IMPROVING THE PROFESSIONAL SKILLS OF ENGINEERING GRADUATE STUDENTS THROUGH CAPSTONE PROJECT MENTORING IN IDAHO ENGINEERING WORKS (IEWORKS)

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EXECUTIVE SUMMARY

Traditional engineering graduate programs focus on classroom coursework and independent thesis research, which may or may not adequately prepare students for leadership roles in industry. This paper describes an alternative graduate program developed at the University of Idaho called the Idaho Engineering Works (IEWorks). IEWorks is focused on developing leadership, creativity, communication, and time management skills in addition to traditional course and thesis work. This paper compares the IEWorks experience to other student experiences, using surveys of current and future graduate students as well as alumni and faculty. The results of the surveys suggest the increased workload in IEWorks interferes with thesis research and coursework. However, the data also suggests the professional skills developed in the program are highly valued by the majority of the graduates and offset the additional workload.

INTRODUCTION

Due to downsizing, the growing global marketplace, and faster new product releases, competitive corporations have to become more efficient and flexible. In order for the corporation to be efficient, its employees must also operate efficiently. In response to this movement, academia is being asked to take more responsibility in the overall development of its graduating engineers [1] [2]. Undergraduate curriiculum are changing to address these issues [3].Graduate programs should also change to accommodate the changing industrial demands.

Typical graduate programs in engineering are structured in functional areas similar to corporate structures. In mechanical engineering, these functional areas include thermodynamics and solid mechanics, with which graduate research groups align. This functional team structure inhibits innovation and efficiency [4] [5] [6] [7]. Several researchers have proposed using a cross-functional structure in which the team members have varying backgrounds and expertise. Ideally these backgrounds would be from across the spectrum of disciplines. In IEWorks, the variety is limited to mechanical engineering members and the machine shop machinist.

In order to be competitive, engineers must possess skills above and beyond technical skills. Valenti surveyed firms and academia in mechanical engineering and compiled a list of skills that emerging engineers need [1]. Table 1 lists the top ten skills emerging engineers need according to the academia and industry. The professional skills listed include both technical and non-technical skills. Those non-technical skills include teams/teamwork, communication, professional ethics, and creative thinking.

The change from a defense-driven to a civilian-driven economy and the coming of the global marketplace has forced this change in education paradigm, according to Valenti. To develop their *Manufacturing Education Plan*, the Society of Manufacturing Engineers (SME) surveyed corporations that employ manufacturing engineers or manufacturing technologists.

Using the results, SME identified project management, written/oral communication, and business knowledge/skills as some of the competency gaps present in newly hired engineering [8].

Table 1 Professional Skills of Emerging Engineers

Rank	Skill	
	Industry	**Academia**
1	Teams/Teamwork	Teams/Teamwork
2	Communication	Communication
3	Design for Manufacture	Creative Thinking
4	CAD Systems	Design Reviews
5	Professional Ethics	CAD Systems
6	Creative Thinking	Sketching/Drawing
7	Design for Performance	Professional Ethics
8	Design for Reliability	Design for Performance
9	Design for Safety	Design for Safety
10	Concurrent Engineering	Manufacturing Processes

In another study, Kelley and Caplan examined the engineers at Bell Laboratories to determine what traits the star performing engineers possessed [9]. They discovered that neither IQ nor GPA was an accurate indicator of the productiveness of these engineers. Instead, the approach the engineers use is what set the stars apart from the mediocre. The consensus from star engineers at Bell Laboratories shows they follow a three-tier strategy (Fig. 1). The fundamental skills are taking initiative, and technical competence. All of these engineers work on teams. Therefore, in addition to the depth of his or her knowledge in a particular field, the engineer's productivity depended upon how well the individual could work with others. This research provides a valuable indication of the abilities expected of a graduate from engineering graduate school. To have an advantage in the job market, or simply to be competitive, the graduate should have developed the skills in the first tier and portions of the second tier.

To further support this notion that this “softer side” of engineering is as important as the technical side, Krackhardt and Hanson claim the informal organization is determines a company’s success [10]. The purpose of the informal component of the organization is to handle the unexpected, when the formal component is too rigid to flex and accommodate the unexpected. Communication with individuals outside of one’s expertise, such as customers, is paramount in order to establish and become a component of the informal organization.

Goleman has found that effective teams have members who exhibit strong interpersonal skills or intelligence [11]. The measure of interpersonal intelligence comes from how well one manages a network of people, be it a formal or informal network. Although academia generally provides students with technical skills, it does not adequately develop these interpersonal/soft skills outside of the undergraduate curriculum. Such skills are typically learned on the job in an unsystematic way based on need. Organized projects or development lessons to teach constructive and effective approaches are seldom available. Instead, the skills are considered byproducts of group projects. And often, the skills are not adequately developed. An engineer with a graduate degree is expected to have all of these skills; yet graduate programs do little to develop these skills directly.

