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Simulating Real World Work Experience in Engineering Capstone Courses

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Abstract

Experiential learning and cooperative education provide students with the necessary tools to succeed in the workplace by simulating their future working environment. Various studies have shown that many graduates have gaps related to their so called "soft skills", which are related to teamwork, time management, working under pressure and tight deadlines. The main purpose of the inclusion of the industry expert in senior design discussions is to provide meaningful feedback through a competitive led by industry practitioners. In this simulation, the senior engineering students take on the role of actual engineering job functions, on a demanding, continuous basis for the entire school year or semester. These job functions come with all the shortcomings and particular difficulties associated with those functions in the real world. In order to develop the interpersonal professional skills needed by industry, a methodology presented in this paper is given which allows the student teams to evolve socially as departments, while supporting them with information such as Tuckman's stages of group development, Myers-Briggs type indication, and recognition of the various personalities and issues arising when working in a cross-functional, team based environment. The application of this methodology and course set-up resulted in engineering graduates that were not surprised by the potential difficulties that may be encountered when ensconced in full-time, permanent engineering employment. This paper will detail some of the necessary elements required to make mechanical engineering and engineering technology capstone courses simulate real world work experience and provide students with immersion in their senior design experience which engages their "soft skills". It presents a method whereby the senior design course is taught by a faculty with extensive industry experience and guided by the panel of experts made up of other faculty from the department and industry representatives. The technique(s) presented in this paper were tailored to the traditional roles of mechanical (design) engineers in the modern industrial setting, but can be reapplied to other engineering areas.

Introduction

The emergence of the global economy has changed many of the business practices of engineering employers in the United States and around the World. Due to recent changes related to trends in the global market, both business and industry now need work-ready engineers who can function immediately in a complex engineering social environment[1]. Extended training periods for newly hired engineers are not broadly available anymore, especially in smaller, mid-sized companies. New hires must contribute to the bottom line immediately. Corporate "engineer in training" programs may be too expensive for some companies. Another problem identified by various researchers is that although students acquire technical knowledge they can still be limited in their ability to apply it[1].

Some studies suggest that engaging students in Problem Based Learning (PBL) activities can improve students' motivation[2] and work readiness[1]. While there is much literature and research regarding implementation of work-related capstone courses for engineers, most of these focus on the logistics of setting up the program, and not the conceptual underpinnings of how to make it an effective work-related experience for each individual student[3,4]. There is both documented and anecdotal evidence for the fact that when many engineering employers think of work-ready engineering graduates, they're not as concerned with the technical, as they are interested in the social intangibles[5,6]. There is a competency gap between graduates' professional attributes and the expectations of their employers, in areas such as communication and problem-solving skills, social skills including leadership, emotional intelligence and the ability to work with people of difference[1,7].

The current economic climate has resulted in a need for work-ready engineers and engineering technologists who can fill positions in the advanced manufacturing sector[1, 8]. Statistics on the state of US education indicate that approximately eight percent of manufacturers reported moderate to serious gaps in the availability of skilled manufacturing candidates. In addition, this skills gap has negatively impacted their company's ability to expand operations[9]. There are additionally about five percent of manufacturing jobs which get unfilled even with the current unemployment levels[10]. Industry needs graduates who are able to perform under the constraints of a workplace which require more competencies than can usually be offered in a typical engineering curriculum. There are some things in place in the academic/corporate structures that help to alleviate this issue. One of those is the system of cooperative employment, and internships which provide students with some work experience. These experiences teach them that in order to succeed on the job, they need to develop both interpersonal procedural knowledge and theoretical knowledge[11]. While these experiences can be quite effective, they still have some limitations: there are not enough positions available for all engineering students, and some students are apprehensive to delay graduation in order to "co-op"[12]. Many companies have either eliminated, or scaled back significantly, their programs, further decreasing the number of opportunities; for some of the companies that have kept cooperative engineering positions, these positions have devolved into assistant engineering positions.

This paper will lay out some of the necessary elements required to enable students to perform in an engineering environment where ambiguity is the norm, there are high expectations for on-time delivery of correct engineering information, and little support or mentoring. Focus on these so-called "soft skills" is accomplished by letting the students apply their formal education in (the simulation of) a real world scenario[13]. One way to approach this problem is to enable students to participate in an engineering capstone sequence utilizing these elements and the overall setup outlined. In this way, engineering graduates will find themselves better equipped to navigate engineering employment where the expectation to perform is very high.

Simulation of a Corporate Environment in a Capstone Course

Many graduating engineers often lack interpersonal professional skills; the so-called "soft skills" that allow them to productively function in an ambiguous technical and social environment where there is little or no mentoring and guidance[10,14]. Many employers must now leave new engineers to "sink or swim" and survive "trial by fire". A solution must be sought which is accessible to all engineering students. This solution must be based in the classroom, but must nearly replicate useful corporate experience. Since capstone implementation has become commonly required at nearly all engineering universities, it makes sense to utilize this classroom setting to address this issue. In addition, the chronological position of the capstone requirement make this a timely point at which to give the student this experience, as this represents the student's last engineering course before graduating and taking on full time engineering employment. Capstone implementation also makes sense because this is the type of course where the professor no longer serves merely as a vehicle dispensing wisdom while the students passively attempt to absorb it[15, 16]. Finally, this type of classroom setting is required for longer term retention of information and the development of the problem solving and independent thinking skills needed for the work-place[17, 18, 19]. In short, the capstone setting is ideal for creating an active learning environment, which will be far more effective than simply lecturing the students on the finer points of engineering team success in the work-place.

Setup and Methodology

The experiential learning techniques provide simulation of various learning experiences such as: problem based learning, critical thinking, collaborative learning and peer evaluation. Through the use of situated cognition, and problem based, active learning, engineering techniques are blended with the sociological and psychological factors associated with engineering team projects. The preliminary setup of the capstone course or sequence is all-important in ensuring the success of the learning experience, as well as helping to assure the success of the chosen project. The correct tenor must be established even before the course begins.

Project Selection and Company Support

When choosing projects for engineering capstone courses that will simulate work experience, ideally, the projects would be industry sponsored, or at a minimum, externally sponsored[20,21]. This provides the environment inside the course with the simulation for the required ambiguity[22], sense of urgency, and intrinsic difficulties which can be encountered in the workplace. In this way, students are immersed into a deeper understanding for how they will use their discipline-specific knowledge and skills in industry[22, 23]. The company or external party should be interested in the outcome of the project; so much so, that they are willing to expend their own resources to ensure the successful completion of the project[22]. An overt example of this would be the appointment of someone from the sponsoring entity to monitor project progress and help resolve issues. This person becomes the overseer, or liaison, of the project, from the company or outside entity, to the University instructor and students. The difficulty associated with choosing candidate projects cannot be underestimated. In this way through this kind of cooperative effort, creative alliance, business, university and industry can work together to create a meaningful design experience for students[24, 25, 26]. The project must be fairly narrow in focus, but still require a cross-functional approach to complete. Each project selection should be carefully reviewed to guarantee that it contributes to the goal of bolstering the simulated, “real world” experience. Choices that do not serve this purpose should be rejected in favor of projects that actually do enhance the realistic nature of the project. Some of the engineering sub-disciplines that need to be exercised include, but are not necessarily limited to, the following, shown in Figure 1 below:

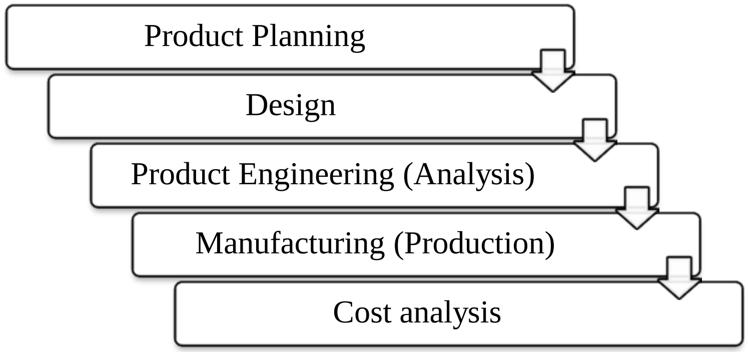

Figure 1: Cross-functional approach required for student senior design project

This requires the project to be relatively simple in scope, have a definable market presence (demonstrated need), be adaptable to analysis without extensive product variations (minimal iterations), and be readily buildable as a prototype. In short, the project should require planning/conceptualization, design, analysis, and product realization. Given this, it is clear that project identification can indeed be difficult. Projects need to be "just right"; somewhere in-between along the continuum of simple wooden block to the space shuttle. It may require extensive work on the part of faculty or administration to cultivate the industry contacts necessary to identify good candidate projects. However, it is well worth the effort.

Selecting Groups and Identifying Teams

The selection of group members and assignment of teams is another critical step in ensuring the quality of the simulation, and the maximization of experiential learning. Leaving team and project assignments to chance is a guarantor that students will learn very little about how to function in an engineering team environment in the workplace. If left to their own devices, students may make selections of both teammates and projects which may not always be ideal. Besides, engineering employees are rarely, if ever, allowed to autonomously choose either the project they work on, or who they work with. The size and scope of the project customarily determines group size and make-up. Generally, based upon socio-psychological factors[27], groups should be no less than three members, and no more than seven students. The primary factor to be considered for team assignment should be the required skill-sets for team and project success. Clearly, this isn't always the way it's done in industry, but the goal is for students to learn the maximum amount, not continually run afoul of insurmountable problems. Even with an ideal team, there will be plenty of difficulties and challenges to be dealt with that will enhance the experiential learning process.

A method must be used to assess not only student skills, but also strengths and weaknesses, as well as personality traits. Instructors may be tempted to make team assignments based on personal knowledge of students. This might work, but, it can be unreliable, and at larger institutions, it may not even be reasonable. The method of making team assignments based on personal knowledge of students should be rejected in favor of a more structured approach. Either early in the senior capstone sequence, or in a previous (at least junior level) course, students should be asked to do self-assessments, using tools such as Myers Briggs Type Indication[28] to reveal their preferences for interaction on teams. This serves at least two purposes: 1) forces the student(s) to recognize their own traits and tendencies. They can subsequently be asked to be introspective about those traits and tendencies. This creates a realistic level of "self-awareness" by the student(s); 2) gives the senior capstone instructor a modicum of understanding of student tendencies. The instructor should of course familiarize himself/herself with all the caveats and limitations that go along with the use of tools like MBTI. The instructor can then assign teams to projects based in part on these factors, in addition to Belbin's nine roles required for successful teams[29]. For engineering teams, a paraphrase of Belbin's roles is shown in Figure 2 below:

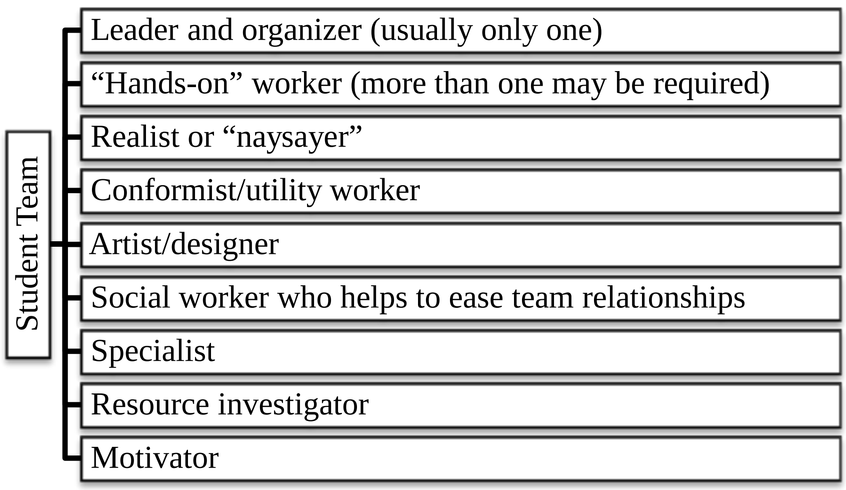

Figure 2: Team roles in senior design projects

Identifying traits in students and assigning them to teams, is not, in and of itself, adequate. The factors at play, individual traits and required role fulfillment, must be explained to students. Along with determination of their Myers Briggs type, students will begin to "buy-in" to group selection criteria. Ultimately, student buy-in must be nearly complete in order to simulate the real-world experience. The reason for this is that most engineering graduates will accept a position at a company that they chose to interview with. They essentially "want" to be there. The same must also be true on senior capstone teams. The final technique used to cement buy-in from students is through direct polling or surveying of student preferences. This may be done entirely manually, through the use of team generation software such as CATME[30], or by a combination of manual and automated techniques using on-line survey resources such as Zoomerang® or Surveymonkey®[31].

<u>Simulation of Real Work Experience in Team Selection</u>: There are three primary areas where students must be given some level of control to aid in securing their buy-in. They are, in priority order; 1. De-selection of one teammate, 2. Project selection and 3. Selection of one teammate. None of these three selections should be "guaranteed" to the student(s). They should however be taken into account while comprehending the decreasing priority level of the selections. The de-selection of another colleague is important for two reasons. It may of course help reduce social team interaction issues that might arise later. More importantly, it serves to address actual issues that mimic problems in a place of employment; harassment is just one such example. The selection of one's own project clearly serves to increase buy-in by the student(s).

Projects are selected by the student(s) from a list provided by the instructor. This helps to ensure that the project meets the perceived needs of the student(s), as well as meeting the afore-mentioned suitable project criteria. Alternatively, students may also be allowed to submit project proposals for approval by the instructor. These are then reviewed by the instructor for suitability and placed in the pool of possible project selections.

Student selection of a project should not guarantee assignment to that project. The instructor must balance the previously mentioned factors (if all the "leaders" want the same project), and meet the educational needs of the student(s), all while securing student buy-in. This still serves to imitate real-world practice. Engineering employees may ask for certain assignments and projects; but they are not guaranteed to get them. Teammate selection is the least important of the three student self-selections. It emulates the work experience inasmuch as engineering employees may work with their "friends". Since most engineering employees don't always work with all their friends, it makes sense to temper this aspect of self-selection. While it naturally fosters buy-in and ownership on the part of the student(s), the instructor again must assure that the group needs, student(s) educational needs, as well as the need to create the correct experiential environment are all met. Finally, beware of all the "good students" self-selecting to be with each other. According to Belbin[32], this can cause various problems for successful team performance.

The process of self-selection and team assignment should be completed no later than the mid-point of the first semester of a two semester capstone sequence, or, before classes begin for a one semester capstone experience. Early identification of teams serves to set the stage for capstone expectations from the start, as well as build excitement and buy-in from students. Another benefit of completing this process as early as possible is to allow the team to move through Tuckman's stages of group development more readily[33]. Participating in stages of forming, norming, storming, and performing, generally requires the team to spend adequate time together. The more time allowed for team development, the better[34]. Utilization and explanation of Myers Briggs Type Indication, Belbin's Nine Group Roles, and Tuckman's Stages of Group Development to students should occur before the project selection and team assignment process is done. However, even if it is not explained before-hand, students will still benefit and learn from the project and team selection process.

Communicating the Setup and Expectations

It is imperative that students understand, before the first capstone class occurs, that the capstone experience is not an ordinary course. To effectively simulate work experience, it must be impressed upon the students that completing their project (successfully) is their ***job***. The instructor (or advisor, or corporate liaison engineer as necessary) is now their boss, taking on the role of manager. To help enhance the simulation, students now refer to the instructor (their new boss or manager) by her first name, rather than "Professor" or "Doctor". The students' new found status as employee means they can call the "boss" for emergent situations, and the boss can call them anytime, if necessary. Combined with the periodic reviews by the customer (the industry partner providing the project), this setup serves to provide a level of creative tension, and hence, pressure to succeed, just like the "real world".

The manager is given weekly engineering updates (design reviews) in both written summary, and in a meeting presentation format. By way of clarification, the manager's role is not to do any of the design or engineering. Rather, the manager's role, as it is in industry, is to monitor progress, provide guidance, make high level decisions about direction that the employees may not be equipped to make, offer feedback, remove roadblocks, and maintain creative pressure. The customers, and other high ranking officials, if appropriate, are provided with three opportunities for formal review, unless other arrangements have been made. These include a preliminary design review (concept selection), an interim design review, and a final review and presentation of results. These reviews should be based on deliverables for milestones in the product development process. The students need to be provided with a clear list of deliverables for the project, along with the timing requirements of those deliverables. These deliverables should not be documented merely to "check a box", but rather should serve an actual engineering purpose. Care should be taken by the manager to ensure that true engineering isn't abandoned in favor of a more heuristic approach because of student expediency and comfort level.

Implementation of Proposed Methods in a Capstone Course at Trine University

The techniques discussed have been employed to varying degrees where possible during three separate semesters of senior engineering capstone courses. The spring of 2011 represents the most successful implementation to date. In this case, a group of eighteen students was broken into three project groups, using the criteria previously outlined in this document. In this scenario, these three groups each developed proposals for the same problem; *an automatic lift for motorized mobility devices*, as shown in Figure 3. The lift had to be designed so that it could be installed in the storage compartment of a recreational vehicle either as an after-market or original equipment manufacturer installation. After team selection and setup was communicated to the students, each team was required to use the product development process to generate viable concept alternatives. Each team then presented their concept alternatives to their manager and the customer, in a simulated corporate design competition.

Figure 3: A recreational vehicle and a motorized mobility device

The most highly developed and commercially viable concept was chosen. After concept selection, the students were then reorganized into three "functional" groups, using the same criteria previously discussed (MBTI, Belbin, teammate de-selection, project (function) self-selection, and teammate selection). The three groups, now functioning toward completing the same goal, were told that they needed to incorporate the most favorable features of each concept alternative into the winning concept. The three functional groups were: *1. Documentation,* *presentation and reporting*, *2. Design and analysis*, and *3. Procurement and prototype build*. The teams were now set-up as three cross-functional "departments" in the same company. Over the course of eight remaining weeks, the students were able to accomplish the following:

- Generation of complete solid models of all components, sub-assemblies and the complete final assembly;
- Performance of virtual kinematic analysis of the solid model of the complete final assembly;
- Performance of closed form solution correlated finite element analysis of key components of the complete final assembly;
- Performance of iterative optimization of key components based on structural analysis results, cost, and material/component availability;
- Generation of two complete drawing "packages", prototype and production, including complete assembly, sub-assemblies, and detail component drawings (thirty-eight separate drawings) suitable for hand-off to industry;
- Generation of complete product specifications;
- Procurement of all materials and components for prototype build;
- Fabrication and build of a functional, high level alpha/low level beta prototype;
- Performance of fundamental functional testing of prototype;
- Performance of engineering cost analysis;
- Completely document, report, present and demonstrate the device for multiple constituencies.

The 3D solid model (created in SolidWorks®) of the final complete assembly is shown in Figure 4a. The actual functional prototype of the final complete assembly is shown in Figure 4b. The Lifting platform was designed to be lifted with a hydraulic cylinder which was designed by one of the team members who was on a co-op assignment in a company which manufactured hydraulic cylinders. The prototype was fully operable at their senior design presentation and used for showcasing at various events such as the engineering exposition day.

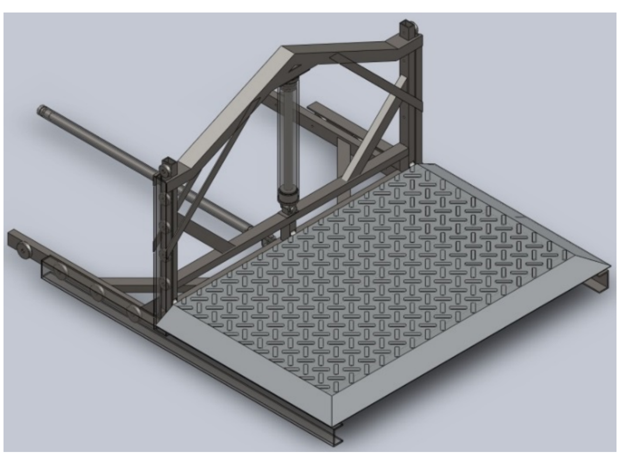

Figure 4a: Final design (SolidWorks® model)

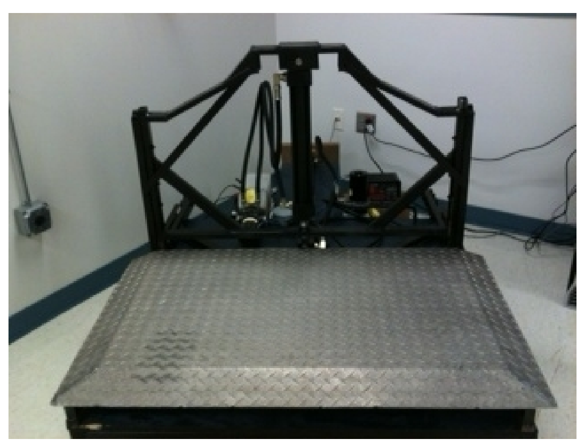

Figure 4b: The built, functional prototype

Students Perceptions of the Corporate Simulation Environment

Dealing with the Ambiguity

Even though the student employees were well supported throughout the capstone experience, they repeatedly demonstrated hesitancy and skepticism during the project. As in the "real world", the simulation used a degree of controlled ambiguity to enable student social and technical growth. The students had to be continuously reminded to be flexible and patient in their approach, allowing solutions to unfold, develop, and present themselves. The controlled chaos, or apparent lack of structure, was highly disconcerting to many students. Most students were initially overwhelmed and took time to adjust to the reality of not only the quantity of ambiguous work required, but also the depth, breadth, and detailed level of the work required. The learning of interpersonal professional skills proved to be intrinsic in the simulation. Student employees were seemingly not aware of what the experience was teaching them about operating in an ambiguous engineering team environment. Only in retrospect did students report understanding this. As an example, as part of their development, students were allowed to let group leaders (supervisors) emerge through consensus.

Assigning Leaders and Accountability

They were not overtly aware that they were identifying leadership through consensus, yet this is exactly what occurred. This is a valuable skill to be developed for engineering teams in the work-place. Frequently, even though no leader is identified for team projects in industry, someone must emerge to support the function of the team. Additionally, even though there was frustration among students, they learned to be self-reliant to accomplish tasks assigned by the team. Student employees had to be encouraged on an on-going basis that they were capable of accomplishing the tasks, and developing problem solutions, even though they did not have the level of structure that they were used to in previous engineering courses. Employers report they need "creative, adaptable and autonomous employees… an ability to assimilate new subjects and technologies quickly, without the expectation of being trained… they train themselves on the skills du jour as the need arises and with minimum help or structure"[35] in graduate engineers.

Faculty Support and Involvement

Finally, while the student employees appeared to learn interpersonal professional skills, and they were successful in completing the project, the manager/instructor needed to be actively engaged in supporting the teams throughout the duration of the capstone project. This raises the potential concern that this could place too much emphasis on the manager/instructor, and not enough on allowing the teams to learn and succeed (or potentially fail) on their own. However, in actual practice in an engineering business setting, a manager would rarely leave the team to fail without support. For most companies, failure of an established engineering team is usually not an option, if the company intends to stay in business. Since the intent is for the student employees to learn from the experience, too much instructor support does not appear to represent a serious concern.

Conclusion

While the simulation was deemed to be fairly successful, clearly there is much additional work and research that needs to be done. The procedure outlined, while effective, is too dependent on individual instructor implementation, and is not a well-structured, turn-key approach to simulating real world work experience in engineering capstone courses. It represents a starting point, from which more development and standardization could ensue. More time is required to effectively assess the outcome, both from a student perspective, and an engineering employer perspective. As an initial step, the desired learning outcomes must be accurately defined. Even though the correct level of project ambiguity is important to implementing the proper environment for the simulation, there clearly needs to be less ambiguity in what is being accomplished in engineering capstone courses. Because the learning appears to be intrinsic, an effective methodology for assessing the results immediately is not readily apparent. As a result, more investigation will be conducted both on refining individual aspects of the methodology, as well as refining assessment techniques. Initial assessments will be conducted as one, three and five year alumni surveys. In addition, employers will also be surveyed as to the efficacy of the training the graduates receive, as well as polling employers for needs and revisions based upon perceived graduate success. There are some glaring questions that arise from the initial implementation. The apparently excessive manipulation by the instructor (manager) may in and of itself contribute to the artificiality of the simulation. Specific recommendations regarding the attenuation of this artificiality need to be made. In addition, the excessive dependence on the attentiveness of the instructor/manager, and the need for many faculty members to act as advisors, mentors, industry liaisons, and managers to help with the implementation must be addressed. Couple that with the fact that faculty need relatively extensive industry experience themselves in order to know what constitutes a realistic engineering team project experience, effective implementation at larger universities may be precluded. There are some recognizable action items that can be recommended to improve implementation. Maturity level of students presented itself as a deciding factor in students being able to cope with the simulation. In support of this maturity requirement, it's advisable to only allow students whose graduation is imminent to participate in capstone courses. Systematically integrating ambiguity into previous engineering courses is also recommended. This can be accomplished through the increased use of appropriate problem based learning. The extensive nature of the student preparation also dictates a two semester capstone sequence as opposed to a one semester capstone course. Finally, faculty must be constantly diligent in forcing the use of true engineering solutions, instead of the use of heuristics. Bridging the gap between the practical and the theoretical is why the students are in school, and it's what sets them apart as engineers. To summarize, a method has been presented that emphasizes the proper setup and attention to simulation that allows for a "real-world" capstone experience. Special emphasis should be placed on project selection, team selection, and equipping students with socio-psychological information to support them in performing in an ambiguous, team based engineering environment. Flexibility and tenacity is required not only on the part of the student, but also on the part of the faculty "manager". When pressed, students not only learn intrinsically, but also are able to accomplish that which they would have previously regarded as not practical, or possible.

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