main methods to better understand how students used such tools in the design process were through interviews and surveys. Specifics on how these were carried out are discussed next.

5.4.2 Group and Individual Interviews

The first step taken in the data collection part of this research was to interview the students who were using the tools in the classroom. Due to time and cost restraints, this was only done at Oregon State University, but was still helpful in driving the research at Humboldt State University. The research literature [37] and expert recommendation [38] suggests that interviewing is a strong method of collecting data, especially in this context. Beyond collecting qualitative data, these interviews were designed to drive the creation of subsequent surveys administered to students in both studies, allowing for quantitative data analysis.

To ensure a scientific sample, students were randomly selected from the entire class to be interviewed. A total of 32 students out of 125 were interviewed; 12 as individuals, 4 project teams (each having about 4 students) and 2 random groupings of students. After random sampling, each of the 4 labs was still represented in a fairly even manner. The interviews took on a semi-formal nature, with questions being outlined beforehand, but allowing for students to openly discuss their thoughts on the use of such tools in the classroom.

Below are several typical questions that were asked throughout the interview:

- How did you use the wiki & Open Pario for class?

- What past experience do you have with such tools?
- What other tools did you use to collaborate & share information? and how?
- Did the provided collaboration tools help/hinder? Will you use in the future?
- What do you feel is the most efficient way to manage projects? (i.e., face2face group meetings, email, wiki?)

From here, the questions diverged for the control and experiment groups, though in the context of the use of web-based tools, the difference was not terribly significant as the use of Open Pario was not mandatory.

To incentivize participation, extra credit was given to students willing to be interviewed. About 44 students were contacted, of which 32 participated.

5.4.3 Surveys

Building on the information collected during these interviews, a survey was developed that formalized the interview data in a form that could be analyzed quantitatively.

The survey consisted of 3 sections: Collaboration, Knowledge Sharing, and Tools. The focus of this paper is mostly on the Tools section. The results from the first part of the survey done at Oregon State University were published in a previous paper by Koch, Schulte and Tumer [56]. As noted before, the use of surveys as a method of understanding human activity is well understood and considered a standard method for such inquiry [37].

The Tools section consisted of the following questions:

- How often did you use each of the following group collaboration methods/tools?
    - Meetings, Email, Phone Calls, Texts, Wiki, Google Docs, OpenPario, Facebook, Instant Messaging
- Overall, how effective did you feel each of these methods were for collaboration?
    - Meetings, Email, Phone Calls, Texts, Wiki, Google Docs, OpenPario, Facebook, Instant Messaging
- How did your team use:

  - meeting times?
  - wiki?
  - OpenPario?
- Have you used wikis or other web-based collaboration tools in the past?
- Will you seek out the use of web-based collaboration tools in the future?
- Comments

For the Humboldt State University version of the survey, some minor changes were made. This included inquiring about the use of Moodle and how it was used in the design process. Also, more feedback was requested on how to expand the functionality of Open Pario so it is more useful to students, as well as an expanded section on how effective students perceived the use of certain tools was to the design process. Oregon State was asked only about email, wikis, Open Pario and meetings, while Humboldt State included all the tools and methods listed above.

These surveys were both administered on the final presentation days for the courses. This was meant to ensure that students were mostly done with the class, and had finished using the tools in the design context. At Oregon State University, extra credit was given for participation in the survey, resulting in 118 out of 125 students taking the survey. At Humboldt State, students were not required or incentivized to take the survey, but still resulted in 31 out of about 45 students participating.

The original surveys can be downloaded at http://openpario.net/documents/359.

5.5 Results

After analyzing the data collected from both universities, it was seen that in several dimensions, the way each class utilized the web-based tools were very similar, though there were several distinct differences. It should be noted that both classes were working in collocated settings. Because of this, the utilization of the web-based tools that were presented in this study will be significantly less than if these classes were operating in a distributed fashion (i.e., some students located at other schools). This is mainly explained by the fact that it is more efficient to work face-to-face when possible. This has been documented in the Computer Supported Cooperative Work (CSCW) research literature [23], and in many ways, has been supported by these studies.

5.5.1 Specifics

Overall, when students were asked how often they used a specific method or tool for collaborating on their design projects, both universities had high percentages of students that utilized text messaging and email 3 or more times per week. Directly related to the web-based tools that were presented to the students, Humboldt State utilized Open Pario very heavily with over fifty percent of students using it regularly, while Oregon State had a similar trend with forty percent using the class wiki. Surprisingly, Humboldt State students met far more regularly then Oregon State students, with a staggering 65% of students meeting over 3 times a week, while Oregon State students tended to meet less than twice to work on their projects. These results are summarized in Figure 11.