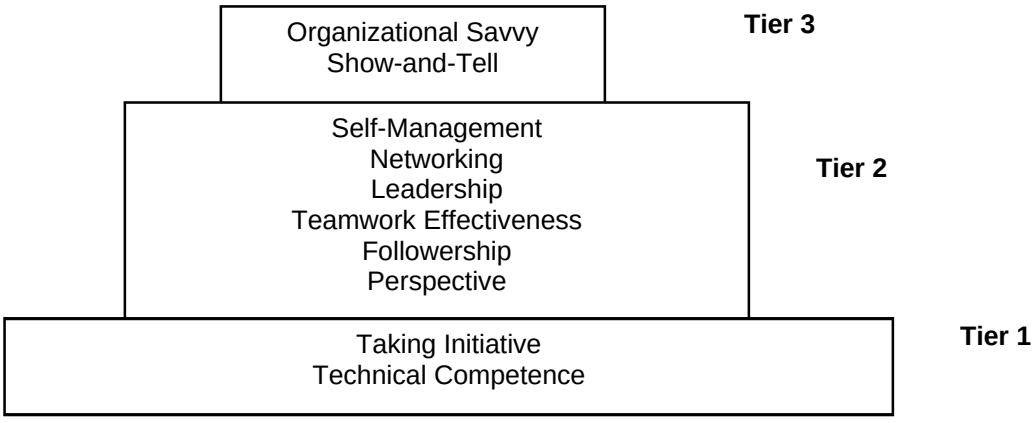

Figure 1. Bell Labs three-tier strategy

To address these issues as well as to improve the system, a relatively informal group, Idaho Engineering Works (IEWorks or IEW) was developed at the University of Idaho under the guidance of Dr. Edwin Odom in 1994 [12]. This group was molded after Kelly Johnson's design of the Skunk Works at Lockheed in the 1940s [13]. Today, IEWorks consists of students involved in the mechanical engineering senior capstone design classes, graduate student mentors, and several faculty members involved in engineering design. This paper will focus on the graduate student experience in IEWorks.

The graduate students are funded as capstone senior design team mentors and, in addition to their regular courses, work together on various projects to challenge the undergraduate students to develop these softer skills. Some may think these extra efforts are not worthwhile and are not the purpose of graduate school. They may believe that the focus in graduate school should be learning about being an engineer. However, IEWorks provides an environment in which these soft skills can be explored and practiced. Research is conducted on the various methods of practicing these skills. According to graduate alumni, the skills gained through the experience of being mentors are well worth the added work. The amount of extra work that helps develop these skills, practiced in a safe environment where career integrity is not at risk, is not only justifiable—it is better than the trial by fire method in industry and classes.

IDAHO ENGINEERING WORKS

The original purpose of IEWorks was to make graduate school more meaningful than a research project and a thesis. As described in the previous section, engineers need more than just the technical know-how taught in academia. Most engineering graduate programs have similar formats: A student is partnered with a graduate faculty member to work on a research project of interest to both. The student is tasked with research work as well as coursework.

In this model, few opportunities occur in which to practice the softer skills. Graduate students are not encouraged to operate in teams. Communication is developed only to the extent of

interacting with thesis committees and research related personnel. Creative thinking is permitted, only if the idea supports the research project description.

IEWorks is currently tasked with assisting senior capstone design classes. Figure 2 shows the process undertaken by seniors in the capstone design course. In this capacity, IEWorks members work as design team mentors, aiding seniors in problem formulation, communication, manufacturing issues, machine shop training and use, and technical consultants.

