PROJECT SEMINAR – RECONSTRUCTING THE CAPSTONE PROJECT PROCESS

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ABSTRACT

The capstone project (CP) process is an essential layer on the path towards an engineering degree. Typically, the purpose of the CP is to build an actual product prototype. In practice, the process of guiding the CP is less structured than a standard course. This is due to the project's scope and span, the interaction between the student and the academic supervisor and the exogenous workload of the student. The CP process thus requires the academic system to provide a combination of creative, professional guidance and, at the same time, strict management of the process. This paper outlines a methodical way to conduct this complex and challenging process, which we have adopted and refined in the last three years and shares some observations we have made during this period. The essence is the separation between the content and procedural aspects of the project. This contrasts with how CPs were previously managed, where the guiding academic staff were responsible for both aspects. This separation standardizes and optimizes the process and is carried out parallel to the execution of the projects. The main change in the curriculum is the addition of two dedicated courses spanning the last three semesters of studies called “CP Seminar 1” and “CP Seminar 2”. These seminar courses are guided by a team of two professors, who meet with students every two weeks, working toward well-defined and structured milestones. During the courses, students develop an understanding of the conception, design, implementation, and operation of the product they develop as their CP. Thus, greater control, and monitoring of the progress of the students in the process is achieved by the supervisors, the seminar team, and the students themselves. The courses frame the CP process and facilitate strict milestones, standardized documentation, and substantial validation.

KEYWORDS

Teamwork, Innovation, Engineering Problem Solving, Capstone Project, Academic Project Management, CDIO Standards: 2, 3, 5, 8, 11

INTRODUCTION

The capstone project (CP) culminates four years of engineering study. The first three years consist mostly of frontal courses, which provide the student with components of theoretical knowledge in various subjects of the academic career, along with several hands-on courses like micro-controllers lab, which provide hardware and software design practices. The CP phase integrates several of these components of engineering knowledge with the aim to design, build, and test a prototype system. As a goal, the prototype system should somehow refer to a specific problem and provide a solution. The CP process simulates, in a summarized way, the product development process in the industry. In view of this, the CP is a critically important phase in the framework of a young engineer education. The CP is usually carried out during the 4th year of studies.

In the literature, there are several reviews of implementing the CP in engineering studies. For example, Roth, et al. (2019) share experiences of a refinement of the Electrical and Electronic Engineering (EE) curriculum involving the integration of design content throughout the program. A direct benefit is exposure to a variety of technological advances so that they perform better on their CPs. Minaie, et al. (2022) present the detailed content of the EE curriculum at Utah Valley University, which includes two two-semester capstone design courses: Capstone I and Capstone II. The faculty advisor meets with each team project individually on a weekly basis on a regular schedule. The two capstone courses are designated as writing enrichment courses that include not only writing assignments but also writing instruction as major components. Other reviews appear with respect to evaluation (Farrell, Ravalli, Farrell, Kindler, & Hall, 2012), methodology (Shurin, Davidovitch, & Shoval, 2021), and experience (Umphress, Hendrix, & Cross, 2002), particularly in Software engineering.

This paper describes some aspects of the CP experience accumulated in recent years in the EE department at Shenkar College and the innovation included in the process. As a basis for understanding the change in the EE curriculum design, the CP follows a 3rd year pre-CP course called “Electronic Product Development”, which was presented in detail at CDIO2022 (Gal, Furman, & Weissman, 2022). This course summarizes the main aspects of the product development process, thus preparing students for the challenge of carrying out a successful CP.

Previously, until three years ago, the CP process in the EE department spanned approximately one academic year. During this period, each group of students was guided by an academic guide (AG), whose engineering background is suitable for the respective CP subject. The AG guided the CP, starting from the conception of an idea and concluding with the final presentation. We call this frame of reference - "the single AG process".

With the single AG in the CP process, there are inherent challenges in the standardization of the CP process that determine the path the CP takes: 1) the AG's personality and method of work: for example some AGs are more permissive than others; 2) the intensity of the interaction between the AG and the student: if they set regular weekly meetings or only meet when the students request it; 3) the external limitations of the students: many of the students work part-time parallel to their study, so the time to work on the project is more limited; and 4) time constraints of the AGs: there are AGs who also work in other places, and some of them have positions that limit the guidance time. This results in variability in the nature of the CP process, as opposed to the CP content, which is in addition to the inherent unevenness in the level of submitted CPs, attributed to the student's efforts and academic qualities.

In addition to the integrative implementation of engineering concepts, a successful CP requires, among other things: 1) strict adherence to a common set of synchronized milestone schedules, 2) provision of standardized documentation on time, and 3) sufficiently detailed (qualitative and quantitative) validation and test results. Considering the challenges mentioned above, fulfilling these CP requirements reveals gaps and shortcomings and illuminates the need for profound structural and perceptual change. By addressing the challenges and gaps found, the CP process can also be used to reduce inconsistencies, while better preparing students for their professional role in a changing environment.

Single AG guiding of CPs has been practiced for years in our EE department, as noted above. This often resulted in an unequal level and time scale in the CPs submitted. About three years ago we concluded that the existing CP process requires restructuring. Basically, the CP process has been separated into two parallel channels: 1. Content-wise channel: guided by the AG, as before. 2. Process-wise channel, which consists of the incorporation of two seminar courses to the EE curriculum, that synchronize and standardize the components of the CP process. It should be noted that for this purpose, a method previously developed and used in software engineering at Shenkar College was adopted, but modified to adapt it the specific needs, characteristics, and skills of the EE profession.

The purpose of this paper is 1) to provide a description of the two-channel CP and 2) to present and discuss the main benefits of this restructuring. Broadly speaking, these benefits concern the quality of the submitted projects, the skills acquired by the students during the CP seminars, as well as their feedback at the end of the CP seminars.

SEMINAR'S DESCRIPTION

Overview

Students prepare the CP along two frontal courses: Capstone Project Seminar 1 (CP Seminar 1), spanning a period of one semester, taught in the second semester of the 3rd year, and Capstone Project Seminar 2 (CP Seminar 2), spanning a period of one year, taught throughout the students' fourth academic year. Both courses are mandatory. The meetings are one every week or every two weeks, depending on the task that the students must prepare. For a student to be included in the CP Seminar 1, the student must have completed all the required prior courses in the curriculum. A student can participate in CP Seminar 2 only if he has successfully completed CP Seminar 1, such that the year of completion of the CP Seminar 2, and hence the completion of the CP, is the year of completion of EE studies.
CP Seminars 1 and 2 are conducted as a form of face-to-face lectures accompanied by demonstrations, presentations, brainstorming, assignments, and feedback. At the beginning of each seminar, the students receive a complete schedule of all frontal meetings, assignment submissions, presentations, and events they are required to participate in during the upcoming seminar period. In this way the students can plan their work in advance.
CP Seminar 1 is a framework for thinking, conceiving, and presenting ideas for the development of projects, while in CP Seminar 2, the students design, implement and operate real-world systems and products for the capstone project. The phases of the CP Seminar 1 course comprise of: 1. the identification of the students' fields of interest; 2. the formation of project groups; 3. the conceptual ideation of the product; and 4. the matching with the academic guide. During CP Seminar 2, the students undergo the following phases: 1. understanding customer needs and use-case and defining product requirements accordingly; 2. designing the product from high-level architecture down to detailed technical design; 3. validation plan preparation; 4. alpha and beta product version implementation of the product; 5. presentation and demonstration of the product; 6. College exhibition of the project; and 7. writing of a project book, and defending the project in front of an academic jury. The stages of both seminar courses are represented in Figure 1, which shows the flow of the phases as

the project advances, as well as the outcomes of each phase. In addition to the formal stages, reviewed in the following sub-chapter, students receive skill development lessons, such as speaking in front of an audience and time management. Future versions of the course will include technical writing lessons. The acquired skills, as well as the qualification methodology, will be reviewed in a separate subchapter. The last subchapter will review the outcomes of these courses in the last two years.

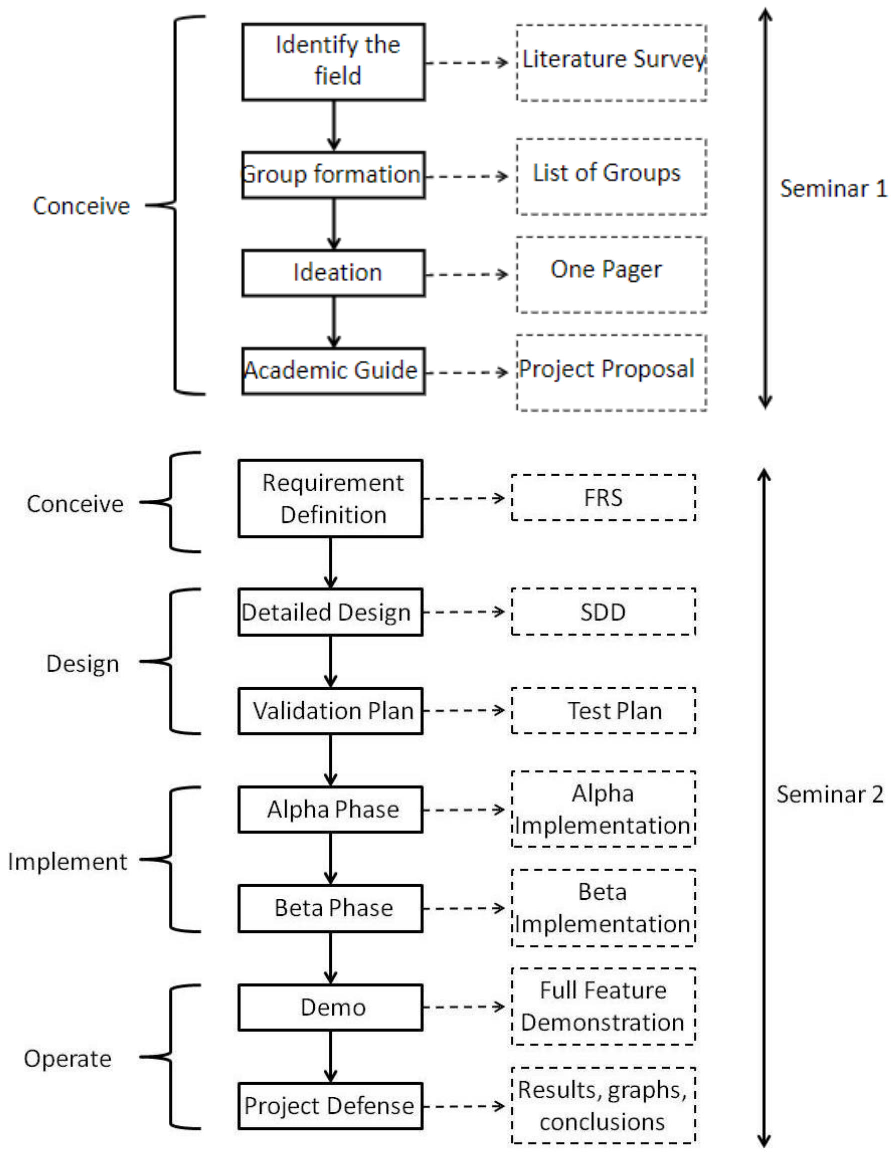

Figure 1. Phases of the CP Seminar 1 and 2 courses and the outcome of each phase, FRS=Functional Requirements Specification, SDD=System Design Document.

Explanation of the CP Seminars' phases

In general, as mentioned above, the CP Seminar courses follow the conceptual framework of the CDIO syllabus (). From this perspective, the phases of the courses are reviewed in detail below.

The phases of the CP Seminar 1 course are:

1. Understand the complexity of CP: In this initial phase, the students go through the process of identifying a field in which they want to get involved and specialize in their CP.

2. Form groups for the project: This step is critical to understanding the connections between team members and the project, the division of responsibilities, the strength of each student, and the common denominators among project participants. At this stage, students strengthen their understanding of teamwork. At the end of this period, students are encouraged to work in pairs. However, we allow few students to work alone on the project, being aware of the "Individual Contributor" type, recognized by Intel corporation as types which work best alone.

3. Ideation and topic approval: At this stage, the students go through a process of ideation and initial research to formulate an idea based on the chosen field. The students practice skills such as asking questions, research skills, understanding other-worldly areas such as the social, economic, and ecological aspects of a product. They learn to identify a problem and think of an effective way to meet the challenge through the development of an engineering product that includes electrical and electronic components. The idea for a capstone project must meet the criteria established by the department for a capstone project for EE career. The students will focus on finding and selecting a suitable capstone project, according to the following criteria: a) The project requires technological research to find a solution to a defined problem, b) The project requires an engineering scope and complexity of research work, characterization, design, implementation, operation, and significant academic and technical writing.

4. Matching an academic guide: In this phase, the students receive an academic guide for the project and begin to formulate an applied solution. The students learn how to write a capstone project proposal, features of scientific writing, time management, and management skills. At the end of the CP seminar 1, the students receive a foundation for the next phases of the project that will be reflected in the CP seminar 2.

After the project teams have chosen and defined a topic for their projects during CP Seminar 1 and having written their project proposal document, the students begin the process phases of design, implementation, and operation, in the order indicated. These are conducted during CP Seminar 2 and are accompanied by a series of technical documents that are similar to those used in the industry.

The phases of the CP Seminar 2 course are:

1. Definition of functional requirements: in this phase, the student must go deeper into his general project proposal and think about the detailed characteristics of the project, that is, the product. This cannot be done without a deep understanding of the problem, need, and challenge that the project is designed to solve. Additionally, students must define the typical user who will use their product and outline possible user scenarios. Once the student has the

use case scenarios, he can derive a list of functional requirements. A common mistake is to confuse the functional requirements with the technical implementation. Therefore, students are advised not to go into technical details, but to stick to the functional requirements from the point of view of the typical user. This entire process is submitted as a Functional Requirements Specification (FRS) document and must be approved by the AG of the respective project. Additionally, the teams prepare a PowerPoint presentation containing the highlights of the FRS document and present it to the class in a ten-minute time slot. Extra time is allocated to each group for questions and answers from the audience, as well as constructive feedback from the course instructors. This concludes the "Conceive" part of the CDIO stage. The next stage of CDIO is the "Design" stage and consists of two phases: the design of the hardware and software architecture, and the development of a detailed validation plan to test the quality of the design.

2. The design of the hardware and software architecture: The first step is the design itself, which is submitted in the System Design Document (SDD). The design consists of defining the architecture of the system, which is a definition of the subsystems (modules), their functionality, and the data and control signals that flow between them. Note that the architecture diagram should not include implementation details, but rather focus on the functional role of each module. In conjunction with this, students must describe a detailed sequence of events that the system handles, specifying the partition with respect to modules. The next step is to define the structure of the database that the software will use. This is mainly a description of the contents of the database table and the relationships between them. The main and arguably the most important part of the SDD is the detailed design section. Unlike the system architecture document, this document should contain a detailed description of the actual components, which provides enough information for R&D engineers to implement at a later stage. Last but not least is the Graphical User Interface (GUI) subsection. Most of today's projects involve some form of data collection from system hardware using a mobile app. The application often processes the data and presents it to the user in graphical form. Therefore, the presentation of the mobile application screens is essential for a comprehensive understanding of the project system as a whole.

3. Once the system is well defined and designed in detail, the students must write a functional validation test plan to ensure that their design works in full compliance with the functional requirements defined in the FRS document. In addition, an engineering validation should also be planned to verify the operational limitations of the system. The teaching of the validation methodology is carried out by an industry expert, who also advises the teams as they progress through the preparation of the validation test plan. After receiving the basic validation methodology from the expert, the students must prepare a mini plan for peer review. They present it to the class and to the expert, to receive constructive feedback and comments on their plan. This feedback is helpful to both the reviewed teams and the listeners teams, in refining their test plan for the final validation meeting. At the final validation meeting, each team presents the completed test plan to a jury of EE department academic staff. It should be noted that the final validation tests presented to the jury do not necessarily have to be fully implemented at that stage, but rather show the infrastructure to test and validate the system. The complete test plan must be fully implemented by the time of the presentation and the demo stage, which will be at a stage close to the delivery of the CP. The final validation meeting finishes the "Design" stage, and the teams are now ready to move on to the "Implement" stage.

The "Implement" stage, in accordance with CDIO process, is made up of two phases: Alpha Phase and Beta Phase.

4. The Alpha Phase: It is an implementation and testing of several product-specific features, mainly those that carry a risk to the success of the product, trying to adhere to industry standard nomenclature. For example, in a greenhouse project, the students wanted to use a light-gathering optical system, which was supposed to channel sunlight from the outside into an indoor chamber, where the plants were located. The optical system was complicated and beyond the scope of the students' prior knowledge. This feature is a classic risk factor and should be implemented and tested at an early alpha phase, before other less demanding features. The alpha implementation is accompanied by a document that describes the features that are implemented and tested at this phase.

5. The following stage is the Beta phase: This phase contains most of the features, making it a usable product for potential users. Unlike in the industry, where beta testing is carried out by external users, the students' beta phase is an internal phase. Since the students only have a single prototype of the product, they cannot distribute it to external users for evaluation. At best, they can test it among a limited circle of friends and family. In this phase, the product (capstone project) is mature enough to be ready for the final demonstration, which takes place at the end of the academic year.

The last phase of the CP Seminars, and according to the CDIO framework, is the “Operate” phase, which includes the final demonstration of the CP, and the submission of the CP book that culminates in the defense of the entire project.

6. In this demo phase, the teams prepare a fifteen-minute PowerPoint presentation, followed by a physical demonstration of the full functionality of the product. This presentation takes place in front of a large forum of 3rd year students, Shenkar College academic staff and industry experts. From the demo podium, the now fully functional products are transferred to an annual showcase of capstone projects hosted by the college for all campus departments and guests from industry, family members, and more. The exhibition is open for two weeks, and visitors from other departments, as well as from outside the university, are welcome. Projects are photographed and featured on the Shenkar College website.

7. The almost final step is the writing of a CP book and the preparation for the most crucial phase: the defense of the project. The CP book is a comprehensive technical description of the entire conception, design, implementation, validation, collection and analysis of results, and operation of the product. The CP book template comprises all the documents presented during the CP seminars and its framework allows the continuation of the project at a more advanced level. Once the CP book is approved by the AG, it is sent to the EE academic staff (the jury) about a month in advance for them to read and comment on. In the CP defense phase of the project, each team presents a 20-minute review of the project to the jury, as it is presented in the CP book. This is the time to ask questions, based on the comments the jury made to get prepared for this last phase.

The seminar course grades are not numerical like most academic courses, but a binary form of "Participated/Not participated". To pass the course, students must have at least 80% attendance, submit the documents approved by their respective AG in the determined time period, and present their progress in the CP in class, as determined in the different faces of the courses. There are penalties for late submission, and these are expressed in the final grade of the CP.

Acquired Skills

During the courses, the students improve skills that were preliminarily acquired in the "Electronic Product Development" course, reviewed in a document at CDIO2022 (Gal, Furman, & Weissman, 2022). The main skills developed in CP Seminar 1 and 2 are "presentation skill" in front of a live audience, "teamwork", "task management" and "time management". Presentation skills are practiced periodically, as students must present some of the milestone materials mentioned in the "Explanation of the CP Seminars' phases" sub-chapter. Also, in a lesson called "Talk like TED", each student is asked to prepare a one-minute speech on any subject and present in front of the class, like an "Elevator Pitch". Teamwork skills have not yet been formally trained, but is well practiced throughout the year, as students must divide the responsibility of the extensive workload among team members in order to manage the completion of the project. Time management and task management skills are naturally enhanced by the course structure, which forces the students to submit documents and develop their project in well-defined time slots. Additional skills, such as independent research, are enhanced by the nature of the project work and research, which contains some innovative areas, in which even the AGs may have limited knowledge. Last but not least are the technical and scientific writing skills, which are practiced to a certain extent. A technical and scientific writing frontal workshop will be added to future courses in the coming years.

Outcomes

This innovative framework of the capstone project process in our EE department has resulted in three notable improvements, compared to the years prior to the change. These improvements are hereby reviewed.

The first improvement refers to an improved level of design, implementation, and integration of hardware-software-mechanics. This results from the positive effect of the seminars, but it is also due to the cumulative effect of three pre-CP courses that were added in recent years: "Arduino Workshop" course, "Raspberry Pie Workshop" course, and "Technology Product Development" course (which was reviewed in a CDIO2022). It is necessary to note that all the components of the CP are developed by the students of the CP team. Two examples of the elevated level of design, implementation and integration of hardware-software-mechanics are shown in Figures 2 and 3.

Figure 2 shows a complex system composed of a photographic camera, connected to a machine learning algorithm based on artificial intelligence (AI) and a mechanical product that acts under the AI trigger, which was placed in the elephant section in the Safari Zoo in Ramat-Gan, Israel. The system uses machine learning algorithms to identify the different elephants in the garden and monitor their social behavior. This behavior is sent by Wi-Fi to a network drive for investigation and follow up. When an elephant touches a virtual button located at the edge of the garden, some fruit is thrown at it as a reward, from a nearby mechanical device.

Figure 3 shows an integrated fall prevention system on a construction site. The system is comprised of a helmet, an In-Site Computing Unit (ISCU) and a mobile application. The helmet alerts the worker to nearby hazards. The ISCUs are placed in potential falling areas and send alerts to all nearby workers. The mobile application concentrates all the data of the site workers in a map of hazards in real-time, used by the administrator of the site.

A second area of improvement concerned the mere fact that all projects adhered to a common timetable and were submitted on time.

Finally, a third improvement referred to a more uniform academic quality of the projects. This is mainly due to the strict milestone schedule, which forced both students and their s to synchronize and submit the respective standardized documentation, as illustrated in Figure 1. In this way, the inherent variation between AG approaches is eased slightly.

a. b.

Figure 2. EleProje – Elephant monitoring system. Figure 2a. System components deployment. Figure 2b. Mechanical fruit reward sub-system.

a. b. c.

Figure 3. NoFall – Construction Site Fall Prevention System. Figure 3a. Helmet and ISCU. Figure 3b. ISCU – In Site Computation Unit. Figure 3c. Mobile app.

Finally, to validate the way students view the modifications made in the CP process, they were polled on several aspects, which included the seminar procedure and contents, and the usefulness of some of the preceding courses. Ten students responded. In general, the response was favorable. Specifically, on the issue of the bi-weekly milestones that they had to adhere to within the framework of the seminars, the mean response (in Likert scale) was 3.9 out of 5. Note that on the negative side, some of the milestones were perceived as somewhat of an overburden.

Despite the extra effort and time required for a course like that, most students think that well-defined milestones and exposure to other student projects help them achieve higher standards. Most of them also perceive the course milestones as beneficial for success in their future work career.

Other responses concerned the importance of the skills practiced in the seminar courses. Here again, the students' view was quite favourable, with respect to the presentation skills (4.3 out of 5), technical writing skills (4.2 out of 5) and independent working capability (4.2 out of 5). Time management and teamwork were favoured to a somewhat lesser extent (3.4 and 3.9 of 5).

DISCUSSION

Our main challenge in managing the CP was to synchronize and equalize the academic process across the various specific projects, time-wise and level-wise. In addition, we intended to enhance the level and complexity of the typical CP. In general terms, the above outcomes indicate that these targets have been achieved by channeling the CP process through the two CP seminars described above.

The students responded favorably, in general. Most of them prefer the seminar format, on working with an AG only. Nonetheless, they noted the increased burden of the need to adhere to the bi-weekly milestones as a disadvantage. In addition, the increased cost, and added course hours may be considered to be somewhat disadvantageous.

It turns out, however, that there is one more aspect that requires attention: raising the level of experiments and validation tests that are carried out on the prototype of the system. There is a need to enrich the experimental part of the CP report, to provide details concerning both the specific functionalities of the system, as well as to quantitatively sketch (using respective graphs) the performance envelope. However, typically, most of the students' energy is invested in building the prototype of the system and demonstrating that it works "reasonably well". There are fewer incentives at the end of the 4th year to carry out meticulous experiments, to cover the performance envelope. Therefore, it is necessary to direct a special effort to that issue. We started this year by requiring that about a quarter of the CP report be devoted to validation and experimental data. We hope to have some indicative results by the end of the year.

To conclude, CP Seminar 1 and 2 courses have substantially improved the level of CP prototyping and reporting in our EE department and are highly recommended.

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