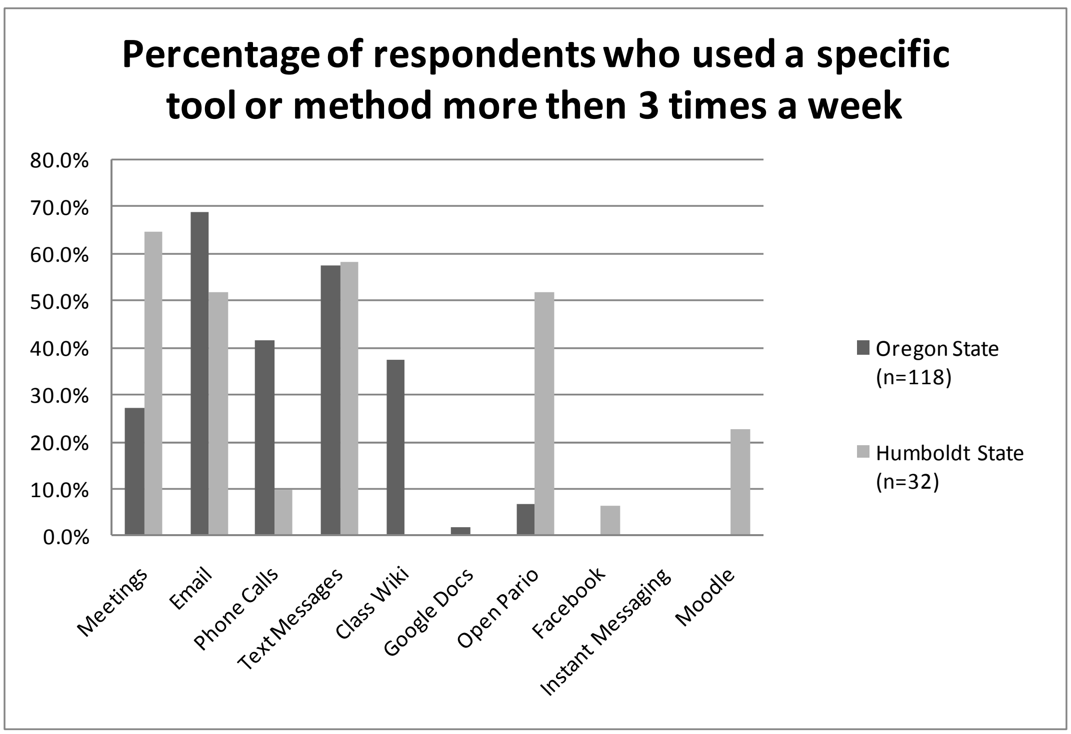

Figure 11 – Regular usage of specific tools & methods for design collaboration

In terms of how effective each group felt about such tools and their relation to engineering design, both groups came to similar conclusions regarding the use of meetings and emails. However, in regards to the main web-based tools used at each school, there was obvious disparity. As seen in Figure 2, the majority of students at Humboldt State found Open Pario to be effective or very effective throughout the design process. On the other hand, less then forty percent of Oregon State students found using a wiki as adequate for design. This was a common concern for OSU students who felt the basic wiki fell short of the tools necessary to facilitate collaboration on design projects.

The results below were adjusted to take into account students that answered “not applicable” to using a certain tool to keep from skewing the results. Also, as Figure 12 shows, Humboldt State was surveyed on a wider range of tools then the Oregon State students.

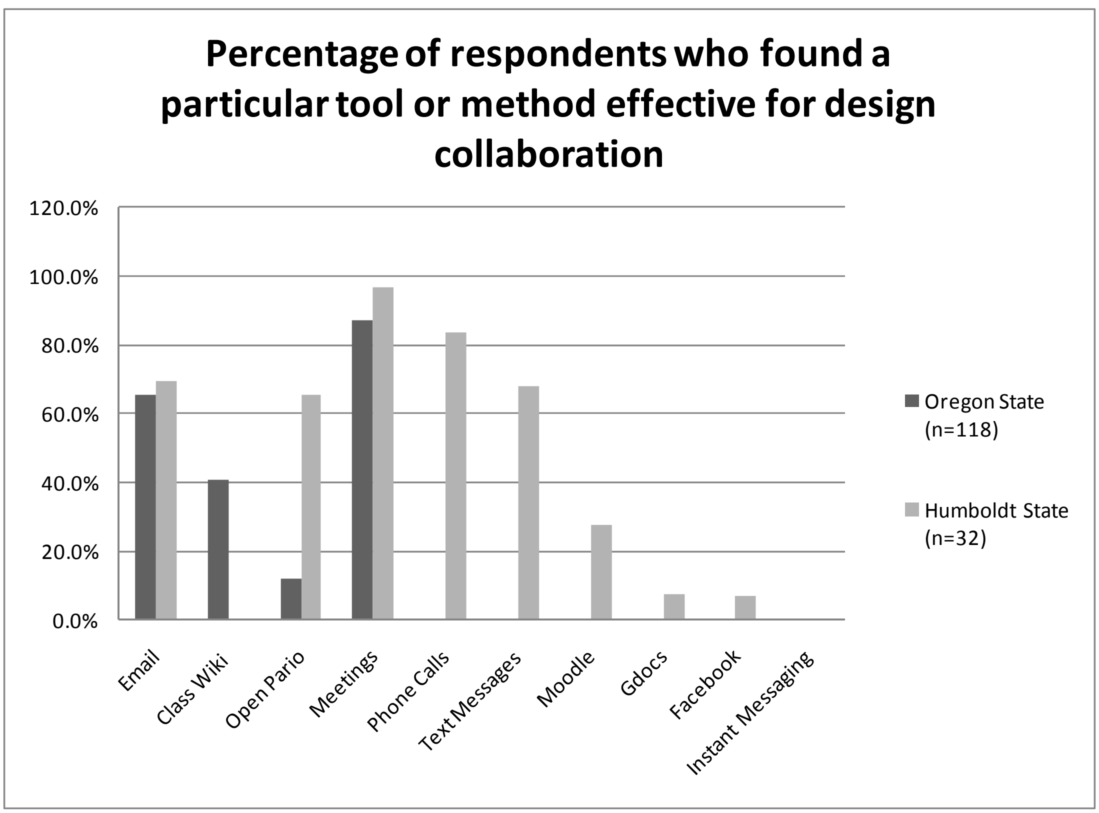

Figure 12 – Respondents who found specific tools effective for design collaboration

Following up on how students utilized several of the tools, we asked specifically how students utilized their meeting times. Common throughout both schools was the division and delegation of tasks to various students. In the interviews at Oregon State, it was reiterated that often due to time constraints, student groups would simply meet to figure out what their responsibilities were for the week, then go their separate ways.

However, the results in Figure 13 imply that students at Humboldt State utilized their meeting times in a more effective manner than Oregon State students, using much of the time to work on tasks and compile reports.

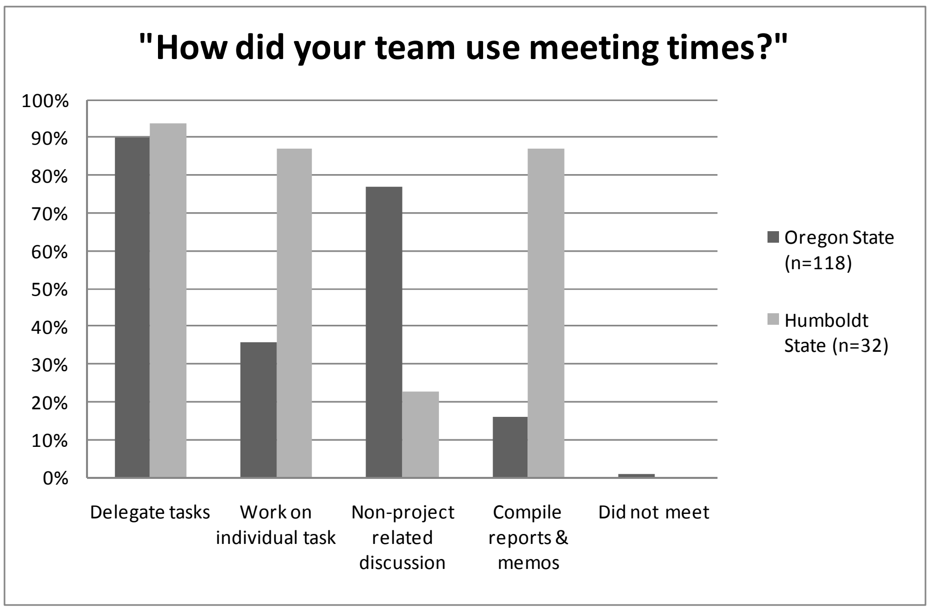

Figure 13 – How groups utilized meeting times

Similarly, students were asked about how their team utilized the various web-based collaboration tools provided to them. Specifically, Oregon State students were queried about the use of Open Pario and the class wiki, while Humboldt State students were surveyed regarding their use of Moodle and Open Pario.

In Figure 14, one can see that students at Humboldt State utilized Open Pario and web-based tools much more than their counterparts at OSU, with almost eighty percent of the class using it as an online storage and organization hub for their design files. In addition, over half the class utilized it to plan and manage their projects. Less than twenty percent of HSU students did not utilize the site at all. On the other hand, Oregon State utilized the wiki for storing files, but to a lesser degree with about 45% reporting usage.

Based on how files were requested to be submitted, students at OSU and HSU used the class wiki and Moodle to submit homework. About 20% of HSU students claimed to draw inspiration from other groups through Moodle, which is a significantly higher figure when compared to the other 3 statistical groups. Moodle was used for some project planning and management, but to a much lesser degree then Open Pario.

Additionally, HSU students reported using Dropbox.com for file sharing and collaboration. This program works by creating a virtual file system so that documents can be easily synced between computers and shared between multiple users, allowing for seamless file collaboration. Four groups out of 15 reported using it with great success during their projects.

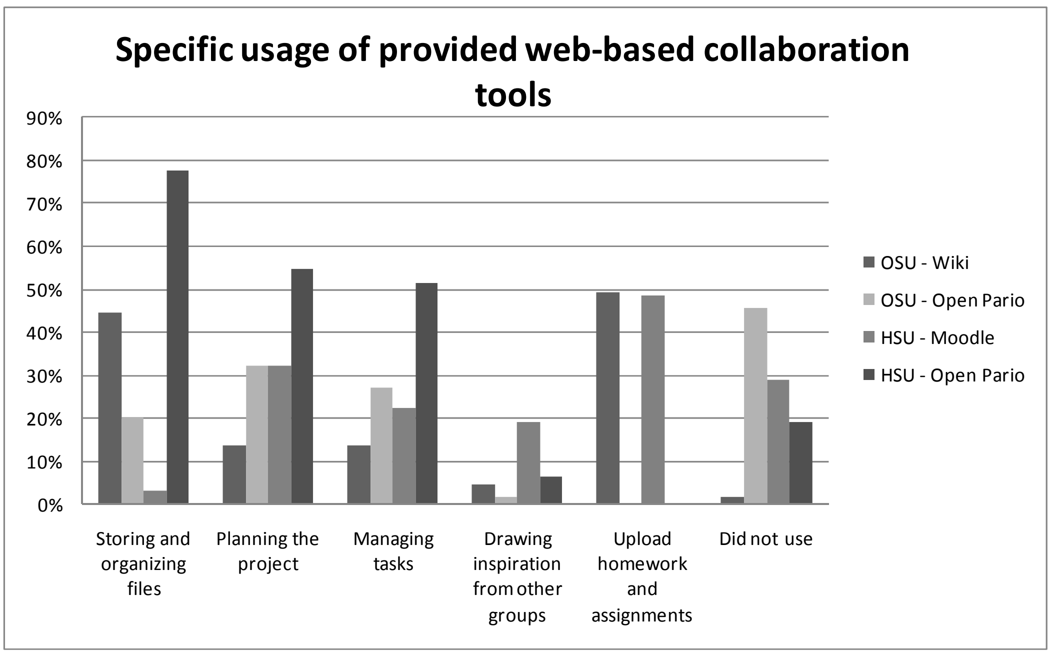

Figure 14 – Usage of provided web-based collaboration tools

Finally, students were surveyed to gauge their experience using web-based collaboration tools. About 22% of students at Oregon State claimed prior experience with such tools, while Humboldt State was nearer to 40%. However, when asked whether they would seek out such tools for use in future group projects, Oregon State reported 69.5% saying they would, while Humboldt State showed 64.5%. These figures are depicted graphically in Figure 15.

