Effect of Guided Research Experience on Product Design Performance

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ABSTRACT

Designing, generally, requires a team effort. Consequently, several variables affecting team performance have been studied, such as team composition, female/male ratio in the organization, and teamwork skills training. This study furthers this effort by investigating the effect of guided external research during the concept generation phase of the design process. The premise of the study is that as resources increase in number and complexity, and time constraints pressure an overcrowded curriculum, professors are challenged to find new methods to train students in the skills needed for the constantly changing workplace.

One technique to address this issue, a creative collaboration and its impact on design team performance, is discussed in the paper. First, the approach for incorporating guided research into curriculum is explained, and then the results of the study are presented, which indicate that a higher design performance can be achieved when guided research is added to design teaching.

Keywords: product design, team performance, information access

I. INTRODUCTION

“Many engineers lack skills in accessing and retrieving information. Yet the ability to monitor, access, retrieve, evaluate, use and communicate information will be critical in a global information society characterized by rapid technological change. Engineers who possess a more thorough knowledge of information retrieval strategies and information resources will be more effective in educating themselves” [1]. Thus begins an abstract for a 1995 conference paper. The need for information literacy has not decreased since that time. While students arrive on campus very comfortable with the World Wide Web, they are not trained in efficient use of electronic or traditional resources, nor are they necessarily able to evaluate resources for quality.

As resources increase in number and complexity, and time constraints pressure an overcrowded curriculum, professors are challenged to find new methods to train students in the skills needed for the marketplace and to encourage learning skills that will prepare them for the life-long learning that is necessary to survive in the constantly changing workplace. Creative collaboration is one technique to address this issue.

One collaborative pairing which directly addresses these needs is the engineering professor with a librarian. The immediate goal is to integrate information literacy skills into the engineering design classroom and specifically as a means to improve product/solution design projects. The long-term goal is to provide future engineers with the skills to succeed in the classroom and to access and utilize the information that will encourage life-long learning and adaptation to the changing technical world.

One factor that must be considered for a successful collaboration is buy-in from both members of the team. The librarian must display both appropriate knowledge of the subject matter and interest in the student projects. The engineering professor must demonstrate that information is important in the engineering design process. If the professor appears to place little value on information or to have no interest in information research, the students may perceive the session as a time-filler or busy work.

Factors that interfere with this collaboration include professional time constraints, classroom time constraints, an already crowded curriculum and the fact that many classes can use the text for all class work. Another factor is meaningful, timely communication between the librarian and the teaching faculty. A clear understanding of what is happening in the classroom, expectations for the class, and the role of the library in meeting these can be lacking.

In this paper, we discuss the methodology and collaboration results, and end with several conclusions. Two are especially relevant to this project. First, time and content are very important. The librarian must know and understand the course, the role of the library in meeting the goals of the course, and tailor the instruction to it. It must also be timely so the relevance is very clear to the students. Second, the goal must be self-sufficiency of the student. Handouts, online help, and tutorials are important and must take into consideration the realities of student needs and skills rather than the preferences of the faculty or librarian.

II. LITERATURE REVIEW

There have been several studies that have addressed the need for library skills in the curriculum. For example, the University of California at Berkeley has studied this need for years [2]. Their Teaching Library was formed in 1993 to “ensure that all graduates of the university are thoroughly familiar with the information resources and tools in their respective fields of study, trained in their effective use, and, beyond that, prepared to conduct a search for information resources in any field of inquiry” [2, pg. 73]. Over the years of study the researchers found that students overestimate their knowledge of libraries and resources. We note that “the most fundamental conclusion … is that students think they know more
about accessing information and conducting library research than they are able to demonstrate when put to the test" [2, pg. 83]. It was shown that students who receive instruction in the use of information resources are more likely to use a broader range of resources [3].

Other studies looked more specifically at science and engineering students. Leckie and Fullerton [4] provide a short review that reiterates the low level of use of libraries and library resources by engineering students. Likewise, Poland [5] states that despite the necessity of information requirements, engineering students are least likely to know about and use the literature in their field, instead depending on informal channels of communication. In fact, Poland states this attitude transfers into their career. Studies have shown that engineers rely first upon their own previous experience, second upon their personal store of information, third upon colleagues, fourth in house technical reports, handbooks and standards, and then upon the published literature [5].

If the lack of use and the lack of skills to utilize a library are an accepted fact and information literacy is considered to be important, then strategies need to be devised to address this problem. Indeed, many attempts have been made in this regard. A number of studies review a variety of library methodologies. These include Huge et al. [6], Holland and Powell [7], Tucker et al. [8], Ackerson and Young [9], Bruce and Brameld [10], Holmes et al. [11] and Weiner [12]. These studies focus however has been mostly on proposing and comparing methodologies, not on the results of the methodologies used or the results of the class projects.

While there are various ways to integrate information literacy training at the undergraduate level, recent research suggests a preference for embedding the teaching and assessment of such skills into existing courses [13–15]. It is argued that instruction is more successful if it has a direct link to a class and is delivered when needed—just-in-time instruction. In addition, a close collaboration between a librarian and teaching faculty is important. Without collaboration, library instruction may not be closely focused on course syllabus. In addition, the examples and assignments may not integrate with engineering assignments. To be judged by the students as worthwhile, library assignments must directly address the immediate needs of the students. In many cases, librarians address general skills or a particular set of resources. The methodology and the resources are used to advance the concept of lifelong learning. However, with no immediate application students may pay little attention, not see the relevance, and not incorporate the skill into their learning schema.

In the above cited applications the effectiveness of the implementation was either not measured [6, 11, 12], or was measured only for the quantity and quality of the information resources used [10], or only the quantity and quality of the information resources used and correctness of the citations [7, 9], mainly to determine the effectiveness of different types of instruction. However, the impact of the bibliographic instruction on the improvement of the student outcomes has not been assessed. For example, information gathering is an intrinsic part of design process and designing is a common activity for most engineers. Yet, none of the studies indicated above assessed the impact of information literacy instruction on the design performance. There are, however, controlled experiments that looked at the information gathering and using behavior during design such as studies by Christiaans and Dorst [16], Ennis and Gyeszly [17], and Bursic and Atman [18].

Christians and Dorst [16] conducted a study to explore the role of the knowledge in industrial design engineering. More specifically, they compared the knowledge seeking behavior of second-year design students with final-year design students. In the study, students were asked to design a litter disposal system for a new Dutch railway carriage, and were expected to ask the experimenter for additional information as they solve the problem. Results indicated that compared to final-year students, first-year students asked for less information about the litter disposal system and the context in which it would be used, and totally ignored information related to customers. A similar experimental setup was later used by Bursic and Atman [18], where they asked engineering students to design a playground for a fictional neighborhood. The results indicated, similar to those in the Christiaans and Dorst’s study, senior students asked more information on the specific system being designed and the situation the system had to function in compared to freshmen students included in the study. Both of these studies were protocol studies where students were given a short time (2–3 hours) and were asked to think-aloud when completing the assigned design task. In addition, Bursic and Atman’s experiment looked at the correlation between information request amount and the quality of the design, defined as the conformance of the design to the design criteria and constraints. A moderate relationship was found (r = 0.61), which partly explained the final design quality. However, in neither of the studies an intervention to improve the information literacy skills of students was included.

One other study by Ennis and Gyeszly [17] investigated how designers introduce information to design by observing six professional engineers as they solved a packaging problem. Three major findings of this study were: (1) concept generation was influenced by information about system topics (distribution environment, production processes, user environment, or corporate environment) as much as by the specific design tasks; (2) the information introduced by designers was divided into three categories, (a) key performance parameters of the specific design task, (b) key performance parameters of the system, and (c) secondary parameters defining the system boundary. Finally, the researchers concluded that information acquisition was an integral part of the design process. However, this study did not consider the relation between information usage and design performance.

Our study fills a void in the literature by investigating the impact of the information literacy training (external guided research) on the performance of design teams.

III. EXPERIMENTAL DESIGN AND APPLICATION

Two sections of the Introduction to Engineering Design (ED&G 100) course at The Pennsylvania State University (Penn State) were included in the study. The same instructor taught both of these sections during the spring 2002 semester. Each section consisted of eight, mostly four-person teams. Experimentation was conducted in two phases: design project 1, and design project 2. The first design project involved building a weighing system using strain gages and beams. After a series of guided, hands-on experiments with electrical resistors, strain gages and beams and lectures on the mechanical behavior of materials, teams were asked to build a weighing system that can accurately weigh objects within a specific weight range to a specified resolution.

After the first design project, teams were presented with the second design project. The design task along with several design
requirements was conveyed to 16 design teams. Each team was given eight weeks to come up with their best solution. During this time, they were to act as companies that were competing to get the project sponsoring company’s business with their design solution.

The second project was to design and prototype all (or part) of the process required to assemble an inverted tooth chain assembly from its individual components. It was sponsored by Morse TEC (Transmission & Engine Components), one of six divisions of BorgWarner. The design task was to develop an innovative process to assemble the components into a finished chain with the design criteria including quality, flexibility, assembly rate, component sorting, and ergonomics.

For both projects the performance was measured using team quizzes, peer design evaluations, and a blind review of the design reports. The weights of these grades were 5 percent, 23.75 percent and 71.25 percent respectively. A team quiz is an assessment during which a set of questions is answered by a team of four in 15 minutes. Only one member would need one hour to solve the same set of questions. The time allowed for completion of the team quiz was adjusted based on the group size. However, for absent/late members, no time adjustment was permitted. The application of team quizzes was practiced during the first design project. Throughout the semester, design teams were kept the same for both design projects.

The aforementioned grades were used to establish a project grade for each design team. Thoroughness of the project report, timeliness of the project report submission, compliance to project requirements, and utilization of engineering problem solving skills were used as criteria for project performance evaluations. For the blind review of the reports, the rubric presented in Appendix A was used. In addition, for late work report grade was reduced. The blind review of the reports was completed by a graduate engineering student who formerly was a teaching assistant for the same course. Peer evaluations of contribution levels within teams during both design projects were used as an independent variable in the study. These peer evaluations were done after the design project was completed. During these evaluations students were asked to rate their teammates’ performance based on 11 different items using a scale of 1–5. Appendix B presents these 11 items. Each student’s evaluations completed by his teammates’ were then averaged and normalized to give his contribution value. Average team contribution level is calculated as the average of these member contribution levels per team.

The gender composition of the design teams was also included in the study as an independent variable. In the data set, gender composition was represented as the number of female students in the design team such as a “0” for an all-male team, and a “2” for a 2-male and 2-female team. Additional independent variables were the meeting time for ED&G 100 course sections that were included in the study, the average GPA of the team, and the training that was varied among sections. Independent and dependent variables of the study are summarized in Table 1.

One section was intervened with a high performing team skills training while the other received external guided research experience to be used during product design task. The content and delivery issues of the high performing skills training were discussed in detail in an earlier publication [19]. The reason for including two interventions as opposed to having one intervention and one control group is to eliminate the potential difference in in-class time allotment to design teams that could impact design performance.

During an 8-week design project where students spend two hours in-class time, an intervention that takes 4 hours in class time could have the potential of confounding study results unless a similar time adjustment is done to the control group. As such an intervention that could be related to improving design team performance was chosen to last a similar amount of time in the control group: high performing team skills training. This control group intervention was implemented in the same course before, and while its impact was not significant, its direction was in a way to positively impact the design performance [20].

### IV. GUIDED RESEARCH EXPERIENCE: CONTENT AND DELIVERY

The planning of the library sessions for ED&G 100 carefully considered the research done on successful information literacy programs and the specific situations in the engineering classrooms. Before any sessions were planned or Web pages developed, long discussions of course goals, assignments, syllabus and projects were held. Guided research experience topics and assignments were reviewed as they were created and revised as the semester progressed to address any changes that were needed.

Course goals, assignments, syllabus, and the final project were reviewed by the instructors when planning the library sessions so the sessions would accomplish two purposes: to introduce resources and skills that would have long term benefits for the students at the university and beyond; and to provide skills to improve their ED&G 100 design project performance. The sessions were approximately fifty minutes long, included demonstration, discussion, and active learning exercises, and graded assignments. The emphasis during these sessions was on practical application of these skills that were transferable from one database and subject to another.

The first session is an introduction to the library sessions, assignments, and the role of the library in engineering research. The librarian emphasizes the relevancy of the library to the ED&G 100 class, engineering education in general, and to the professional work that follows formal training. Basic library skills are taught: the catalog, resource formats (handbooks, dictionaries, standards, etc.), library services (interlibrary loan, online renewals, etc.). After the review, the students take a tour of the engineering library and meet the staff.

<table>
<thead>
<tr>
<th>Table 1. Independent and dependent variables.</th>
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<tbody>
<tr>
<td><strong>Independent Variables</strong></td>
</tr>
<tr>
<td>1. Gender composition of the team</td>
</tr>
<tr>
<td>2. Class meeting time for sections</td>
</tr>
<tr>
<td>3. Training</td>
</tr>
<tr>
<td>4. Average cont level</td>
</tr>
<tr>
<td>5. Average GPA for design team</td>
</tr>
<tr>
<td><strong>Dependent Variables</strong></td>
</tr>
<tr>
<td>1. Design project performance</td>
</tr>
<tr>
<td>Team quizzes</td>
</tr>
<tr>
<td>Peer project evaluation</td>
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<tr>
<td>Blind review of reports</td>
</tr>
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</table>

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The short assignment is provided reinforcing the skills related to searching the catalog. Each student is required to do this graded assignment.

The second session builds on the first. The librarian looks for common errors in the graded assignment and reviews these in class to correct the misunderstandings. The major focus of the session is the large number of databases available for research in journal, magazine, and newspaper articles, as well as conference papers and reports. The databases discussed include ProQuest Direct, Compendex, Applied Science and Technology, and NTIS. The first is a good index to interdisciplinary research articles and to business information, the others are basic indexes in engineering and especially useful to beginning students. All of these are in electronic format and some have full text articles linked to the index record. Again, a short assignment requires students, now working in teams, to explore each of these databases.

The third session begins with a review of common errors and then moves on to the Web resources. Students are very “Web-savvy” and often turn to the Web before searching other more appropriate resources. The benefits and drawbacks of this are reviewed and some quality sites are noted. Last, the students are given a number of Web sites and review them in their teams using criteria as presented in class. Sites from government, professional organizations, educational institutions, and businesses are used and discussed for accuracy, authority, objectivity, currency, coverage level, and appropriateness. One interesting twist is the inclusion of a bogus site that meets all of the criteria of a good site except accuracy. This provides both a little humor, as well as a valuable example of how difficult Web evaluation can be. In the end, teams have an assignment to find several specific types of evaluated Web pages that will advance their research.

The fourth session begins as the previous sessions and then moves to a patents database and a discussion of the role of patents knowledge in engineering design. The importance of correct bibliographic citations is introduced by an exercise in which the teams try to find a record for citations that do not include all the necessary information. While a mundane topic, it is necessary for quality research papers. The last topic discussed is plagiarism, a topic of extreme importance and increasingly easy to do with the copy and paste nature of online resources.

The final assignment brings together all of the skills learned in the four sessions. The students, working as a team, are expected to search the catalog, databases, and Web to find appropriate resources in all the areas studied. These resources are related directly to their final design project. The design of this final assignment is the result of careful collaboration between the instructors. The assignment is not “busy work” but research that can be directly related to advancing and improving the design project.

V. RESULTS

The data set, collected as described with experimental design and application section, is given in Table 2. In the table, under the column heading “Training” type of the training received by teams is represented with the numerical values “1” for high performing team training and “2” for external guided research training.

As can be seen in Table 2, despite a higher average GPA for team 9–16, their overall average project grade was 90.24, which is about 5 percent lower where a 100 is the perfect score. Furthermore, in an earlier study it was shown that average GPA of design teams significantly affects their design performance [20]. This result, a higher average design performance despite a lower average team GPA, is attributed to the difference in training they have received, and the positive impact of the guided research experience intervention on the performance of design teams.

When the independent variables were investigated for their potential effect on the design project performance using a multiple regression the following results were achieved, where:

\[ C_6 = 71.7 + 3.04 C_2 + 6.92 C_3 + 12.4 C_4 - 31 C_5 \]

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coef</th>
<th>SE Coef</th>
<th>T</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>71.70</td>
<td>22.54</td>
<td>3.18</td>
<td>0.010</td>
</tr>
<tr>
<td>C_2</td>
<td>3.038</td>
<td>1.236</td>
<td>2.46</td>
<td>0.034</td>
</tr>
<tr>
<td>C_3</td>
<td>6.920</td>
<td>2.279</td>
<td>3.04</td>
<td>0.013</td>
</tr>
<tr>
<td>C_4</td>
<td>12.447</td>
<td>7.545</td>
<td>1.65</td>
<td>0.130</td>
</tr>
<tr>
<td>C_5</td>
<td>-31.53</td>
<td>24.11</td>
<td>-1.31</td>
<td>0.220</td>
</tr>
</tbody>
</table>

\[ S = 3.702 \quad R^2 = 57.7\% \quad R^2(\text{adj}) = 40.8\% \]

Analysis of Variance

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>4</td>
<td>186.83</td>
<td>46.71</td>
<td>3.41</td>
<td>0.053</td>
</tr>
<tr>
<td>Residual</td>
<td>10</td>
<td>137.08</td>
<td>13.71</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>14</td>
<td>323.91</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

As seen, the model accounted for 58 percent of the variation in design performance (project grade). Training’s relative importance
for its effect on the design performance is clear as seen in the statistical analysis, and this effect is significant. The implication of this is very powerful: even when the average GPA in a team is not very high, addition of a guided research intervention to the engineering design teaching improves the design performance in engineering teams.

The above regression analysis provides estimates of the dependent variable, and measures of the errors that are likely to be involved in using the regression line to estimate the dependent variable. Below a correlation analysis is also presented (Table 3), which provides estimates of how strong the relationships are between study variables. In following table, each cell contains first the Pearson correlation coefficient, and then the $p$-value. The $p$-value is the probability of getting a value of the test statistic as extreme or more than actually observed, given that the null hypothesis is true [21, pg. 312].

As seen in Table 3, while very close to being significant ($p = 0.06 > 0.05$), the correlation between training and design team performance is not significant. However, it is in the direction that was hypothesized, and its magnitude is substantial. Given the fact that the experiment included two different training interventions in order not to confound the results due to potential differences in allotted in-class time for participants, and the fact that only a small sample size is included in the experiment, it is concluded that the effect of the “guided research training” on design team performance is underestimated. Nevertheless, further experimentation with a larger number of teams is planned. Overall, inclusion of such an intervention to engineering design teaching is recommended for two reasons: (1) it is an avenue to improve design performance; and (2) it provides a mechanism for skill acquisition in support of life-long learning. It is believed that a valuable experience gained in such a manner will likely transfer to other courses and into the engineering practice of our graduates.

VI. Conclusion

To date, several variables affecting the performance of design teams have been studied, such as team composition, female/male ratio in the organization, and teamwork skills training, to improve the performance of product designs. This study furthers this effort by investigating the effect of guided external research during the concept generation phase of the development process. The premise of the study is that as resources increase in number and complexity, and time constraints pressure an overcrowded curriculum, professors are challenged to find new methods to train students in the skills needed for the constantly changing workplace. A creative collaboration “A Guided Research Intervention to Engineering Design Teaching” is one technique to address this issue, which is presented in the paper.

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APPENDIX A

Design Report Evaluation Rubric

1. Design Team Members (2 points): In this opening section, brief introductions of the design team members are included. The required information for each member includes: semester standing, major (declared, undeclared), relevant courses taken before this class, education goals, and major project duties undertaken/completed.

2. Executive Summary (4 points): This section should contain a brief summary of the characteristics of the product you have designed, along with the features designed in addition to requirements of the design problem. Also, a picture of your prototype or an isometric drawing (of the whole design or an important part of it) should be included.

3. Problem Statement (5 points): This section will include the rephrasing of the design problem you are given. It is intended to reveal any misunderstanding if there is any. Accordingly, the list of end-user and customer requirements you have established based on given project info and your research should be included.

4. Design Process (5 points): This section should consist of a brief discussion of why there is a constant need for improving products and hence product designs, and a discussion of how product development companies design new products (Please give at least 2 example of design cycles from existing companies. Remember to indicate references.) As the last item, your team’s approach for product design should be indicated.

5. Product Design Activities and Their Management (10 points): Based on your product design cycle outlined in the section above, list all the activities that should be completed. Applying Critical Path Method with associated time estimates for activities, indicate how your activities are managed (Delegation of activities, management of time, total working hours on the project etc.).

6. Application (30 points): This section summarizes your design process detailing every activity you have listed in the previous section—your approach to solving problems or overcoming obstacles, considerations, technical research done, engineering methods used, and in particular, creative ideas considered and significant ideas discarded. It addresses key design issues such as safety, standards and environmental impact. It is expected that throughout this discussion you will include: (1) weighted design objectives tree; (2) a functions/features list your design should do; (3) calculation of design specifications; (4) morphological chart, which shows all possible options for decomposed functions/features; and (5) concept selection matrix with supporting research documentation.

7. Assumptions (2 points): This section is a numbered list of assumptions necessary to enable the design. Justify each one. An assumption is only necessary if the design cannot proceed without it.

8. Warnings (2 points): This covers known deficiencies in your design that are beyond the scope of the project. Warnings serve to alert other engineers and management associated with the project, not the consumer, hence restrict them to technical deficiencies.

9. Design Drawings, Parts List and Bill of Materials (20 points): These summarize and communicate your design and must be sufficient to manufacture the design. Drawings should have scale information and must include: (1) a pictorial drawing (isometric) of your design; and (2) principal views of the assembly and major parts. A Parts List is necessary if parts are numbered in order to associate names with numbers: (1) use professional conventions, and include all dimensions, and (2) do not draw details of standard hardware (nuts, bolts, washers, etc.). The bill of materials lists: (1) materials and their specifications (sizes and quantity) necessary to manufacture Parts; and (2) off-the-shelf hardware. It may include weights and costs.

Typical Bill of Materials

10. Calculations (15 points): For necessary parts of your design consider possible working scenarios. Analysis should be used to determine dimensions or to check critical issues related to the design specifications you have indicated earlier (stresses, deformations, linear momentum, kinetic energy). Title each calculation set by Part/Feature name.

11. References: This section is a bibliography of report, internet and other sources. Cite each where used in the body of the report and list its details in this section.

Examples of References in the References section:

Examples of citations in the body of the report:
- Using the formula for shear stress (Ogot and Kremer, 2004), we find:…
- From AlloyTech’s web site, we found properties for Aluminum 6061-T6…

12. General Quality of the Report (5 points): The design report should be clear, written in correct grammar and spelling with adequate margins; and should follow the sections (in order) discussed above. It should be concise and well illustrated. Text should be typed in 12 pt. size font. Pages should be numbered.
APPENDIX B

Peer Evaluation Rubric

Name of Evaluatee

Name of Evaluator

Thinking about all the interactions that you have had with your team members, please indicate your agreement with following statements using the scale provided:

1 2 3 4 5
Not at all Moderate Amount A great deal

____ 1. Committed to the team goals
____ 2. Participated in the team discussions
____ 3. Comments were clear, relevant and helpful
____ 4. Contributed to the leadership functions
____ 5. Encouraged participation by other team members
____ 6. Kept discussions / work on track
____ 7. Avoided conflict with other team members
____ 8. Tasks done on time
____ 9. Tasks done accurately
____ 10. Tasks done completely