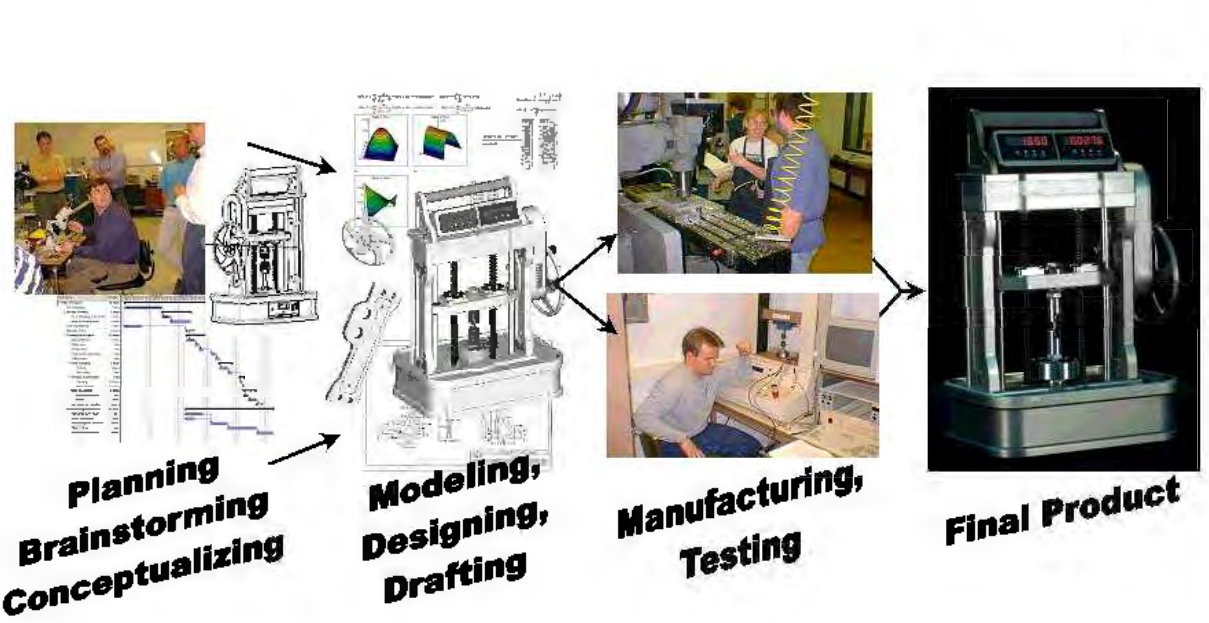

Figure 2. Senior capstone design process

The power of mentoring is well described by Healy and Welchert [14]:

> There are two essential goals of mentoring: transformation and reciprocity. Both individuals are changed and enlarged by the experience. Both people learn and grow. Ultimately one cultivates within the protégé, qualitative changes in his/her approach to tasks and to initiatives. The clear goal of the transformation in mentoring should be for the mentee or protégé to no longer be an understudy, but to become a peer.

As mentors, IEWorks members practice team leadership skills as well as interpersonal skills, such as inspiring motivation and effective communication. This provides a environment in which to practice the skills that industry has identified as important skills for new hires.

In addition to the senior design mentoring, a semester-based directed study course, which addresses particular skill sets, is offered at varying credit levels. In these classes, graduate students review literature on leadership, creativity, and other non-engineering curriculum topics, which work to give the student more insights into these skills. To challenge the student, difficult projects are assigned aimed to stretch the capacity of each student involved. All of this is above the typical class load and research work. The stretch goal challenges the student, thereby pushing him or her to truly learn and understand the skills being taught through application [15]. Furthermore, coming together as a team to accomplish these projects develops trust between members and strengthens the team [16].

For example, the IEWorks group members manufactured heat sinks of various exotic materials for a leading computer chip manufacturer for performance testing. The timeline and exotic materials made the task challenging to the students. Another stretch goal was to design and fabricate an aluminum yo-yo that had the same shape, polar moment of inertia, and performance as a Tom Kuhn Roller Woody Yo-Yo [17]. The most recent challenge was to

A **B** **C**

Figure 3. (A) Heat sink project; (B) Yo-Yo project; (C) Stirling project

reengineer the MIT Stirling Engine Project to fit within the fee structure and machine shop resources available to the University of Idaho [18] [19]. In order for the tasks to be

accomplished on time, scheduling, costing, customer communication, and the manufacturing processes had to be mastered by the team. These high energy, short-term projects challenge each IEWorks member to interact effectively in a team. Without excellent teamwork, these challenges would overwhelm an individual.

IEWorks operates as a heavyweight project team [20]. This environment gives the team member a great deal of ownership in the group. Through this feeling of ownership, the team members are typically well motivated [21] [22]. The project manager position is rotated between student members. Generally the more senior member is given the task of project management while taking a newer IEWorks member under his/her wing. This provides students with the opportunity to manage a team and to hone the skills learned in the directed study course.

In addition to group projects, each IEWorks member has a major professor who may or may not be actively involved in IEWorks. Considering the heavyweight team analogy, each major professor would be considered the functional group manager and each member a functional group. This is the beauty of IEWorks. In IEWorks, students from various categories of mechanical engineering are working together. This provides a variety of perspectives on projects, since it mirrors the advantages of a cross-functional team. However, to be truly cross-functional, members from disciplines outside of mechanical engineering are needed. Due to the commitment of IEWorks members on projects outside of their research, few professors feel comfortable involving students from outside the mechanical engineering department.

EVALUATION OF IEWORKS

In order to evaluate IEWorks, we conducted a series of surveys. Current members and IEWorks alumni were surveyed, as were mechanical engineering faculty, seniors and alumni. The surveys were structured to indicate traits or skills the participants consider important for an engineer. It also solicited their opinions of IEWorks, its principles, and effectiveness.

The faculty, mechanical engineering alumni, and IEWorks alumni surveys were conducted over the internet. IEWorks alumni were solicited by email. Twelve mechanical engineering alumni who were not members of IEWorks were also solicited through email. The participants were instructed to forward the survey on to other alumni who have graduated in the last three years who were not included in the original solicitation. Responses from all mechanical engineering faculty members were solicited. Current seniors and IEWorks members were solicited in person and completed hardcopy surveys.

Each survey group was given a distinct survey (see Appendix). However, all of the surveys had common questions. The common questions of interest to this report asked for them to identify the most four important professional skills and to discuss how IEWorks affects the development of these skills. The unique questions on the surveys related to job experience, graduation, and participant's background.

Survey Results

Ninety-three candidates were asked to participate in the survey. Sixty-four candidates participated. Figure 4 shows the distribution of the surveys by group. This section is divided into four subsections corresponding to each survey group and addresses only the results from the questions common to all surveys.

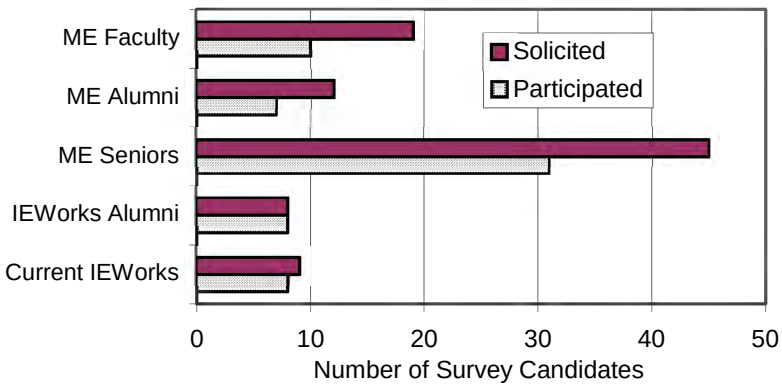

Figure 4. Survey candidate solicitation and collection by group

Current IEWorks Members

Eight IEWorks members participated in the survey. All members found IEWorks either very or somewhat important to them right now. With the exception of one participant, all found the added work involved in IEWorks does result in developing the professional skill sets. .s 5 through 8 show the survey results from the current members.

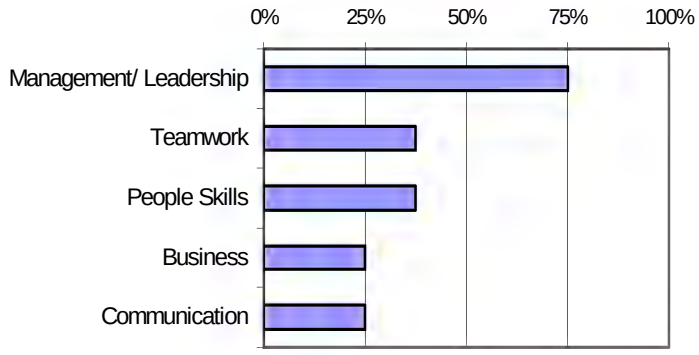

Figure 5. Top professional skills identified by current IEWorks

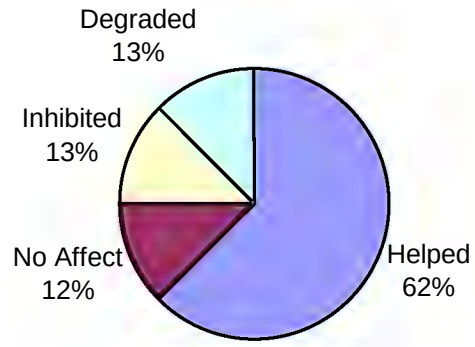

Figure 6. Effect of IEWorks involvement on GPA

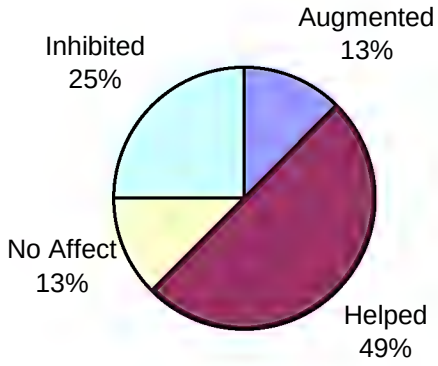

Figure 7. Effect of IEWorks involvement on research

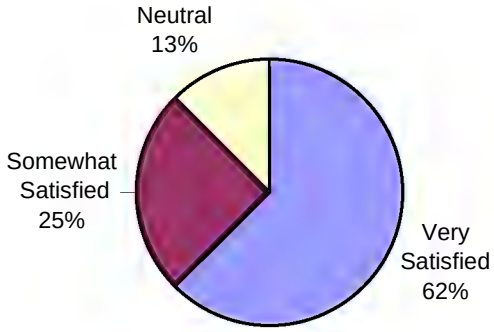

Figure 8. Satisfaction of current IEWorks with graduate experience

A study was performed in the mechanical engineering department comparing a graduate student's undergraduate and graduate GPAs from 1995 through 1997. The undergraduate and graduate GPAs of 12 non-IEWorks students and 8 IEWorks students were compared. All students in the study completed their undergraduate degrees at the University of Idaho and

were enrolled or graduated from the mechanical engineering graduate program in 1997. The student sample population included all graduate degrees in the Mechanical Engineering program: M.S.M.E., M.E.M.E., and Ph.D. The average GPA of IEWorks students improved 17 percent, while the average non-IEWorks student GPA improved only 7 percent.

IEWorks Alumni

Seven IEWorks alumni participated in the survey. Of the 7 participants, all found IEWorks to be a very important experience to them now. While the participants were involved in IEWorks, one found the experience somewhat important and 6 found IEWorks very important. All found involvement in IEWorks helped develop professional skills, but one recent graduate felt it hindered research work. Figures 9 through 11 show the results from the IEWorks alumni.

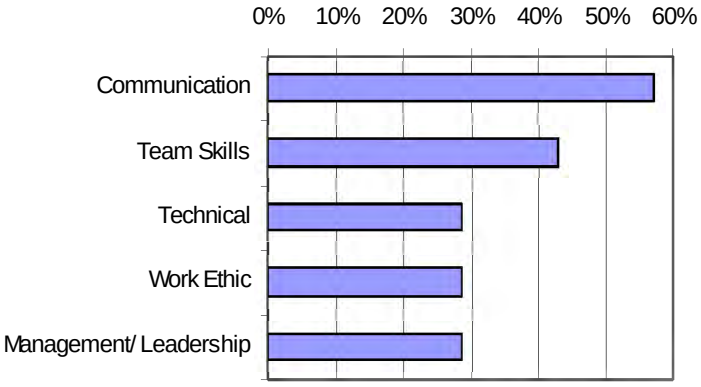

Figure 9. Top five IEWorks alumni professional skills

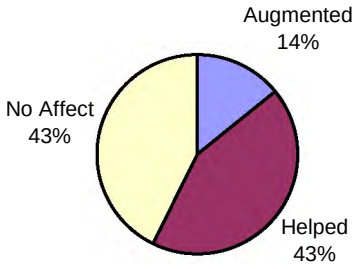

Figure 10. Effect of IEWorksinvolvement on gPA

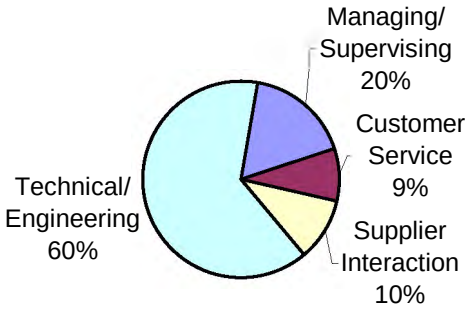

Figure 11. Average time spent by IEWorks alumni

Mechanical Engineering Seniors

Thirty-one seniors participated in the survey. All of the participating seniors were currently enrolled in the senior capstone design course.

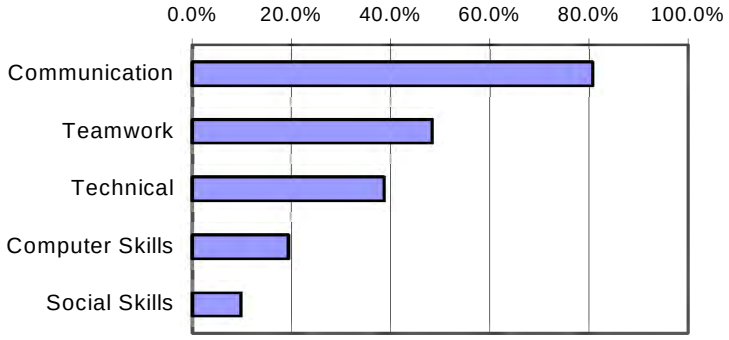

Figure 12 Senior Top Five Professional Skills

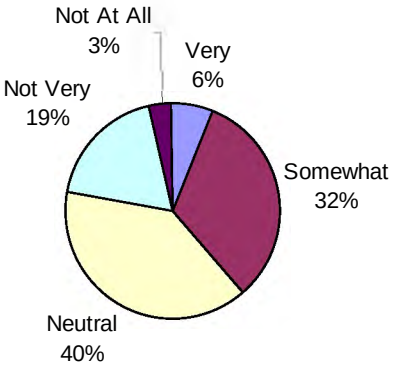

Figure 13 How IEWorks Assists in Developing Skills

Mechanical Engineering Alumni

Eight alumni who were not members of IEWorks participated in the survey. Six of the participants are currently in engineering positions, and 2 are in engineering management positions. The earliest graduate is from1986, and the most recent is from 2001. One participant has a M.S.M.E. while the rest have B.S.M.E. degrees. Three of the participants found IEWorks helped develop the professional skills. Two felt IEWorks had some affect, but did not adequately develop the skills, and two participants did not describe how IEWorks helped develop the professional skills.

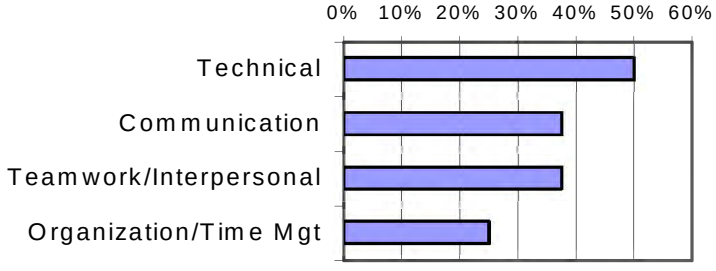

Figure 14. ME alumni top four professional skills

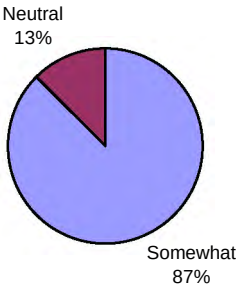

Figure 15. How IEWorks assists in developing skills

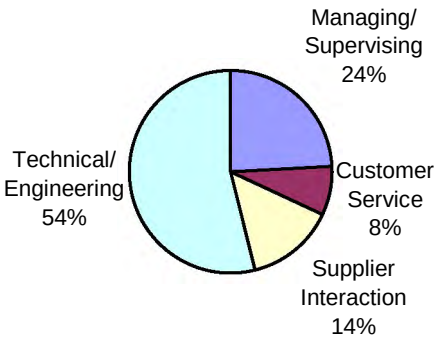

Figure 16: Average Time Spent on the Job by ME Alumni

Mechanical Engineering Faculty

Ten faculty members completed the survey. All faculty participants felt graduate school helped develop the professional skills. Six participants interacted with current IEWorks members weekly, three almost never interacted and one interacts monthly. These interactions are related to research or social in nature.

The faculty participants had interesting responses to the question regarding the value of the extra workload in IEWorks. One professor did not consider the workload to be larger than any other graduate student's and felt the assistantship compensation adequately compensates for the work. Three participants believed the added workload weakens research and overloads students. Four participants felt the added workload results in highly valued skill development.

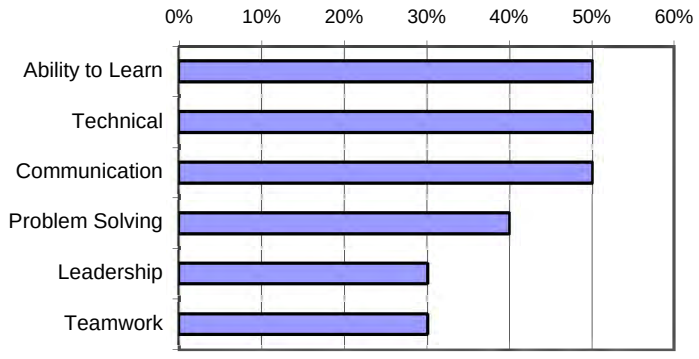

Figure 17. Top professional skills identified by faculty

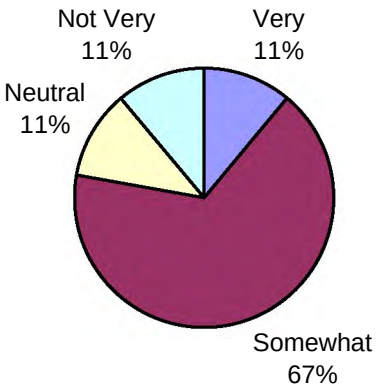

Figure 18. Faculty satisfaction with current graduate students

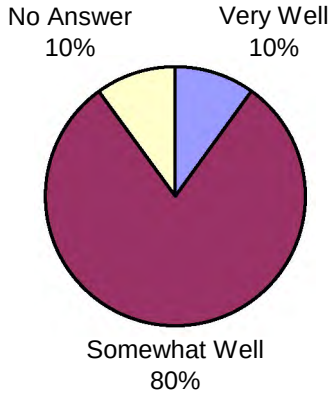

Figure 19. Ability of graduate school to develop skills

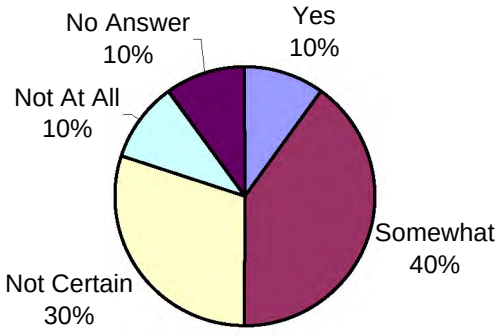

Figure 20. Is IEWorks workload too much?

Discussion

Considering the small sample size of the surveys, the results do not have enough statistical validity to form well-supported conclusions. However, the data is substantial enough to indicate trends and general opinions. The results also serve to generate guidelines for how to compose subsequent surveys for the purpose of evaluating IEWorks.

There are noticeable differences in the responses from current and past IEWorks members. Figure 10 and Fig. 6 show the past members did not find the extra workload of IEWorks to noticeably interfere with or degrade research and GPA. Half of the faculty, according to Fig. 20, indicate the current workload is too much. This is most likely attributed to the changes in course structure in capstone design, expanding responsibilities of IEWorks members, and the recent influx of students whose major professors are not actively involved in IEWorks.

The design projects in the capstone course have grown in complexity and depth, which places greater manufacturing demands on the mentors. In the last several years, members of IEWorks have been called upon to provide course instruction in the department's solid modeling course as well as provide assistance to sophomore and junior level design courses. Currently the members of IEWorks have had responsibilities for capstone design mentoring,

shop support and mentoring for various team projects such as Formula SAE, teaching a solid modeling class, infrastructure development, laboratory equipment procurement, and teaching the advanced strength of materials class. These professors may not fully understand the process of IEWorks and serve to interrupt and overload the student. One current member in IEWorks stated having particular difficulty managing the extra work and maintaining grades. Some responses from both current members and IEWorks alumni indicate a certain personality or openness is needed to fully benefit from the experience.

It is interesting to note that the graduate student alumni and undergraduate alumni tend to distribute their time in similar manners according to Fig. 11 and 16. For both groups, the majority of time is spent in engineering functions. The researchers had expected the graduate alumni to spend more time in managing/supervisory functions. This may become the case when more time has elapsed since their graduation.

The faculty responses indicated there are several misunderstandings of IEWorks. Three of the faculty appear to view IEWorks as merely a group of lab teaching assistants. Unlike a materials lab assistant whose responsibilities are report grading and conducting lab sessions, IEWorks members are responsible for aiding the students in developing team structure, manufacturing, and time management among other skills in addition to the directed study courses. Other faculty respondents find IEWorks to be invaluable in the development of a graduate student. One faculty participant stated:

> Additional responsibilities/ workload are required but unique experiences/personal benefits are borne of this commitment. Even students who are not directly involved in IEW benefit slightly through conversation/association with IEW members.

Half of the faculty participants indicated that the mentoring aspect of IEWorks helps develop professional skills. The other participants could not justify the extra workload.

Of the faculty participants, 60 percent would consider becoming involved in IEWorks and 40 percent did not want to be involved. Those who did not want to be involved did not consider the extra skills developed in IEWorks to be of value to a graduate student while in school and felt that such involvement would take time away from the more important research. In contrast, the consensus from the IEWorks alumni participants shows the work in IEWorks emulates the professional workplace. They value the skills learned through IEWorks and indicate that these skills would not be as well developed if they lacked the IEWorks experience. Being involved in IEWorks demands one to balance the workload and communicate with people of multiple backgrounds.

Referring to Fig. 5, 9, 12, 14, and 17, all survey groups listed communication, teamwork, and technical skills in the top professional skills. These skills are also found in the professional skills discussed in the literature and listed in Fig. 1 and Table 1. This shows that all the survey groups value these skills. Ranking the skills listed by the participants to identify the top five skills was difficult due to the survey size. The mechanical engineering alumni have only 4 top skills since the remaining skills listed by the participants were evenly ranked. The faculty list has six skills since leadership and teamwork tied for the fifth position. The remaining groups' top five skills were easily identified through ranking.

CONCLUSION

The results suggest the professional skills listed in Fig. 1 and Table 1 are developed in IEWorks. However, there is a cost to the development. The added workload appears to interfere with other graduate work such as coursework and research. Depending on the individual, the professional skills developed in IEWorks may or may not be of value to the student during graduate school. The organizers of IEWorks will need to evaluate the work screening process in which extra jobs or duties are evaluated before being assigned to IEWorks. Also having the newer faculty members in IEWorks become more active in the planning and decision-making activities of the group may help alleviate the high workload.

From the faculty and senior responses, it is apparent few fully understand or appreciate what IEWorks entails. More work is needed to explain what IEWorks does and how it operates. This paper should prove valuable in explaining some of the inner workings of the group and its capabilities. The challenges of balancing the workload, answering to students and faculty, and managing time appear to prepare the student well for the same challenges in industry.

To improve the results for future work, it is suggested that the survey sample size increase. Unfortunately, there are a small number of graduates from IEWorks since its inception in 1994. An interesting perspective that may provide a larger sample size would be from the employers of IEWorks alumni. Since they are the primary customers of our graduate students, their unbiased input would be valuable in a side-by-side comparison of an IEWorks alum to a non-IEWorks graduate student. As IEWorks continues to grow and develop, it will be interesting to see how the alumni from the group will perform and advance in their careers.

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APPENDIX

Faculty Survey

1 Name the 4 most important skills in your opinion that a graduate with an MS needs to be competitive in today's market:

2 How well is graduate school developing the skills listed in #1?

Very Somewhat Neutral Not very Not at all

Briefly describe how these professional skills are being developed:

3 How satisfied are your with your current graduate students?

Very Somewhat Neutral Not very Not at all

4 Briefly describe your current working relationship:

5 How often do you interact with with your graduate students about research work and other projects?

Daily Weekly Monthly Semesterly Rarely

6 How often do you interact with fellow engineering faculty about research work and other projects?

Daily Weekly Monthly Semesterly Rarely

7 How often do you interact with IEWorks members?

Daily Weekly Monthly Semesterly Rarely

8 What is the nature of the interaction if any?

Social Class Work Shop assistance Research Other (describe)

9 From the interaction that you do have, describe your perspective on what IEWorks is:

10 Do you consider IEWorks to be too much of a workload for a graduate student?

Yes Somewhat Not certain Not very No

11 Considering the work mentioned in #10, do you see any advantage to the extra work? Please elaborate:

Yes Somewhat Not certain Not very No

12 Would you consider becoming or are you involved in IEWorks? Yes No

13 Why or why not?

Capstone Senior Design Survey

1 When do you expect to receive your bachelor's degree?
Immediate career goal

2 What type of job do you intend to have after graduation?
Engineering Business Eng. Grad School Bus. Grad School Other

3 Have you had an internship? If so, what type?

4 Name the 4 most important skills in your opinion that you will need to be competitive in today's market:

4 How much does IEWorks assist you in developing professional skills through your senior design project?
Very Somewhat Neutral Not very Not at all

5 Could you develop the skills listed in #4 through some other mechanism outside of the IEWorks involvement in senior design while in college (i.e., class, club org, Greek system, etc)?

6 Would you recommend IEWorks continue to provide mentoring in senior design?
yes no maybe, provided the following conditions exist:

7 How important is IEWorks to you now?
Very Somewhat Neutral Not very Not at all

8 If you were staying for graduate school, would you want to be part of IEWorks? Why or why not?

Capstone Design Alumni Survey

1 When did you receive your bachelor's degree?

2 What is your highest degree?

3 Have you been employed since graduation?

Current/most recent Position info**:**

4 What best describes the position:

Engineer Eng Mgt Operations Operations Mgt Other

5 How long were you in this position__

6 Percent time spent on following operations:

7 Managing/supervising ____

8 Customer service___

9 Supplier interaction___

10 Technical/engineering ___

11 How important is IEWorks to you now when you look back upon your undergraduate experience?

Very Somewhat Neutral Not very Not at all

12 While in senior design, did you know how important IEWorks would be to you as you defined it in #11?

Very Somewhat Neutral Not very Not at all

13 How much did IEWorks assist you in developing professional skills through your senior design project?

Very Somewhat Neutral Not very Not at all

14 How did IEWorks involvement affect your senior design project?

Augmented Helped No affect Inhibited Degraded

15 If IEWorks involvement helped you in coursework and/or research, please describe.

16 Name the 4 most important skills in your opinion that a graduate in mechanical engineering needs to be competitive in today's market:

17 Did IEWorks help you develop these skills? If no, could you have developed the skills listed in #16 through some other mechanism outside of the IEWorks involvement in senior design while in college (i.e., class, club org, greek system, etc)?

18 Would you recommend IEWorks continue to provide mentoring in senior design?

yes no maybe, provided the following conditions exist:

IEWorks Member Survey

1 How long have you been involved in IEWorks?

2 When will you graduate?

3 How important is IEWorks to you now?

Very Somewhat Neutral Not very Not at all

4 How much does IEWorks interfere with the academic portion of your graduate experience, coursework, thesis research, etc?

Very Somewhat Neutral Not very Not at all

5 How long will your involvement in IEWorks delay your graduation?

0 1 semester 2 semester 3 semester >3 semester

6 How does IEWorks involvement affect your research?

Augmented Helped No affect Inhibited Degraded

7 How does IEWorks affect your GPA?

Augmented Helped No affect Inhibited Degraded

8 If IEWorks involvement has helped you in coursework and/or research, please describe.

9 Name the 4 most important skills in your opinion that a graduate with an MS needs to be competitive in today's market:

10 How well is graduate school developing the skills listed in #9?

Very Somewhat Neutral Not very Not at all

11 Briefly describe how these professional skills are being developed.

12 How would you have developed the skills listed in #9 outside of the IEWorks group while taking classes and research?

13 How satisfied are your with your current graduate experience?

Very Somewhat Neutral Not very Not at all

14 Briefly describe your current state of satisfaction:

15 How often do you interact with your major professor about research work and other projects?

Daily Weekly Monthly Semester Rarely

16 How often do you interact with fellow engineering graduate students about research work and other projects?

Daily Weekly Monthly Semester Rarely

17 If you were entering grad school next semester and had a choice between a position in IEWorks and another funded research position, which would you choose? Why?

18 Would you recommend IEWorks to an individual entering grad school?

yes no maybe, provided the following conditions exist: