122nd ASEE Annual Conference & Exposition
June 14 - 17, 2015
Seattle, WA
Making Value for Society
Paper ID #12043

Problem solving in a multidisciplinary environment: observations from a newly developed program

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Problem solving in a multidisciplinary environment: observations from a newly developed program

This paper examines how students deal with problem solving in a multidisciplinary environment, during the development of their final project for the semester. Problem solving is considered an important skill for both professionals and students. The paper analyzes one of two courses created for a new multidisciplinary program; this course uses a design studio model. Students attending this course come from disciplines as diverse as computer and network technology, computer graphics technology, electrical and mechanical engineering technology, building construction management, exploratory studies and others. This study is based on the experiences of one of the course instructors, as well as class observations conducted during the final month and a half of the Fall 2014 semester. The findings indicate that students are motivated by opportunities to look at each other's work, and they are engaged by the process of providing feedback during presentations. On the other hand, some issues were observed, such as females being quieter in groups than male students. Regarding problem solving strategies, the groups of students were found to engage in developing one solution as opposed to first considering a range of options and then narrowing down to the best option to further develop. Alternate solutions were considered only when a problem was detected. This corroborates with research on novice problem solving.

1. Introduction

Problem solving is seen as a desirable skill for recent graduates[1], and also for students in general[2–5]. This paper analyses problem solving strategies of first year students in a newly developed program. The program has been created to focus on developing students for a new economic and social reality, in which higher order thinking skills are the driving force. Higher order skills, such as analysis, evaluation, and creation, are extremely important for critical thinking and unstructured problem solving. Or-Bach[6] indicates "…the retrieval and handling of information; communication and presentation; planning and problem solving; and social development and interaction…" (p. 17) are abilities much in demand by the general professional market. The program goals are also aligned with the ones proposed by the Accreditation Board for Engineering and Technology (ABET) for student outcomes in engineering technology accredited programs, such as: design for engineering technology problem solving, teamwork, effective communication, world context awareness, self-directed continuous learning, and problem solving, amongst others[7].

Students who chose to participate in the program have an interest in disciplines as diverse as electrical and mechanical engineering technology, building construction management, computer graphics technology, and exploratory studies. The students enrolled during the semester focused on in this paper attended two core courses: (1) design lab, an introduction to the design process in a studio setting, and (2) seminar, a collaborative experience incorporating English and communication as well as digital literacy, intended to merge technical and liberal arts topics and help students see the world and their domains of study in a more well-rounded and connected way.

In the program students with diverse interests collaborate to develop projects. Multidisciplinary groups are believed to be beneficial for problem solving and creativity because people working in that type of environment tend to produce a wider range of solutions, in less time, showing improved self confidence[8]. This ability has been recognized by ABET´s student outcome "(d) an ability to function effectively as a member or leader on a technical team"[7] (p. 3). Also, most real life problems tend to need input from various disciplines in order to be solved[3]. Because the primary interests of students in this program are in different disciplinary areas, their contributions to problem solving tasks may also vary. Working in a studio environment, students may take advantage from these diverse contributions in order to also learn from peers.

This study uses a qualitative approach to better understand how students with different disciplinary interests apply their problem solving skills in a studio based learning environment, through the use of case study analysis of the design lab class. Observations were made during class time, in the last months of the students' first semester in the program. Using Jonassen's[9] seven steps of ill-defined problem solutions to classify the observations and analyze how successfully peer contributions are made by each student, researchers are able to follow how students collaborate, organize themselves, and share experiences to conduct their design tasks. Also, one of the authors of this study, who was one of the course instructors, shares his thoughts on the experience of teaching this course for students with varying backgrounds and interests.

This paper approaches multidisciplinary problem solving through the lens of social constructivism. In this sense researchers assumed that students learn from sharing experiences and social interactions[10–12]. The study provides complementary information to already-developed theory from the field, but presents findings from students that are not only enrolled in a multidisciplinary class, but who also participate in a fully multidisciplinary program. Findings from this study can help researchers and faculty develop activities that build upon peer learning in a design studio environment. It can also be used to improve the development of ABET´s student outcomes in newly created programs. The driving question for this study is: "how do students in a multidisciplinary studio class undertake problem solving tasks?"

2. Literature Review

This paper uses literature from three main areas: problem solving, multidisciplinary teamwork, and studio environments. The first area, problem solving, is the driving force for the other two (multidisciplinary learning environment, and studio environment).

2.1. Problem solving

As previously mentioned, educational organizations related to K-12 education indicate that problem solving is a necessary skill for students[2,5]. Jonassen[9] takes his definition of problem solving from Anderson[13] who defines it as a series of cognitive operations applied towards a defined goal. In this paper, the authors consider the design activity to be also a problem solving activity. Jonas[14] indicates this as an accepted concept within engineering and industrial design.

Jonassen[15] defines the design problem as a specific type of problem. The design problem is complex and ill-structured. Because of this lack of structure, the design problem often requires that the problem-solver spend a considerable amount of time in structuring the problem. Le, Loll, and Pinkwart[4] indicate that the definition of ill-defined problem is not rigidly established, but general characteristics include: large solution space, no previous defined criteria to judge success, and need to justify choices made.

Jonassen[15] indicates that one of the possible strategies to solve this type of problem is to break it down into smaller and more manageable problems, which are connected to each other. It is also common for designers to interpret the initial criteria to select which constraints should be taken in account while evaluating the final product[15]. This selection requires problem-solvers to think critically about which criterion is more relevant, and which are less important, in order to define guidelines for the generation of possible solutions. Critical thinking can be defined as: "…a purposeful, self-regulatory judgment which results in interpretation, analysis, evaluation, and inference, as well as explanations of the evidential, conceptual, methodological, or contextual considerations upon which the judgment is based"[16] (p. 53). Therefore, critical thinking is also constantly used during ill-defined problem solving.

While developing a model for instructional design of ill-defined problem activities, Jonassen[9] proposes a seven step process for solving ill-defined problems. Although this process seems fairly linear, Jonassen[9] indicates that this is a cyclical process. Learners must understand how to deal with information and decide if revisions of previous steps are needed before moving forward. The phases encompass strategies that problem-solvers deal with, in order to achieve a final goal. The seven steps[9] are presented below:

1. Define problem space and constraint definitions;
2. Consider possible alternate solutions and points of view;
3. Generate possible solutions;
4. Verify viability of alternate solutions;
5. Monitor problem space and possible solutions;
6. Implement solution;
7. Adapt solution

One of the main characteristics of ill-structured problem-solving is a large solution space; consequently, group work may contribute to the assessment of viable solutions and alternatives by providing multiple and varied perspectives on the problem and the definition of the solution space. Therefore, group problem solving can also be seen as a beneficial exercise that enables students with different opinions to think critically towards a common goal[17].

2.2. Multidisciplinary teamwork

Milliken, Bartel and Kurtzberg[18] demonstrate that heterogeneous groups may help increase creativity and innovation in groups. Rogers[19] stressed the importance of heterogeneous population in his widely cited work about the spread of innovation. He mentions that too much difference can be prejudicial to communication, but populations that are restrained to communication with others that are very similar hinder the process of diffusion of innovations. Milliken, Bartel, and Kurtzberg[18] and Denton[8] found similar results about the value of divergent thinking and heterogeneous groups for idea generation. In this case, group diversity increases the number of alternate solutions to be considered, and strengthens the rationale for making decisions during the design process. Finally, research about problem-solving in the field of design indicates that team performance is often higher than that of individuals working alone, and is also more motivating to students[8].

The term 'multidisciplinary' has no widely accepted definition[20]. According to Denton[8], the term indicates teams of students that come from several different disciplinary backgrounds. Hong, Page and Baumol[21] write that "… diversity in a group of people refers to differences in their demographic characteristics, cultural identities and ethnicity, and training and expertise" (p. 16385). In the case of this paper, multidisciplinary refers to students who wish to pursue different majors, but also to the diversity of interests of students in the program. Observations during class time indicate that students have interests in diverse areas such as music, online gaming, and electronics.

Through interaction with peers in multidisciplinary groups, students must adapt their beliefs and resolve conflicts that may arise. This corroborates with Dewey´s[10] approach of learning as a socially constructed activity. Several researchers have assessed group member learning within teams, through group discussions and feedback[22–24]. In their study, Hong, Page and Baumol[21] compared problem solving skills in diverse groups with that of experts. They have found that "…in a problem-solving context, a person´s value depends on her ability to improve collective decision. A person´s expected contribution is contextual, depending on the perspectives and heuristics of others who work on the problem"[21] (p. 16389).

But diversity in groups is not always productive due to difficulties in interaction and communication[20,25]. In some cases, researchers have found that diverse grouping may have a negative influence on group behavior[18]. Researchers indicate in order to make sense of the diversity in groups, some members may make use of categorization and distinction between members. This is more notable in what Milliken, Bartel, and Kurtzberg[18] indicate as 'detectable differences', such as gender, ethnicity, age. They say: "…when a group is diverse on detectable variables that are salient to members, the simple act of observation of such differences may create a barrier to developing a shared group identity"[18] (p. 37). This suggests that individuals tend to act more closely to members they identify as similar in the group, and distancing themselves from the ones they regard as different. This differentiation may affect how individuals interact within groups. Milliken, Bartel, and Kurtzberg[18] indicate that social identity theory may influence how people deal with information given by members who are not seen as equal. As an example, people tend to take in consideration opinions and suggestions from other similar people, and reject the ones from others. This increases the chance for conflict within groups[18].

Even though difficulties may arise, team work and collaboration seems to be of high importance in the learning process. It also allows students to practice critical thinking especially in diverse groups, because of the evaluation process needed to accept or reject new ideas.

2.3. Studio environment

Studio based learning was traditionally a model developed for design based disciplines, such as architecture and industrial design[26]. The studio model is often applied to design based instruction[26], and design itself is considered a type of ill-defined problem[15]. Brandt et al.[26]

indicate that "Managing the complexity of ill-structured, open-ended problems is key to design work where the work of a designer involves working with uncertain parameters in particular settings that evokes meta-knowledge..." (p. 331). Design problems are accounted by Jonassen[15] among the most ill-defined problems that exist, and a study conducted by Jonassen and Hung[3] questions the benefits of problem based learning for design problems and indicate that maybe a studio approach is more adequate.

In the studio model, it is also common for students to participate in critique sessions that provide them with different points of view and considerations that must then be judged and applied if considered helpful, in an iterative process[26,27]. This stimulates critical thinking, another desired trait for learners in today's society[1,2,5,28].

Learning through critique reviews that occur in design studios is an important aspect for creative thinking. Budge, Beale, and Lynas[27] emphasize that "peer feedback and critique is integral to the creative practice of designers" (p. 147). In critique sessions, peers are often encouraged to give their opinions and review, and this ability to also give constructive reviews is seen as of highest importance in design disciplines[27].

The importance of peer interaction has also been analyzed by Brandt et al.[26]. They analyzed studio learning through two different disciplines (architecture and industrial design), as well as human computer interaction courses that attempted to adapt the studio approach to their courses. They have observed that students often used visual aids, such as sketches, to communicate their thoughts, and that they tried to review and incorporate suggestions that were made by peers and reviewers. The industrial and architecture studios, disciplines in which this teaching method is common, provided space and time for critiques, as well as design revisions. In the human computer interaction sessions that had elements of studio learning, the authors indicate that space and time limitations hindered the development of both larger group work and revisions[26].

3. Methods

This section of the paper is broken down into three subsections (research context, data collection, and data analysis), to facilitate comprehension. This research uses a case study methodology to analyze student interaction within the class. The case study method is a good fit for this study because of the uniqueness of the environment.

3.1. Research context

The course was taught by two male instructors with occasional help from three teaching assistants. The laboratory where class took place (figure 2) provided students access to white-boards for brainstorming, computers, tools, and other resources to aid in realizing their design, including a three dimensional printer. Tables, chairs, and two sofas could be moved around by the students during their semester, to best fit their needs. Students could request materials needed for their projects, including wood, plastic boards, water pumps, special lamps… The space was available for students to work on their own every week day from 9 am to 9 pm, in addition to in-class time. Laboratory assistants, who were also the teaching assistants for the course, were available during non-class time.

Figure 2 – Laboratory setting for the Design Lab course

The Design Lab course, an introductory design thinking course for undergraduate students, had the primary goal of introducing learners to the design process, and making them aware that this is a complex, non-linear process. As a secondary goal of the course, students were expected to explore domain-specific material. Students were presented with the semester project general description during their first month of classes. For the first half of the semester, students spent time on design methods, understanding how to do research for problem-solving activities, and brainstorming. They also worked on smaller projects (in groups or individually) that supported the development of skills they would later need for the 'garden-in-a-box' project, such as building a tower from Lego parts, designing a functioning electronic clock and creating a working thermostat. The goal of the semester project was to develop a garden that could feed or help feed a family in a "food desert" (such as an urban setting). With this, the students could deal with the problem of hunger in the world. Some of the required deliverables of the project were:

- Selection of plants they wanted in their garden;
- A prototype "garden in a box";
- A presentation, made at the end of the semester.

Students were expected to research appropriateness of various plant species and the various types of materials they could use to produce their garden-in-a-box prototype; they were asked to think carefully about such open-ended questions as "is this affordable?" and "will it be easy to use?," which were included in the project definition. Other than these requirements, students worked in groups of three to four students, and were free to develop their design to their liking. They were given some lectures during the course about the design process and physics and electronics principles that could help them develop their work.

3.2. Data collection

As mentioned before, the design lab course is part of a new program under development. The program was launched in Fall 2014 and has a unique architecture. Therefore, comparisons with other years or other programs are not possible. The case provides a new perspective on multidisciplinary learning that is important to be considered, through an "intrinsic case study", as defined by Stake[29]. Stake´s definition of "intrinsic case study" considers that even though generalizations are not possible, the case is still of importance to be analyzed.

The use of multiple data sources is important to support validity (or "trustworthiness") of qualitative studies[29]. In the case of this research, the authors propose the use of an investigator triangulation based on two different observers: (1) instructor´s review of the experience and (2) class observations. Figure 1 illustrates how the different pieces of this paper connect.

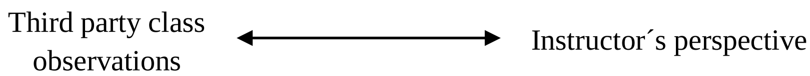

Figure 1 – Proposed triangulation for the observations

The instructor's review of the experience consists of impressions of students' progress during the project of their final presentation and deliverables. Special emphasis is given to group interaction, divergent thinking, and peer learning within the design and problem solving task.

The participants for this research include thirty-three students who were enrolled in the course. Students were working toward a degree in a variety of disciplines, including Aviation Technology (3), Building Construction Management (1), Computer and Information Technology (5), Computer Graphics Technology (3), Electrical or Mechanical Engineering Technology (12), Technology Leadership and Innovation (1), and "Exploratory Studies" students who have not yet chosen a major (8). Among the Exploratory Studies students, interest was expressed in Computer Science, Industrial Distribution, Manufacturing Engineering, and Mechanical Engineering, although several had not yet selected a field).

Observations of the course by the third party observer were made from November 3rd, 2014, until December 10th, 2014. The design lab course met formally twice per week, from 11:30 am, until 3:20 pm. A total of ten different classes were observed. Duration of observations ranged from 45 minutes to one hour. The final presentation of the projects, which happened on December 11th, 2014 was observed in its entirety. During these periods, one researcher (who was not an instructor) attended for approximately one hour of each of the meetings. An observation form provided a method for notation regarding the overall theme and participation of the class, as well as observations of small group behaviors. In the form, the researcher indicated in which phase of Jonnasen's[8] ill-defined problem strategies the groups were currently working. The observations included the students' work development for the course final project, called "the garden-in-a-box project" and their final course presentation.

As a second observer, one of the instructors of the course, who was responsible for reporting to this study his final impressions. He was present at all but one class during the months of November and December. His impressions of the course were written after the end of the course, and described his experiences in teaching a first-year course to students with diverse academic interest, in a studio setting.

This study assumed that students were performing most of their design lab work during class time, and that the observations performed through November and December classes are representative of their semester of work. Due to time and resource limitations, the researchers could only base their findings in periods of one hour observation per meeting, and only after they had already started working on their final semester project. Observations were made at different times on different days, allowing for the researcher to note any differences in activities across the four hour session.

3.3. Data analysis

Data analysis was performed in two phases. First, following the guidelines of provisional coding[30] an initial coding scheme was developed, based on Jonassen[9]'s problem solving strategies. This scheme was used to code the observation notes.

The second phase included comparing the third party observer's reflections to those of the instructor. Both observers reported their impressions individually in written form. The observers reviewed one another's notes. Results were then analyzed by both observers in an iterative process, with special attention to reducing bias and emphasizing complementary information in order to produce a more accurate view of the course experience.

4. Results

Results are separated into two main areas: first, the instructor's view of the course and student progress, and then observations made by one of the researchers.

4.1. Instructor's impressions

One of the instructors of this course is also a co-author of this paper and has described his thoughts about the course and, more specifically the garden-in-a-box project, in the following paragraphs.

The instructor noted that most of the students were unfamiliar with the design process, including the difficulties and frustration of dealing with complex problems. He indicated that all of the students were able to demonstrate at least a rudimentary view of the process by the end of the semester.

One important aspect of the course design was the use of space—in both a physical and a metaphorical way. The room was deliberately filled with movable, lightweight, and/or wheeled tables, chairs, and whiteboards to allow for learners to transition quickly and easily from discussion to planning to prototyping, as can be seen in figure 2. Additionally, the furniture included couches and a "lounge area," to provide a space for students to break from their work for short periods of time. The lab was available to students until 9:00 pm daily, and the class sessions were relatively "free-form," allowing students to come and go as they saw fit; attendance wasn't a specific concern; completion of work and demonstration of improvement was, and students were given the option to attend and receive the benefit of ongoing formative assessment, or to leave and work independently. Additionally, learners were given some leeway in the amount of focus they put into their work in class at any given moment; in part, this was because some research suggests that stepping away from design problems when the learner/solver is frustrated is essential to the creative process—sometimes the brain needs to work in the background. The instructors discussed this early in the semester, and while they didn't encourage off-topic time, they did permit it. When it seemed to become the focus of learners, as opposed to a deliberate distraction, they would step in and redirect.

Developing the working problem for the final project was also a difficult task, because it needed to be at the same time open-ended, authentic and complex, and yet manageable for students and instructors. The instructor indicated that the garden problem had all these characteristics, and also allowed for students to develop their creativity through divergent designs. Although some constraints given to students did not allow for them to be as divergent as a more open-ended problem could have been, he felt that students needed some guidance and structure to deal with the openness of the design problem. The instructor indicated that the amount of openness was adequate for the first semester class, given the struggle the students faced with the reduced structure of the course, even though this may have reduced the variety of solutions presented at the end of the semester.

The use of the studio model posed a number of challenges for the instructors. The instructor indicated that it takes more one-on-one time in comparison with a traditional lecture-and-lab course. He mentioned that he wished the course could have three instructors instead of only two, so they could have provided more just-in-time instruction for the students. The class had a ratio of approximately 17 students per instructor. Students frequently struggled with the lack of instructions and sought extra guidance, but lacked the ability to formulate specific questions for the instructor, and often asked vaguely that instructors "teach more". This required the instructors to be ready to rapidly adapt in order to provide not only feedback but guidance that was tailored to the design phase and struggles of each group of students of students and the specific technology students were struggling with.

Three laboratory assistants were available, mainly during out-of-class time to monitor the lab and provide assistance to students that requested it from them. The instructor indicated that these graduate students could have been better used as teaching assistants to the design lab, as they could also have been trained to help more directly with the projects and course work.

The instructor also indicated that more resources, such as references and lectures, could have been used, as to provide learners with a more solid base for the design process they were undertaking. This could also provide them with more references that would help them develop their garden project.

The instructor was pleasantly surprised by the final design review presentations on multiple levels. To begin with, it was not entirely clear that all groups would have working prototypes of their designs ready to demonstrate for the design review; however, by the review session, all but one group (an outlier group whose members failed to attend class or perform any work for the course) had working projects (albeit with varying degrees of polish). Additionally, learner participation in the review process—both giving and receiving peer critique—was extensive.

Of the eight projects presented, four (informally known by students and instructors as the "5-gallon jug" project; the "wooden drawer" project; the "long enclosure" project; and the "single-plant wicking" project) were fairly polished prototypes. The remaining four projects presented (the "asparagus" project; the "big box" project; the "jug-and-rack" project"; and the "plant-pot cover" project) were rougher and presented as earlier prototyping models. All eight projects addressed—in some way—irrigation, temperature control, lighting control, plant selection and enclosure. Some projects also tackled user manuals/user training methods. Divergence in overall solutions—as expected, given the established bounds of the problem—was not incredibly high; however, within the context of specific elements of the project—irrigation, lighting, etc.—some groups showed greater divergence than anticipated. For example, two groups focused on wicking and capillary action as an irrigation solution, while the other groups focused on more straightforward valve/tube/pipe systems.

The instructor was also quite pleased with the ability of the majority of learners to give and receive constructive feedback during the review sessions throughout the semester, but particularly at the end of the semester, when the stakes were admittedly higher for the learners. There were a number of examples of opportunities for learners to berate some of their peers for less-than-polished prototypes, yet this did not happen; learners instead focused on the ways in which those prototypes were successful, while acknowledging where improvements could be made. Additionally, a handful of learners were confronted with questions they could not answer or with concerns they had not considered in their design; in most cases, these were accepted by the learners as opportunities to think through their design from a new perspective. In only one case did learners receive such comments defensively; however, only minor redirection was required to reframe their perception of these comments.

4.2. Observations

Most of the class sessions observed consisted of group work on the garden project. One of the observations happened during a fluids lecture (November, 3rd). The content of this lecture was explained as it pertained to the student's final project. During some observations, instructors constantly reminded students about group time management. During at least one class, one of the instructors gave a brief explanation for students about submitting their work through an online system in order to be considered for approval. Attendance for class was not rigidly demanded, although strongly encouraged by the instructors. During class time, class engagement was mixed.

There were a total of nine groups, consisting of three to four students each. Female students were a minority, and no groups had more than one female student. Of the nine groups in the design lab class, four were observed constantly working on the project, either through discussions, manual work, and brainstorming ideas. Three groups were not as engaged in the beginning of observations, but appeared to gain interest towards the end of November. Finally, two groups did not seem as engaged as others.

Another recurring behavior during the observations was that student often digressed to other subjects, or non-class related issues. These digressions happened many times during the observations, but generally did not last for longer than five to ten minutes per digression. These were not repressed by the instructors, unless the majority of group was distracted by these activities. The digressions appeared to be a way students coped with the stress of coursework and the design process. They also contributed to the formation of stronger social ties between students.

Some groups experienced difficulties with their design. Reactions to these difficulties were diverse. One group had difficulties making their water pump to work automatically, because the one they had purchased was not strong enough to take the water from the bottom of the garden to where the soil was. They appeared to be frustrated with this problem, because they would not have time or money to replace the pump. During one of the observations this same group, composed of all male students were observed considering alternative solutions for watering the soil.

One of the less-engaged groups in the group was another male triad. Of the three students in the group, only one was constantly in class. He would often work alone, but because of the lack of team members and engagement, he was frequently observed working in activities that were not related to this course. Instructors have noticed this behavior and probed routinely about the team's progress. At least one of the students was observed mentioning that he would not continue to enroll in the program in the following semester.

Student behaviors were fairly consistent across the most engaged groups. Much discussion between team members was seen. Most of these groups chose to have discussions around a whiteboard in order to organize their thoughts. Another recurring pattern seen in these groups was that they were curious about the other teams' progress. During one of the classes observed, one of the groups (consisting of one female and two male students) was working on testing their garden. The female student was not present at the time of this observation. After trying their system and noticing it was successful, one of the male students called out in excitement. This yell made students that were working in two near-by groups stop their work and inquire about the reason for their excitement. One of the male students from one of the other groups stopped his work to get closer to the group and observe their project. This interaction was brief, but showed the students' satisfaction with the success of their design. It also made the observing students more engaged in pursuing the development of their success.

Peer learning was also observed, especially when one of the students mentioned that he or she was not able to understand an issue they were working on, or when one student mentioned that he or she will not be able to perform as expected. An example was the observation of a group of three students (two males and one female) that were working individually on computers, but beside each other. During this time, one of the students mentioned he did not understand all the requirements for the garden project. Upon hearing this, the other male student offered to help him with the requirements. A similar example, although more focused on peer encouragement, was observed when instructors informed students that they would have to turn in construction drawings for their design, and that one of the ways to do this was to work on specific software. Two male students discussed the topic, and one of them mentioned that he is afraid he will not have enough time to learn the software. The student that was sitting beside him mentioned that he learned to use this software package in high school, and that "*if* [he] *could do it as a sophomore in high school, than* [you] *can do it now!"*

Observations made for this study indicated that out of the seven steps indicated by Jonassen[8] to solve ill-defined problems, the students in the design lab focused mainly in steps one (problem articulation and constraints), three (generate possible solutions) and six (implement and monitor solution). During the first four classes observed, students seem to alternate from evaluating constraints and requirements, and brainstorming possible solutions. From observations five to nine, the groups focused on step six (implementation and monitoring of solution). Problems frequently appeared during this phase, and were dealt with as they became an issue. For example, a group composed of three male and one female students was assembling a box for their garden. One of them was putting the wooden pieces together, but used screws that were too long. The screws therefore came out on the bottom of the box. The student who was assembling the box was apparently frustrated with the inconvenience and discussed with two other students, who were not in his group, how to solve this problem. After a brief discussion, he then decided to take action and started hammering the screw, in an attempt to fold the edge that was sticking out of the wood. The solution did not turn out to be viable. He then took a saw and started sawing the points that were too long. The process took too long, and the students left the issue for the duration of that observation. This observation exemplifies how students dealt with problems that arise during the implementation of solutions.

Only 3 design reviews took place across the semester: one for research and problem framing, one for preliminary design concepts, and a final review of the prototype garden projects at the end of the semester. Of these, only the last one was observed as part of this research. During the ten observed periods, instructors were often observed giving feedback to groups upon request, or going around the laboratory asking about the groups' progress. The final presentation made by the students was taken as a final design review, during which other students also provided feedback to peers.

It became apparent to the researcher that made the observations that most female students often appeared quieter in groups than male students. A total of six female students participated in the design lab class. No group had more than one female student, so six of the groups were either in a triad or quartet consisting of two or three male students and one female. During discussion between group members, more than once it was observed that the female students were quieter than male students, choosing not to make comments. During assembly, again female students were often observed handling materials and making notes, but appeared to be less engaged in wood work and cutting materials than the male students, Even though these differences were seen by the researchers, on no occasion did the researcher observed the female students complain about these issues nor did male students display behavior that would suggest female students should not participate in group activities. Again, these observations consisted of portions of the design lab and may not reflect the actual role of females in groups. When questioned about this issue, the instructor who is also co-author of this paper and has a background in feminism, queer, and gender theory pointed out several moments of female presence in groups, such as: (1) one female student working with a group of four did most of the CAD drafting and modeling for her group; (2) another in a group of four led most of the research and lobbied for the final design the group pursued; (3) another in a group of four did most of the programming; (4) another in a triad did most of the "hard construction" (i.e., cutting of aluminum and acrylic components); and (5) another did all of the cutting of wood components and most of the assembly for her triad.

Finally, the tenth observation made for the design lab class consisted of the final presentations for the semester (figure 3). Students were required to present their design, and also talk about their work process. The whole group was present for this session, and for the first hour, one of the instructors for the seminar class (the other component of this program) also participated. Three other researchers and a staff member who did not frequently interact with the students were also present.

Figure 3 – Design lab class during final presentations (Photo credits: John O´Malley, Purdue University)

Most of the groups appeared to have rehearsed their presentation. This was confirmed by the seminar instructor, who mentioned he tried to assist students in preparing for this presentation. During presentations, groups discussed issues such as their design idea, goal for their project, target population, plant selection, design functionality, major issues and setbacks they encountered. After each group's presentation, questions were taken from the audience. All students seemed to be engaged in questioning their peer's design, and offered helpful critique. Only a few groups took comments defensively and tried to defend their design. Most were welcoming to critique and indicated that the comments were about things they had not considered during design, but were certainly worthwhile points. Questions were often cut down because of time constraints, as all presentations took place during a single three and a half hour class session.

An example of group interaction during presentations was that one of the groups, consisting of four males, who had the biggest garden. Their project consisted of a 3'x 3' x 4' wooden box, with an automated watering and lighting system. Their watering system did not work as expected due to problems with their water pump installation, and box execution. This group's design was significantly different from others because it was much bigger than the others (who targeted populations living in smaller spaces), and because their garden was completely hidden inside the box. After the students' presentation, many other peers commented on their design, indicating that they thought it was smart to focus on quantity, given that the goal given was to fight hunger. Several suggestions were made to the students regarding how to embrace the decision to "go bigger" such as to use the box as a furniture piece, to be careful about dimensions in order to fit the garden through doors, and to place a side window (for users to access the garden without disrupting the water and lighting system) or an alternative way of accessing the garden. This group was very receptive of feedback, and discussion was productive until the point that one of the instructors had to intervene in order to move on to the next group presentation.

As mentioned previously, students' designs varied considerably, from portable and fully automated, to bigger and less automated gardens. The quality of the prototypes also varied. Some students presented neatly crafted wooden or metal prototypes, while others were in a more of a developing phase. Figure 4 presents four designs presented by the group of students.

Figure 4 – Examples of gardens presented by the design lab students (Photo credits: John O´Malley, Purdue University)

After all presentations were complete, the instructors mentioned that individual feedback would take place in the following week. These sessions were private with only instructors and students, therefore no observations were made.

5. Discussion

In this class, there are no traditional grades; students are expected to show their work in order to obtain competency badges. The badge system is being used currently in classes for this program (seminar and design lab). Evaluation and discussion of this system is outside of the scope of the current paper.

It is interesting to notice that several of ABET´s student outcomes were encouraged through the garden-in-a-box project. Table 1 presents the student outcomes for engineering technology accredited programs that were used in the project. For the full description of the student outcomes ‘a’ through ‘k’, please see ABET´s report on engineering technology accreditation program[7].

Table 1 – Engineering Technology ABET student outcomes as it pertains to the garden-in-a-box project

ABET Engineering Technology baccalaureate student outcomes[7]	Relation to the garden-in a box project
(b) use of STEM for engineering technology problem solving	• plant selection for garden • determining amount needed for water and plant nutrients • defining the design characteristics and constraints of the garden-in-a-box
(c) ability to conduct and interpret experiment results for processes improvement	• students should test their product in order to search for flaws or improvement opportunities
(d) design problem solving	• students were free to develop their own design solution for the problem stated
(e) be an effective team member or leader	• students worked in groups
(f) engineering technology problem solving;	• students should develop ideally a working prototype of their solution
(g) technical and non-technical communication skills	• students had to present their project, while justifying their design at the end of the semester to peers and instructors
(h) self-directed professional development;	• students were stimulated to look for ideas and answers in materials outside class environment, such as internet, journals…
(j) world context awareness	• the background for this project was to address the food deserts issue

The instructor indicated that students struggled with idea of dealing with an ill-defined problem, where an open ended solution was required. The same difficulty was also seen in class observations, when some students struggled with understanding goals and requirements of the project. This is consistent with Jonassen[15], who indicated that students spend a considerable time in understanding and defining the constraints of their problem. They also were guided by the instructors to focus on planning. During the planning phase, students were able to break the task in smaller and more manageable pieces. This is suggested by Jonassen[15] as a common way for learners to deal with ill-defined problems. Research performed by Liikkanen and Perttula[31], derived from novice and expert differences, suggests that partitioning problems in smaller pieces is common to novices and experts. The difference between them regarding this fractioning while searching for solutions seems to be that experts do it explicitly, while novices do it implicitly. This idea of creating sub-problems can be also found in Gick[32], who indicates problem decomposition as especially useful for design problems such as architectural or software design.

Regarding Jonassen´s[9] seven steps for solving ill-defined problems, results indicate that students do not use all the steps in a linear order. Steps one (problem articulation and constraints), three (generate possible solutions) and six (implement and monitor solution) were observed most frequently. This may be the result of limited observation, although research on novice and expert differences in design[33] indicates some similar patterns. Cross[33] analyzed several studies on novice and expert differences in design. He indicates that most expert designers may not concentrate as much time and attention in defining problems as would be expected of expert behavior: "… studies have suggested that over-concentration on problem definition does not lead to successful outcomes"[33] (p. 439). Instead, researchers[33,34] suggest that the most important feature for expert designers are correct scoping and information gathering. This information is also corroborated by Björklund[34]. Therefore, the generation of alternatives is not as important as for other types of ill-defined problem solving: "Generating a very wide range of alternatives may not be a good thing: some studies have suggested that a relatively limited amount of generation of alternatives may be the most appropriate strategy"[33] (p. 440). Therefore, the observation of students' behavior that generated a narrow vocabulary of alternatives before moving to executing and evaluating is an acceptable behavior within design problems.

The observations and instructor's review also indicate that students were eager to receive feedback. One of the limitations for the class was that design reviews seemed scarce for the 'garden-in-a-box' project. Three reviews were planned and executed during the semester (although only one was observed by the researcher). A greater number might have been beneficial for learners to become more confident with their design and the process of design development. But even though design reviews did not happen often, it was observed that during the presentation students were highly motivated to make comments and suggestions about each other´s work. The diversity of thinking in class reflects previous research on creativity, studio learning, and social constructivism learning[8,10,27].

Finally, as mentioned by Milliken, Bartel, and Kurtzberg[18], having students work in diverse groups has some drawbacks, such as problems in communication and tendency for individuals to give most support to group members that are seen as similar to them. Observations made have shown female students to be less participative in discussion and during project assembly, but these were not confirmed by the instructor´s impressions. Observations were limited, but suggest further research needed with this group of students about varying participation in tasks by gender. Research conducted by Kimbel and Stables[35] indicates that gender influences how solvers deal with a problem solving task. Females tend to act more reflective during problem-solving activities, while males have a more active approach[35]. Rosser[36] also indicated that gender and ethnicity distribution in groups may influence minority students' motivation and learning outcomes in group tasks.

6. Conclusion

This paper analyzed student strategies for problem solving during a design lab class. The results presented here are based on the last month and a half of activities for the class, during which students have developed a project that should deal with hunger in the world today, mentioned here as "the garden-in-a-box project".

Results indicate that students were unprepared to deal with ill-defined problems, and that the lack of structure of the design problem was often a struggle for them. On the other hand, students found motivational help from their peers, which helped them to progress in the course. Peer feedback and suggestions made during the final project presentation showed that students were motivated to comment and improve each other's work.

As for Jonassen´s[9] seven steps for solving ill-defined problems, analysis indicated that students tended to focus on steps one (problem articulation and constraints), three (generate possible solutions) and six (implement and monitor solution). This corroborates with a different problem solving strategy that is applied to design problems and discussed by Cross[33].

This study suggests several areas for future research. It would be useful to further investigate how technology students deal with the shift of well-defined problem learning techniques to ill-defined problem learning techniques, and more in-depth studies about cognitive strategies used by learners in multidisciplinary environments to deal with design problems. The gender differences observed are not unexpected based on Kimbell and Stables[35] and Rosser[36], but need to be explored further within this context. Authors also wish to further explore whether the addition of more critique (instructor and peer feedback) sessions into the course in subsequent years helps students become more sophisticated in their problem-solving strategies, and better at providing one another with valuable critique (as many will need to do on-the-job as part of design reviews).

Finally, this study shows efforts made for the development of several concepts indicated by ABET as student outcomes during one course within a newly developed program. The first year students have struggled with the lack of class structure, but have found in peers sources of motivation and knowledge. This indicates interesting directions regarding how to accommodate learning goals and student outcomes while adapting course structure to the needs of first year students.

7. Acknowledgements

This research was supported in part by funds from the Purdue Polytechnic Institute.

References

1. Saavedra, A. R. & Saavedra, J. E. Do colleges cultivate critical thinking, problem solving, writing and interpersonal skills? *Econ. Educ. Rev.* **30,** 1516–1526 (2011).

2. International Technology Education Association. *Standards for Technical Literacy: content for the study of technology*. 260 (International Technology Education Association, 2007).

3. Jonassen, D. H. & Hung, W. All Problems are Not Equal : Implications for Problem-Based Learning. *Interdiscip. J. Probl. Learn.* **2,** 6–28 (2008).

4. Le, N.-T., Loll, F. & Pinkwart, N. Operationalizing the Continuum between Well-Defined and Ill-Defined Problems for Educational Technology. *IEEE Trans. Learn. Technol.* **6,** 258–270 (2013).

5. National Research Council. *A Framework for K-12 Science Education: Practices, crosscutting concepts, and core ideas*. (The National Press, 2012).

6. Or-Bach, R. Higher Education—Educating for Higher Order Skills. *Creat. Educ.* **04,** 17–21 (2013).

7. ABET. *Criteria for Accrediting Engineering Technology Programs, 2015 – 2016*. 33 (2014). at <http://abet.org/uploadedFiles/Accreditation/Accreditation_Process/Accreditation_Documents/Current/tac-criteria-2012-2013.pdf>

8. Denton, H. G. Multidisciplinary team-based project work: planning factors. *Des. Stud.* **18,** 155–170 (1997).

9. Jonassen, D. H. Instructional Design Models for Well-Structured and Ill-Structured Problem-Solving Learning Outcomes. *Educ. Technol. Res. Dev.* **45,** 65–94 (1997).

10. Dewey, J. *Logic: The theory of inquiry*. (Holt, Rinehart & Winston, 1938).

11. Hirtle, J. S. P. Coming to Terms: Social Constructivism. *English J.* **85,** 91–92 (1996).

12. Jackson, P. & Klobas, J. Building knowledge in projects: A practical application of social constructivism to information systems development. *Int. J. Proj. Manag.* **26,** 329–337 (2008).

13. Anderson, J. R. *Cognitive psychology and its implications*. (Freeman, 1980).

14. Jonas, W. Design as problem-solving? or: Here is the solution —what was the problem? *Des. Stud.* **14,** 157–170 (1993).

15. Jonassen, D. H. Toward a design theory of problem solving. *Educ. Technol. Res. Dev.* **48,** 63–85 (2000).

16. Astleitner, H. Teaching Critical Thinking Online. *J. Instr. Psychol.* **29,** 53–76 (2002).

17. Lamm, A. *et al.* The Influence of Cognitive Diversity on Group Problem Solving Strategy. *J. Agric. Educ.* **53,** 18–30 (2012).

18. Milliken, F. J., Bartel, C. A. & Kurtzbert, T. R. in *Group Creativity: Innovation through collaboration* (eds. Paulus, P. B. & Nijstad, B. A.) 32–62 (Oxford University Press, 2003).

19. Rogers, E. M. *Diffusion of Innovations*. 551 (Free Press, 2003).

20. Ratcheva, V. Integrating diverse knowledge through boundary spanning processes – The case of multidisciplinary project teams. *Int. J. Proj. Manag.* **27,** 206–215 (2009).

21. Hong, L., Page, S. E. & Baumol, W. J. Groups of diverse problem solvers can outperform groups of high-ability problem solvers. *Proc. Natl. Acad. Sci. U. S. A.* **101,** 16385–16389 (2004).

22. Dym, C. & Little, P. *Engineering Design: A project-based introduction*. (MIT Press, 2004).

23. Edmonson, A. Speaking up in the operating room: How team leaders promote learning in interdisciplinary action teams. *J. Manag. Stud.* **40,** 1419–1452 (2003).

24. O´Brien, W., Soibelman, L. & Elvin, G. Collaborative design processes: an active-and reflective-learning course in multidisciplinary collaboration. *J. Constr. Educ.* **8,** 78–93 (2003).

25. Frigotto, M. L. & Rossi, A. Diversity and Communication in Teams: Improving Problem-Solving or Creating Confusion? *Gr. Decis. Negot.* **21,** 791–820 (2011).

26. Brandt, C. B. *et al.* A theoretical framework for the studio as a learning environment. *Int. J. Technol. Des. Educ.* **23,** 329–348 (2011).

27. Budge, K., Beale, C. & Lynas, E. A Chaotic Intervention: Creativity and Peer Learning in Design Education. *Int. J. Art Des. Educ.* **32,** 146–156 (2013).

28. Green, K. & Jax, C. Problem solvers are better leaders: facilitating critical thinking among educators through online education. *Procedia - Soc. Behav. Sci.* **15,** 727–730 (2011).

29. Stake, R. E. *The Art of Case Study Research*. 173 (Sage Publications, 1995).

30. Saldana, J. *The coding manual for qualitative researchers*. 240 (Sage Publications, 2009).

31. Liikkanen, L. a. & Perttula, M. Exploring problem decomposition in conceptual design among novice designers. *Des. Stud.* **30,** 38–59 (2009).

32. Gick, M. L. Problem-Solving Strategies. *Educ. Psychol.* **21,** 99–120 (1986).

33. Cross, N. Expertise in design: an overview. *Des. Stud.* **25,** 427–441 (2004).

34. Björklund, T. a. Initial mental representations of design problems: Differences between experts and novices. *Des. Stud.* **34,** 135–160 (2013).

35. Kimbell, R. & Stables, K. *Researching Design Learning: Issues and Findings from Two Decades of Research and Development*. 324 (Springer, 2007).

36. Rosser, S. V. Group Work in Science, Engineering, and Mathematics: Consequences of Ignoring Gender and Race. *Coll. Teach.* **46,** 82–88 (1998).