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Distinct Challenges to Senior Design Projects

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Proper planning for Senior Capstone Design courses is important to establish an effective academic environment that is as close as possible to real engineering practice world. However, this does not guarantee freedom from challenges. In the first part of this paper a description of the critical milestones required to form an effective Senior Design environment, based on years of experience and best practices, is provided. In the second part of the paper, a set of selected challenges are described alongside the methods and techniques used to handle them and turn them into educational opportunities. In addition, this paper discusses how to handle challenges by using a selected example from the Capstone Design projects. The NASA-Psyche competition projects sponsored by Arizona State University and the NASA Psyche Mission are used as examples to explain the concepts because of their unique formation characterizing the content of this paper.

Keywords: Senior Design Planning, Students' Motivation, Team Formation, Students' Evaluation

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Introduction

Senior Capstone Design Projects (SD) are typically offered in a sequence of two consecutive semester courses. SD courses are very different from classic college courses because they mainly include active, and experiential learning centered on a specific project. During SD, students are provided the opportunity to apply their knowledge and skills toward solving a real-world engineering problem as a culminating experience of their education. In addition, SD provides students the opportunity to learn and practice numerous essential skills, which are critical to the profession but are not emphasized enough in the rest of the jam-packed engineering curriculum. Examples of these skills include teamwork, communication, inclusion of societal and economic dimensions of engineering, and most importantly: the realities of real-world practice [1]. Meanwhile, SD allows advisors to coach their students about project management, ethics, and teamwork while going through the design and build cycle [2]. Due to this unusual nature of SD courses, proper planning with a level of flexibility, continuous monitoring and communication, and clear expectations, are key to the success of SD projects.

At the University of Texas at Tyler (UTT) – Department of Mechanical Engineering (ME), SD has a well-defined structure that ensures consistency and efficiency throughout the courses. In the 2021/2022 academic year there were 101 ME students enrolled in the SD class and they were distributed among 21 groups (8 groups on the Tyler campus and 13 on the Houston Campus). An administrative coordinator per campus carries out the prep work of SD during the semester preceding its start as well as administrative and organizational tasks during the courses, overseeing all activities, logistics, and contingency plans. Each team has a faculty advisor who is a member of the SD Project Board (SPB) which is chaired by one of the coordinators. The SPB meets frequently throughout SD and is responsible for all the decisions made regarding these courses. Advisors meet with their teams at least weekly to ensure the project is on track and to provide guidance to the teams. The advisor has a vital role in enforcing the expectations and detecting early issues with projects, as well as evaluating the individual performance of students. All the structural details are documented in the Faculty Handbook and the Student Handbook describing all roles, policies, and expectations.

In spite of all the effort invested in structuring a dynamic ecosystem for SD that simulates real-life engineering work environment while providing flexibility to accommodate any challenges, there will always be situations that will put the system to the test. Causes of such challenges could be anything varying from internal project issues to external occurrences such as the COVID-19 pandemic. Handling such unexpected challenges depends on the level of resilience and flexibility of the SD ecosystem and the continuous improvement process built in it to keep it robust. Therefore, exchanging different experiences by instructors of SD is important to maximize continuous improvement.

This paper consists of two parts related to SD: the first part includes a listing of milestones that are critical to the structure and execution of SD based on numerous years of experience. The second part discusses handling selected challenges using the context of the Psyche projects as an example.

Critical Milestones in Senior Design

Critical milestones of SD are set at the beginning of the semester on a strict timeline. Figure 1 shows these milestones in a chronological order. Following is a description of each milestone:

1. ***SD Orientation:*** During the first two weeks of SD, available projects are announced, teams are formed, and expectations are set. In addition, multiple essential skills are strictly emphasized such as professional communications, team contract and protocols, and professional behavior.

Figure 1: SD Milestones

2. ***Team Selection:*** There are many theories and methods for team formation or selection [3]. Each of these has its advantages and disadvantages. Previously at UTT ME department the method of placing students at similar performance levels in the same team was applied. The disadvantage of this method was that a few students used it as an excuse for their lack of performance because they did not like the project they were on. This year a different method was applied where each project was given a relevant tile and a two-line description then announced in a list. Students were required to submit their choice of three projects in order of preference. 90% of the students ended up being placed at their first-choice projects and the rest at the second-choice project. As a result, no complaints were received this year regarding the team placement or project selection.

3. ***Literature Review:*** In this stage, regular communication with the sponsor is established. As much data about the project as possible is collected to be employed in formulating the project specifications. In parallel, preliminary acceptance criteria for project completion is discussed corresponding to specifications. This milestone helps in establishing system thinking skills and in building students' ability to see the big picture. Following this stage teams engage in design ideation, concept generation, and solutions formulation to the engineering problem at hand. A concept from amongst multiple is selected and discussed with the advisor and the sponsor for justification.

4. ***Scope Presentation:*** In this stage, students present their project to a panel of SPB members with a focus on concept selection and plans to move forward. All details related to the presentation content and mechanics are provided to students ahead of time, including the grading sheets and rubrics used to grade them. This milestone is timed to be completed by the middle of the first semester. The presentation goal is to thoroughly examine progress and scrutinize proposed conceptual solution for technical feasibility. It also serves as the first realistic feedback to the teams providing a reality check. . Students use this feedback to correct and improve their concepts while working with their advisors towards a complete technical design.

5. ***Design Review (DR):*** This milestone starts 4 weeks after the scope presentations. There are two design reviews, one with the SPB members and another one with the sponsor. It is also described, in details, in the students' handbook and all expectations are provided with a grading rubric. Students are asked mainly to defend their technical design decisions (synthesis) and provide evidence that it will work (analysis) in front of a panel of SPB members first, and with the sponsor joining the panel at a following DR. The goal of the DR is to ensure that the proposed design is functional and ready for implementation. The DR is based on a presentation that is continuously interrupted by discussion, questions, notes, and feedback. Successful completion of this milestone means seeking sponsor approval in a following DR and consequently securing permission to order materials based on an approved budget. As a side note, the DR is an effective way to explore strengths and weaknesses of a curriculum because it forces students to put the hard skills and knowledge they acquired before SD into real application. The DR also serves a testbed for students' ability to design.

6. ***Complete Design:*** This milestone takes place when all DRs are completed, and students are granted approval to purchase materials and start building. Therefore, it is critical to ensure that budget and planned actions, especially testing, are set correctly at this point for the project to move smoothly during the

entire following semester. At this milestone, mutually approved acceptance criteria are reviewed and re-emphasized with the sponsor. This milestone is usually at the end of the first semester, and it clearly defines a successful project.

At UTT, these milestones are covered during the first semester of SD. The second semester is reserved for building, testing, and demonstration of outcomes. Design changes are expected as the team moves toward the implementation but are only allowed after a mutual agreement between the team and the sponsor with supervision from the faculty. In the case of major changes a DR might be required which is usually called and run similar to the first-semester practice. External judges and sponsors are usually invited at the end of the second semester to attend a design expo where all projects except confidential ones are presented and feedback Is provided for both students and the program for continuous improvement.

Selected Challenges

Challenges are part of SD and will never cease to exist. Some challenges are repetitive and will take one form or another such as the lack of performance of one student hidden behind a performing team. Other challenges are unique such as the COVID-19 pandemic. Some challenges are internal while others are external to the project and academia such as a sponsor ignoring their commitment to SD. A description of selected interesting challenges is provided next in the context of the Psyche projects. The approach used at UTT ME department to address these challenges, based on pest practices and experience, is also reviewed. The Psyche projects were selected because they encapsulate most of the highlighted challenges. These projects are named after the Psyche NASA mission (this is the name of the asteroid as well) which is an exploration mission to a metal asteroid to be launched in Summer 2022. The spacecraft will embark on a four-year journey to reach the Psyche asteroid which is orbiting the Sun. The goal of the mission is to spend twenty-one months orbiting Psyche and mapping it and learning about its surface. Back on Earth, students and scientists alike are working on systems that aim to land on Psyche, navigate its terrain and collect samples. UTT applied and was awarded four capstone projects (Hypothesized surface: Landing System, Robotic Explorer, Sampling System, and Returning Samples) from the main Psyche project at Arizona State University (ASU). All the current student projects are designed for hypothesized surfaces which makes them both exciting and speculative. This made it the perfect case study for this paper besides the thousand miles between UTT and ASU. It is to be noted here that most of these challenges are correlated at some level and do have reciprocal effects on each other.

1. ***Motivation:*** Students' motivation is influenced by many factors especially in a new and challenging experience like SD. On the one hand, a unique event causing major demotivation was the COVID-19 pandemic because it forced a sudden change in the entire educational process including social distancing and remote communication [4]. On the other hand, annually repeating demotivators include grade anxiety caused by students' inability to estimate their standing in these "open-ended" courses. Another repeating demotivation results from students not being able to choose their team or project. In general, demotivation is strongly connected to uncertainty and anxiety. To ensure continued levels of high motivation among students a continuous clear communication carrying timely feedback and instructions, as well as continuous highlighting of stepwise accomplishments along the way by the advisors, proved to be a significantly effective approach in increasing and preserving motivation levels. Moreover, allowing limited flexibility to accommodate uncontrollable occurrences adds another motivational element as it targets grade anxiety directly. One other major internal cause of demotivation is the students' unrealistic expectations about the amount and consistency of the workload in SD based on experience in other courses with similar credit allowances. This misunderstanding is expected but is usually overlooked causing significant challenges to students' motivation and success. Again, continuous clear communication with a focus on SD nature, workload, and expectations, as well as an early set of exercises to get used to uneven workload distribution helps resolve this issue. Finally, this challenge is common to all SD projects and the Psyche projects were no different. In fact, the Psyche projects led to higher levels of student uncertainty and anxiety, by incorporating a remote sponsor. However, the same prescribed approach of timely, continuous, clear communication and responses was effective in resolving the motivation challenge even with the Psyche.

2. ***Students' Performance Evaluation:*** Because of the emphasis on teamwork during SD, students with inherently problematic time management skills or with tendencies to do the minimum end up exploiting the situation by taking a free ride. This causes complex problems, the simplest of which, is loss of trust in the system by the hard-working team members leading to demotivation. Evaluating students' performance equitably, individualistically, and clearly, while performing team tasks is a very challenging balancing act for the instructors. Therefore, from the onset of SD at UTT,

each team is requested to sign an internal contract that includes specifics regarding performance measurement, expectations, due process in case of issues, and the expected penalties. The advisor reviews the contract for legal and professional purposes and the signed document is used as a reference in cases of conflict. Moreover, multiple activities were required to be completed during SD by each student individually, and an advisor subjective portion of the final grade was included. Aligned with professional practices, a guided peer evaluation with clear expectations and a rubric was required after the team clears a milestone that required the team to pull efforts together such as the Scope Presentation. All of these elements help in providing different facets to individual student's performance with built-in warnings that would be transferred to the student by the advisor as constructive but serious criticism. There is no doubt that issues related to students' contribution to the project will arise due to differences in students' resourcefulness, time management skills, and level of mastery of previous knowledge and skills. However, Continuous monitoring of individuals' performance by the advisor, combined with indicators from different built-in activities, helps tremendously in resolving many issues and turning them into educational moments before they grow into a serious problems. Finally, one grader was assigned this year for each activity across all teams to guarantee the equitable treatment of the same activity. This became clearly effective when handling individual submissions such as peer evaluations. For the Psyche projects, the same elements and rules were applied since this is a universal challenge across all SD projects.

3. ***Misalignment:*** This challenge is a collection of challenges that will show repeatedly with different levels of intensity depending on the nature of the project and the individual students in the team. The first example of these challenges is a mix of metacognition inability and inexperience by the students. It is usually seen in the discrepancy between students' answers in the self-evaluation at the beginning of the first semester and reality, or their estimation of resources to satisfy a particular task as they plan the project. This discrepancy stems from lack of knowledge and experience and represents a learning opportunity.". The second example of misalignment challenge is conceptual. It occurs when dealing with uncertainty such as open-ended problems with many possible solutions. Such situation is opposite to what students are familiar with during their education where only one single specific answer is possible. A similar misconception is that the budget and initial spending limit established at the start of the project are the same. This confusion causes students to think that they can spend what was budgeted instead of trying to optimize the project economically, again, because of familiarity with linear thinking only. The third example of misalignment challenges is professional. Students often receive negative results and constructive criticism as personal instead of professional, reducing their openness to learning from failure. The Psyche projects exhibit all of these examples, ranging from high uncertainty to limited budget and from a vast range of solutions to students' shock when knowing that their traditional knowledge in engineering has to be extrapolated outside the box to solve this problem. The good news is that all of these misalignments can be handled and turned into effective educational moments with the same approach of careful planning, early detection, and agile responses.

Conclusion

Careful planning on a strict timeline of SD is critical to achieve success, but challenges will continue to occur. Continuous communication, clear expectations, and timely responses have proven to resolve most challenges. Careful team formation and project selection can help in improving motivation and reduces complaints significantly. Milestones provide a reality check so errors can be corrected quickly and efficiently. Design reviews are critical for the success of the project with a side benefit of exposing the strength and weakness points in a curriculum. By the end of the first semester a budget, test plans, and a clear timeline for testing should be established alongside a completed and verified design, to ensure smooth project completion. Emphasizing life-long learning concepts, the open-ended nature of engineering projects, the professional aspect of providing and receiving feedback, and the necessary considerations of other dimensions such as economical, societal, and global, will go a long way in resolving many challenges.

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