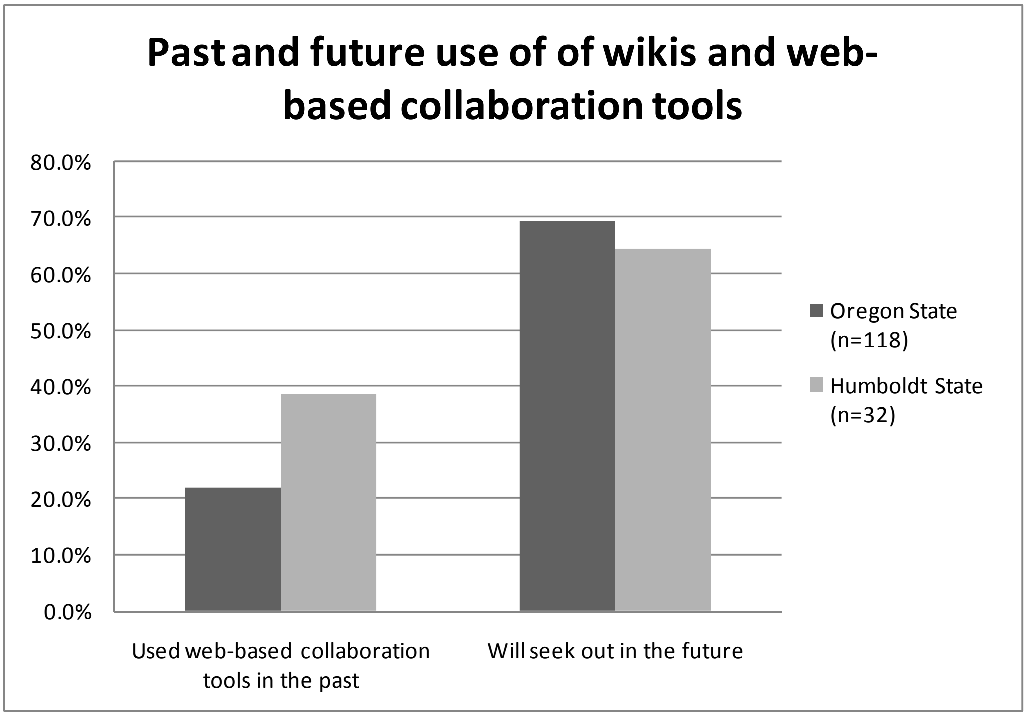

Figure 15 – Past and future use of web-based collaboration tools

5.6 Discussion

From the aforementioned results, there seem to be several takeaways that can be outlined.

First, the tools that are provided to students for use in the classroom must be meant to directly accomplish what students are required to use them for. In the case of the wiki at Oregon State, students were required to use it for document preparation and file upload. Many struggled with this as most wikis are not great for final document preparation or even file upload, but rather for simple text editing. This became an issue for many when trying to add pictures and other media content through the web-based editor which could not easily handle this task. Since the majority of Oregon State students utilized the wiki only, this was a problem that was present throughout most of the responses. On the other hand, Humboldt State utilized Open Pario more fully with differing results. Since Open Pario is based on Redmine, an open source software engineering project management tool, the issues regarding usability complaints were almost non-existent. Issues regarding file upload and document preparation were avoided as the software utilized kept the tasks of document preparation and file upload separate. The OSU wiki tried to combine the two features creating problems.

The key take away from this is that choosing tools appropriate to the task is of utmost importance. In this research, we found that tools developed for software engineering design tends to be very robust since it is developed by software engineers for software engineers. Additionally, tools that are open source tend to be more robust as there is a often a community in place to keep updating and fixing bugs that might arise, something that can be problematic when using enterprise software. From our research thus far, using Open Pario as the basis for organizing the student projects, even in collocated settings, can be very successful as long as proper training is performed and the number of outside tools is limited to reduce confusion.

Additionally, introducing tools such as wikis, file upload repositories and related web-based collaboration tools early in the education process is important. Students at Humboldt State University reported utilizing Appropedia.org in the past, a wiki geared towards sustainable technologies, and seemed able to pick up such tools with little training. Oregon State students on the other hand had little past experience, and as such, tended to struggle with adopting new technologies, which was confirmed by teaching assistants. This might have been confounded by the fact they were introduced to multiple software packages too.

In addition to offering increased collaboration between students and making project management throughout the design process much easier, the subject of design reuse and keeping a repository of past knowledge should be noted. By using such tools as Open

Pario or wikis, a living database can begin being constructed from which future students can refer too and gain insight for their own design projects. At Humboldt State, the Engr 215 class has digital documentation of student projects all the way back to 1995 in regular website form, and back to 2005 in wiki format (thru Appropedia.org). Students felt having access to such documentation was very beneficial as it allowed them to learn from what past students had done, even if it was something as simple as formatting a memo. And the reality is that doing this is fairly simple as long as the proper tools are used from the outset. For Oregon State, the wiki can be easily used to show future students what past groups did in a similar fashion to what Humboldt State has implemented.

As such, the need to institutionalize such web-based platforms looks to be both an important and fairly straightforward step that engineering design courses should look into. It is preferable that all steps of the design process can be catalogued so that students can look at the whole process that students went thru, making a system like Open Pario, which catalogs all activity including files uploaded, wiki changes, task completion, amongst others, seem rather useful. Wikis have similar functions that might be suitable depending on the situation. Since many of these software packages are free and open source, the ability of universities to implement such programs should be fairly straightforward. As a service to the community, both Appropedia and Open Pario are free to use, making them great testing grounds for universities that are interested in using such software for their own purposes. These sites can be located at **www.appropedia.org** and **www.openpario.net**.

As part of this study, feedback was gathered on how to improve the tools for students in engineering design with most focus being on Open Pario. Use of the tool in engineering design will continue at Humboldt State and possibly at Oregon State. The goal is to continue to understand what engineering design students need to aid in project collaboration and expand the set of tools found within the package to aid in this process. Currently, most of the feedback centered on usability requests, but as more features directly related to the design process are implemented, more changes and updates will be imminent.

5.7 Conclusion

The world that engineering design students are entering upon graduating is advancing and changing at a rapid pace. The exchange of ideas and distributed nature of the professional work place continues to grow due individuals to easily connect and communicate in ways like never before. No longer is it sufficient to just be fully versed in the principles of engineering, but students must be prepared to collaborate and work in teams that bear little resemblance to what engineers of the past were accustomed too. Because of these changes, the nature of design education must also keep pace to ensure that students are prepared to deal with and operate in these fairly new and exciting environments.

As such, this paper presented several practical steps that design educators and professionals can take to integrate emergent web-based technologies into the classroom or workplaces and the benefits that doing so can yield. By looking not only at tools provided to the students, but also trying to better understand how students choose to collaborate on their own, a more holistic view of the design process has been analyzed. Of course, each situation is unique with different needs and protocol that must be met, and because of this, educators and professionals must be willing to continuously experiment and improve upon their approach until a successful solution is found for their situation.

5.8 Future Work

In order to advance the work in this area, research will continue into how such tools can be used in engineering design. Specifically, the expansion of Open Pario to be more directly useful to engineering design in terms of the tools that are available to students and engineers is being explored. Already there are a large number of tools geared towards software development that are available as plug-ins and just need to be installed. Also, better understanding how the use distributed repositories such as Git will be looked at as they continue to grow in popularity in the software design realm.

As part of this, developing training materials in the form of wiki documentation and online streaming videos are in the planning stages. Such tools are important as many students and people in general look to the internet when they want to learn something new, especially if it has to do with software. Creating such tools will make the training process much easier as more engineering students start using the site, as well ensure that the importance and usefulness of such tools are conveyed.

Finally, gaining a better understanding of how such platforms can tap into the wider network of engineers, students at other schools and hobbyists is important for giving students outside outlets to discuss engineering problems and grow their knowledge.

5.9 Acknowledgements

Our team would like to thank the following for their help and support: Richard Schulte for his expert advice and contributions to the design of this study as well as previous research; Dr. Denise Lach for her help in designing the interviews and surveys; Dr. Robert Stone for allowing us to run these experiments on the ME382 class; Kerry Poppa and Anthony Nix for setting up the wiki for the different treatment groups, and also gathering server log data for us; Douglas van Bossuyt, Sarah Oman and Mike Koopmans for helping with logistics in the ME382 course; Yousef Alhashemi for installing, maintaining and modifying the Open Pario site, as well as developing the modules needed to collect site usage information.

6 Conclusion and Future Directions

As seems obvious, one of the most fast paced and rapidly changing parts of human life is the methods and tools through which we collaborate and share knowledge. For the most part, many of these activities now take place in some sort of Internet enabled environment. Whether it is uploading CAD drawings to a web repository or emailing meeting directions to a client, engineers spend much of their time communicating, collaborating and sharing knowledge through this medium. Due to constant innovation in this area, email is no longer the sole medium, but more advanced tools such as wikis, distributed repositories, social networking sites and mobile internet continue to push the envelope on how connected we can be in our daily lives.

Because of this rapid innovation, engineering design education must be able to keep pace with such changes to ensure that students are prepared to deal with and understand how to use various tools in the workplace. No longer is it sufficient to teach only engineering principles. Rather, students must feel comfortable operating and collaborating with individuals that they may never see face to face.

As such, this thesis aimed to broadly focus on understanding how students collaborate, communicate and share knowledge throughout the design process and what methods and tools they use to accomplish these tasks. It was found that there are a number of methods used including texting, meetings and web-based platforms, each having its own unique place in helping the students complete their projects. With specific focus on web-based tools, creating mechanisms for easy online file storage can aid students when they are coordinating complex projects as well as archiving such knowledge for future students' utilization. Such platforms are becoming ever more ubiquitous, effectively lowering the barrier for educators and professionals looking to utilize such tools for their own use. As part of this, ensuring that students understand classroom policy in regards to collaborating with other groups is key as information because more openly and publicly available. Understanding the difference between plagiarism and drawing inspiration was a topic that came up, especially as groups were given access to each other's information. As such, the need for having policy in place that helps to guide students was found to be an important aspect as the use of such tools and methods becomes more commonplace.

In terms of future work in understanding collaboration and knowledge sharing in engineering design, there are several areas of focus that should be looked at to extend this work. First and foremost, there is much more that can be learned from the software design and development world, especially in open source, as much of the collaboration occurring relies on advanced web-based solutions. Some of these tools, like wikis for text editing or Open Pario for task and file management, were looked at in this research. However, there are other more advanced tools that should be considered. Specifically, the use of distributed repositories, such as Git, have been playing a significant role in software development. Basically, Git allows for users to access and work on project files without having to rely on a central server or internet access. Once changes are made, they can be merged back into the main project files or kept separate. Many top software projects now rely on Git, and its uses in engineering design look to be very promising. However, as they are rather advanced, special consideration should be given to training and making sure students are competent utilizing such tools.

Related to this, surveying those working in the open source software and hardware realms will be important for understanding how groups can operate outside the confines of a traditional organization. Such insight could possibly lead to a deeper understanding of design collaboration, especially since many participating in such projects make heavy use of web-based collaboration methods and may only know each other through electronic communications. As part of this, mapping out interactions that occur in such online communities as well in collocated settings will be important to understanding exactly how students, professionals and others make use of such platforms. Plans to do such an analysis are underway and should be finished by summer of 2010.

Finally, running experiments with students in distributed locations would allow for a better understanding of the power of such web-based tools. Ideally none of the students participating would be collocated to control for face-to-face interaction, but logistically this may be difficult. Rather, it seems that getting a school to partner with another school and have projects split between students at both institutions would work well. This would open up many possibilities in broadly looking at the differences not only between collocated and distributed design, but also how variables like culture affect the design process.

In the end, there is a multitude of directions such research could take, and with the rapid innovation and changes occurring in this realm, the number of areas that must be better understood will continue to grow. As such, it is the author's belief that this area of research will continue to be of utmost importance to the design engineering field.

Bibliography

[1] Y. Benkler, “Coase's Penguin, or Linux and the Nature of the Firm,” *Yale Law Journal*, vol. 112, Dec. 2002, pp. 369-446.

[2] J. Pearce, L. Grafman, T. Colledge, and R. Legg, “Leveraging Information Technology, Social Entrepreneurship, and Global Collaboration for Just Sustainable Development,” *Proceedings of the NCIIA 2008 Conference*, pp. 201-210.

[3] F. Machlup, *The Production and Distribution of Knowledge in the United States*, Princeton University Press, 1973.

[4] C. Savage, *Fifth Generation Management, Second Edition: Dynamic Teaming, Virtual Enterprising and Knowledge Networking*, Butterworth-Heinemann, 1996.

[5] P. Drucker, *Landmarks of Tomorrow: A Report on the New "Post-Modern" World*, Transaction Publishers, 1996.

[6] G. Morgan, *Images of Organization*, Sage Publications, Inc, 2006.

[7] R.H. Coase, “The Institutional Structure of Production,” *The American Economic Review*, vol. 82, Sep. 1992, pp. 713-719.

[8] E.S. Raymond, *The Cathedral & the Bazaar: Musings on Linux and Open Source by an Accidental Revolutionary*, O'Reilly Media, Inc., 2001.

[9] P. Meyer, “Episodes of Collective Invention,” *U.S. Bureau of Labor Statistics*, Aug. 2003.

[10] A. Kusiak, *Concurrent Engineering: Automation, Tools, and Techniques*, Wiley-Interscience, 1992.

[11] S. Weber, “The Political Economy of Open Source Software,” *BRIE Working Paper Series*, 2000.

[12] S. Weber, *The Success of Open Source*, Harvard University Press, 2005.

[13] C. Shirky, *Here Comes Everybody: The Power of Organizing Without Organizations*, Penguin (Non-Classics), 2009.

[14] “Open system - Wikipedia, the free encyclopedia.”

[15] Netcraft.com, “Web Server Survey Archives,” *http://news.netcraft.com/archives/web_server_survey.html*, Dec. 2008.

[16] Netcraft.com, “Web Server Survey Archives,” *http://news.netcraft.com/archives/web_server_survey.html*, Dec. 2008.

[17] D. Tapscott and A.D. Williams, *Wikinomics: How Mass Collaboration Changes Everything*, Portfolio Hardcover, 2006.

[18] C. Leadbeater, *The Rise of the Amateur Professional*, Oxford, England: 2005.

[19] R. Vallance, “Open Design FAQ,” *http://www.engr.uky.edu/psl/omne/OpenDesignFAQ.htm*, Dec. 2008.

[20] H.W. Chesbrough, *Open Innovation: The New Imperative for Creating And Profiting from Technology*, Harvard Business Press, 2005.

[21] Y. Benkler, *The Wealth of Networks: How Social Production Transforms Markets and Freedom*, Yale University Press, 2007.

[22] M. Koch and I. Tumer, “Towards Open Design: The Emergent Face of Engineering,” *Proceedings of the International Conference on Engineering Design*

2009, Stanford University, .
[23] R.M. Baecker, *Readings in human-computer interaction*, Morgan Kaufmann, 1995.
[24] S. Finger, D. Gelman, A. Fay, M. Szczerban, A. Smailagic, and D.P. Siewiorek, “Supporting collaborative learning in engineering design,” *Expert Systems with Applications*, vol. 31, 2006, pp. 734-741.
[25] S. Oberoi and S. Finger, “DesignWebs: Towards the creation of an interactive navigational tool to assist and support engineering design learning,” *2009 ASEE Annual Conference and Exposition, June 14, 2009 - June 17, 2009*, Austin, TX, United states: American Society for Engineering Education, 2009, p. BOEING.
[26] S. Rosenthal and S. Finger, “Design collaboration in a distributed environment,” *36th ASEE/IEEE Frontiers in Education Conference, FIE, October 28, 2006 - October 31, 2006*, San Diego, CA, United states: Institute of Electrical and Electronics Engineers Inc., 2006, p. American Society for Engineering Education (ASEE); Educational Research and Methods (ERM) Division; Institute of Electrical and Electronics Engineers (IEEE); IEEE Computer Society; IEEE Education Society.
[27] R.O. Briggs, “On theory-driven design and deployment of collaboration systems,” *International Journal of Human-Computer Studies*, vol. 64, Jul. 2006, pp. 573-582.
[28] J. Fjermestad and S.R. Hiltz, “An assessment of group support systems experimental research: methodology and results,” *J. Manage. Inf. Syst.*, vol. 15, 1998, pp. 7-149.
[29] A. McGaughey and J. Michalek, “Wiki-based learning in the mechanical engineering classroom,” *2008 ASEE Annual Conference and Exposition, June 22, 2008 - June 24, 2008*, Pittsburg, PA, United states: American Society for Engineering Education, 2008.
[30] A.J. Phuwanartnurak, “Exploring the use of Wikis for information sharing in interdisciplinary design,” *Proceedings of the ACM 2009 international conference on Supporting group work*, Sanibel Island, Florida, USA: ACM, 2009, pp. 385-386.
[31] T. Joo and J. Mark, “An evaluation of tools supporting enhanced student collaboration,” *38th ASEE/IEEE Frontiers in Education Conference, FIE 2008, October 22, 2008 - October 25, 2008*, Saratoga Springs, NY, United states: Institute of Electrical and Electronics Engineers Inc., 2008, pp. F3H7-F3H12.
[32] S.M. Plummer and L.J. Fox, “A wiki: One tool for communication, collaboration, and collection of documentation,” *2009 ACM SIGUCCS Fall Conference, SIGUCCS'09, October 11, 2009 - October 14, 2009*, St. Louis, MO, United states: Association for Computing Machinery, 2009, pp. 271-274.
[33] S. Minocha and P.G. Thomas, “Collaborative Learning in a Wiki Environment: Experiences from a software engineering course,” *New Review of Hypermedia and Multimedia*, vol. 13, 2007, pp. 187-209.
[34] J. Lang and E. Davis, “Redmine - Open Source Project Management Web-Application,” Feb. 2010.
[35] “2010 ASME Student Design Competition - Student Design Contest,” Dec. 2009.
[36] R.A. Fisher, *The Design of Experiments*, Macmillan Pub Co, 1971.
[37] W. Trochim, *The Research Methods Knowledge Base*, Atomic Dog Publishing,

2001.
[38] D. Lach, “Interview regarding methods for social analysis,” Sep. 2009.
[39] R Development Core Team, *R: A language and environment for statistical computing*, Vienna, Austria: R Foundation for Statistical Computing, 2009.
[40] W. Revelle, *R: Find two estimates of reliability: Cronbach's alpha and Guttman's Lambda 6.*, 2010.
[41] L. Cronbach, “Coefficient alpha and the internal structure of tests,” *Psychometrika*, vol. 16, 1951, pp. 297-334.
[42] S. Wasserman and K. Faust, *Social network analysis*, Cambridge University Press, 1994.
[43] J. Scott, “Social Network Analysis,” *Sociology*, vol. 22, Feb. 1988, pp. 109-127.
[44] C. Butts, “network: A Package for Managing Relational Data in R,” *Journal of Statistical Software*, vol. 24, May. 2008.
[45] S. Goodreau, M. Handcock, D. Hunter, C. Butts, and M. Morris, “A statnet Tutorial,” *Journal of Statistical Software*, vol. 24, May. 2008.
[46] J. Ooms, *Web Development with R*, San Francisco - Bay Area useR Group: 2010.
[47] J. Loeliger, “Collaborating Using Git,” *Linux Magazine*, Jun. 2006.
[48] Y. Benkler, *The Wealth of Networks: How Social Production Transforms Markets and Freedom*, Yale University Press, 2007.
[49] E.R. Haley, G.B. Collins, and D.J. Coe, “The wonderful world of wiki benefits students and instructors,” *IEEE Potentials*, vol. 27, 2008, pp. 21-26.
[50] M. Alier and M. Casany, “Creating wiki communities in blended learning environment and the creation of the Moodle New Wiki,” *Proceedings of the 2008 International Conference on Frontiers in Education: Computer Science and Computer Engineering, FECS 2008*, 2008, pp. 99-105.
[51] M. Cole, “Using Wiki technology to support student engagement: Lessons from the trenches,” *Computers and Education*, vol. 52, 2009, pp. 141-146.
[52] E. Obonyo and W. Wu, “Using web-based knowledge forums to internationalize construction education,” *Electronic Journal of Information Technology in Construction*, vol. 13, 2008, pp. 212-223.
[53] T.J. Ellis and L.P. Dringus, “Evaluating threaded discussion forum activity: Faculty and student perspectives on categories of activity,” *Frontiers in Education - 35th Annual Conference 2005, FIE' 05, October 19, 2005 - October 22, 2005*, Indianapolis, IN, United states: Institute of Electrical and Electronics Engineers Inc., 2005, pp. T2H-24-T2H-29.
[54] L. Liu, M. Huguet, and T. Haley, “Work in progress - SAGES: Podcast, wikis and emerging technologies in the engineering classroom,” *38th ASEE/IEEE Frontiers in Education Conference, FIE 2008, October 22, 2008 - October 25, 2008*, Saratoga Springs, NY, United states: Institute of Electrical and Electronics Engineers Inc., 2008, pp. S3J13-S3J14.
[55] J. Xu, J. Zhang, T. Harvey, and J. Young, “A survey of asynchronous collaboration tools,” *Information Technology Journal*, vol. 7, 2008, pp. 1182-1187.
[56] M. Koch, R. Schulte, and I. Tumer, “The Effects of Open Innovation on Collaboration and Knowledge Sharing in Student Design Teams,” *Proceedings of*

the ASME 2010 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference, Montreal, QC, Canada: ASME, 2010.

[57] "SourceForge.net," *http://sourceforge.net/support/getsupport.php*.

[58] "Git - Fast Version Control System," Jan. 2009.

[59] "Engr215 Introduction to Design syllabus."

[60] A. Al-Ajlan and H. Zedan, "Why moodle," *12th IEEE International Workshop on Future Trends of Distributed Computing Systems, FTDCS 2008, October 21, 2008 - October 23, 2008*, Kunming, China: Inst. of Elec. and Elec. Eng. Computer Society, 2008, pp. 58-64.

Appendices

ME382 Survey

Lab:	Group:

Collaboration

On a scale from 1 to 5, with 1 being very ineffective and 5 being very effective, how effective was your group at:

	Very Ineffective 1	2	3	4	Very Effective 5
Designating & managing tasks	○	○	○	○	○
Following through on tasks	○	○	○	○	○
Face to Face Communication	○	○	○	○	○
Meeting Project & Class Deadlines	○	○	○	○	○
Design Collaboration	○	○	○	○	○
Sharing information within the group	○	○	○	○	○
Sharing information between groups	○	○	○	○	○

Knowledge Sharing

How does collaboration and/or sharing knowledge between groups effect the outcome of engineering design projects? *(please check all that apply)*

- ☐ It provides a greater pool of ideas and inspiration
- ☐ It provides different approaches to the same problem
- ☐ It increases the variety of skills and knowledge
- ☐ Reduces workload
- ☐ Plagarism - non-attributive/non-voluntary use of other groups' ideas
- ☐ I'm not sure because I have not collaborated between groups on a project yet
- ☐ Other - *please specify:*

What are the barriers to increased collaboration between groups, if any? *(please check all that apply)*

- ☐ Lack of applicable technology
- ☐ Lack of communication
- ☐ Lack of willingness to collaborate
- ☐ A lack of knowledge about class policy that allows collaboration between groups
- ☐ There are no barriers to increased collaboration between groups
- ☐ Other - *please specify:*

Did you ever share project information with another group?

○ Yes ○ Not Sure ○ No

Did your draw inspiration from other groups for your own project?

○ Yes ○ No

If Yes, how did you acquire this information? *(please check all that apply)*

- ☐ During Shop time
- ☐ During Class/Lab
- ☐ Outside of school
- ☐ Through Wiki or OpenPario
- ☐ Asking face to face
- ☐ Other - *please specify:*

Tools

How often did you use each of the following group collaboration methods and tools?

	Never	1 or 2 times a week	3 or 4 times per week	5 or more times per week	Several times a Day
Meetings	○	○	○	○	○
Email	○	○	○	○	○
Phone Calls	○	○	○	○	○
Text Messages	○	○	○	○	○
Class Wiki	○	○	○	○	○
Google Docs	○	○	○	○	○
OpenPario	○	○	○	○	○
Facebook	○	○	○	○	○
Instant Messaging	○	○	○	○	○

Overall, how effective did you feel each of these methods were for collaboration?

	Very Ineffective 1	2	3	4	Very Effective 5
Email	○	○	○	○	○
Class Wiki	○	○	○	○	○
Open Pario	○	○	○	○	○
Meetings	○	○	○	○	○

How did your team use meeting times? *(circle any that apply)*

Delegate tasks	Work on individual tasks	Non-project related discussion	Compile reports & memos	Other	Did not meet

How did your team use the Wiki? *(circle any that apply)*

Storing and Organizing Files	Planning the project	Managing Tasks	Drawing inspiration from other groups	Upload Homework & Assignments	Other	Did not use

How did your team use OpenPario? *(circle any that apply)*

Storing and Organizing Files	Planning the project	Managing Tasks	Drawing inspiration from other groups	Other	Did not use

Have you used wikis or other web-based collaboration tools in the past?

- ○ Yes - *please specify:*
- ○ No

Will you seek out the use of web-based collaboration tools for future group projects? (ie wikis)

- ○ Yes
- ○ No

If you have any comments or suggestions about improving group collaboration in engineering design classes, whether with or without software, please include them below:

HSU Open Pario Survey

There are 19 questions in this survey

Identification

This group of questions will help to categorize the responses of this survey.

1 [1]Which project were you a team member of?

Please choose **only one** of the following:

- ◯ HelpHaiti
- ◯ HERE ON EARTH
- ◯ PickUpStix
- ◯ Rubblution
- ◯ team A.C.E.
- ◯ Humangineers
- ◯ Seas of Change
- ◯ Solar Saints
- ◯ Energy-Caters
- ◯ Cubic
- ◯ Esquared
- ◯ Pandora's Box
- ◯ Goobers
- ◯ JTRM
- ◯ Design Lab
- ◯

The answers in the dropdown are based off group names entered into Open Pario.

2 [2]Age:

Please write your answer here:

Collaboration

3 [1]On a scale from 1 to 5, with 1 being very ineffective and 5 being very effective, how effective was your project team at: *

Please choose the appropriate response for each item:

	1	2	3	4	5
Designating & managing tasks	○	○	○	○	○
Following through on tasks	○	○	○	○	○
Face to Face communication	○	○	○	○	○
Meeting project & class deadlines	○	○	○	○	○
Design collaboration	○	○	○	○	○
Sharing information within the group	○	○	○	○	○
Sharing information between groups	○	○	○	○	○

Knowledge Sharing

4 [1]How does collaboration and/or sharing knowledge between groups effect the outcome of engineering design projects? *

Please choose **all** that apply:

- ☐ It provides a greater pool of ideas and inspiration
- ☐ It provides different approaches to the same problem
- ☐ It increases the variety of skills and knowledge
- ☐ Reduces workload
- ☐ It can cause plagiarism, or non-attributive/non-voluntary use of other groups' ideas
- ☐ I'm not sure because I have not collaborated between groups on a project yet
- ☐ Other: ____________

5 [2]What are the barriers to increased collaboration between groups, if any? *

Please choose **all** that apply:

- ☐ Lack of applicable technology
- ☐ Lack of communication
- ☐ Lack of willingness to collaborate
- ☐ Lack of knowledge about class policy that allows collaboration between groups
- ☐ There are no barriers to increased collaboration between groups
- ☐ Other: ____________

6 [3]Did you ever share project information with another group? *

Please choose **only one** of the following:

- ◯ Yes
- ◯ No
- ◯ Uncertain

7 [4]Did you draw inspiration from other groups for your own project? *

Please choose **only one** of the following:

- ◯ Yes
- ◯ No
- ◯ Uncertain

8 [5]If Yes, how did you acquire this information? *

Please choose **all** that apply:

- ☐ While constructing
- ☐ During Class/Lab
- ☐ Outside of school
- ☐ Through wiki or OpenPario
- ☐ Asking face to face
- ☐ During client meetings
- ☐ N/A
- ☐ Other: ____________

Tools

9 [1]How often did you use each of the following group collaboration methods and tools for this design project? *

Please choose the appropriate response for each item:

	Never	1 or 2 times a week	3 or 4 times per week	5 or more times per week	Several times a day
Meetings	○	○	○	○	○
Email	○	○	○	○	○
Phone Calls	○	○	○	○	○
Text messages	○	○	○	○	○
Moodle	○	○	○	○	○
Open Pario	○	○	○	○	○
Class Wiki (Appropedia)	○	○	○	○	○
Google Docs	○	○	○	○	○
Facebook	○	○	○	○	○
Instant Messaging	○	○	○	○	○

10 [2]Overall, how effective did you feel each of these methods were for collaboration? *

Please choose the appropriate response for each item:

	Very Ineffective	Ineffective	Neutral	Effective	Very Effective	N/A
Meetings	○	○	○	○	○	○
Email	○	○	○	○	○	○
Phone Calls	○	○	○	○	○	○
Text Messages	○	○	○	○	○	○
Moodle	○	○	○	○	○	○
Open Pario	○	○	○	○	○	○
Class Wiki (Appropedia)	○	○	○	○	○	○
Google Docs	○	○	○	○	○	○
Facebook	○	○	○	○	○	○
Instant Messaging	○	○	○	○	○	○

11 [10]Were there other tools that you used for collaboration or knowledge sharing during this class project?

Please write your answer here:

12 [3]How did your team use meeting times? *

Please choose all that apply:

- ☐ Delegate tasks
- ☐ Work on individual tasks
- ☐ Non-project related discussion
- ☐ Compile reports & memos
- ☐ Did not meet
- ☐ Other:

13 [4]How did your team use Moodle? *

Please choose all that apply:

- ☐ Storing and organizing files
- ☐ Planning the project
- ☐ Managing tasks
- ☐ Drawing inspiration from other groups
- ☐ Upload homework and assignments
- ☐ Did not use
- ☐ Other:

14 [5]How did your team use Open Pario? *

Please choose all that apply:

- ☐ Storing and organizing files
- ☐ Planning the project
- ☐ Managing tasks
- ☐ Drawing inspiration from other groups
- ☐ Did not use
- ☐ Other:

15 [11]What suggestions do you have for improving Open Pario? (i.e. features, bugs, add ons, usability problems, etc)

Please write your answer here:

16 [6]Have you used wikis or other web-based collaboration tools in the past? *

Please choose **only one** of the following:

- ○ Yes
- ○ No

17 [7]If so, which tools did you use?

Please write your answer here:

18 [8]Will you seek out the use of web-based collaboration tools for future group projects? (ie wikis) *

Please choose **only one** of the following:

- ○ Yes
- ○ No

19 [9]If you have any comments or suggestions about improving group collaboration in engineering design classes, whether with or without software, please include them below:

Please write your answer here: