Key Success Indicators for Implementing the Capstone Project Assessment Ruler (PAR)

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Abstract

Capstone courses that integrate faculty-generated or industry-sourced projects all have a common factor and a key stakeholder: the instructor of record for the class. These individuals oversee and run a class that most departments use to assess all seven ABET Criterion 3 outcomes. The projects that these instructors choose then must motivate the achievement of these student learning outcomes. Thus, they are uniquely qualified to express opinions and give feedback on the development of a universal Project Assessment Ruler (PAR) for mechanical engineering capstone programs. Three professors from the institutions of the Author and Co-Author were interviewed with a standard set of questions to determine their observed key indicators for a successful project. One institution is a large public research university, and the other is a mid-sized private university. These question sets were designed to illuminate successful best practices as well as pain points in selecting a capstone project. The questions triangulated around 3 overarching themes: Physical Capabilities, Programmatic Capabilities, and Group Capabilities. Physical Capability questions centered on facilities students can access and use to complete projects. Capstone programs can be run with limited internal manufacturing ability when an emphasis is placed on the Quality Assurance of and managing lead times for off-the-shelf and custom-manufactured parts sourced externally. Programmatic Capability questions focus on expertise present in the department or vested in a friendly collaborator. While the program may have physical resources, capstone instructors of record still face the hurdles of hidden assumed student capability and experience. Moreover, since capstone projects are extremely varied, arriving at an optimal design might require expertise that no member of the faculty, staff, or external collaborator team possesses. Covering these experience gaps can strain faculty. Group Capabilities questions centered on skills, personality compatibility, time investment, and specialized knowledge. Major weaknesses reported for groups as a whole included focusing on perfection at the cost of task competition, lack of experience and skill to write and carry out test protocols, lack of design decision documentation, tendency for graduating seniors with job offers to invest inadequate focus on capstone, and tendency of students pursuing ambitious graduation timelines to overload course schedules leaving insufficient time for capstone.

Key factors that made a successful project were 1) passing a test of viability based on instructors' engineering intuition, 2) proper scope, 3) adequate support for students in managing key stakeholders, 4) not allowing scope creep, and 5) properly forming balanced groups based on Gallup strengths. Consideration of potential project pitfalls and success attributes led to the selection of a benchtop injection molding machine as the first example of a PAR capstone project to be implemented. This paper illuminates how this PAR project choice addresses challenges while leveraging benefits illuminated during the capstone faculty interviews.

Introduction

The concept of the capstone Project Assessment Ruler (PAR) was introduced in Banks & Traum to enable quantitative and systematic comparison between different mechanical engineering senior design projects and between capstone programs at different universities [1]. That previous paper focused on defining key parameters a good mechanical engineering capstone project. With that background established, the next step in creating PAR projects is to select a representative project that meets all PAR criteria. Some practitioners of capstone instruction hold that "analytics must be kept in balance with the dynamics of creativity" when selecting "good" capstone engineering projects. While this qualitative approach can yield excellent results, lack of a quantitative project selection protocol makes it challenging for instructors and program to select projects that present students with consistent challenge, rigor, interdisciplinarity, and open-endedness year upon year. This process is even harder for ABET-aspiring or newly created and accredited programs, as witnessed by the author, due to a lack of institutional knowledge in how to teach capstone and existing processes placed in lower-level design courses to begin developing key skills and capabilities in students. There are also a variety of durations over which mechanical engineering capstone classes and experiences are offered: single semesters, multi-semesters, multi-quarters, or single quarters [2]. PAR seeks capstone delivery procedures, methods, and projects that can be implemented across the variety of modalities in which mechanical engineering capstone is taught. The purpose of PAR is to codify ways of working and structures that ensure the consistent success of any department implementing PAR for metric measurement that enables program self-improvement and ultimately student growth and learning. This process must start with the instructors who teach capstone senior design courses.

Background

University engineering programs use a wide range of approaches for selecting and running capstone projects. Some programs partner with industry to offer open-ended, sponsor-driven challenges [2]; others create projects tied to faculty research or specific curricular goals [3]. Competitions such as SAE Mini Baja provide another source of projects [3], while some programs permit student-proposed topics that are faculty vetted [4]. Projects typically span multiple subdisciplines and demand students integrate skills across areas (for example, thermal systems, robotics, and manufacturing in mechanical engineering). Beyond topical variety, most capstones aim to combine technical knowledge with teamwork, communication, and professional ethics in a final design experience. Because institutions differ in how they define, source, and assess capstone projects, it is difficult to compare student performance and learning outcomes across programs [5], which in turn complicates benchmarking and continuous improvement efforts such as accreditation documentation [6].

Research on capstone instruction indicates that faculty develop teaching expertise across several domains, including team dynamics, technical content, pedagogy specific to capstone courses, project management, scoping, design practice, and professional skills [7]. Instructors learn from teaching experience, interactions with colleagues, industry backgrounds, and personal experiences, with on-the-job learning and informal peer networks being especially common. Industry experience strongly influences faculty approaches to project management and authentic design practice, while managing team dynamics—mentoring, conflict resolution, and coaching—emerges as a particularly demanding aspect often acquired without formal training. These findings suggest that teaching capstone courses benefit from targeted faculty preparation and institutional support rather than relying solely on informal, experience-driven learning.

While researching tools for assessing capstone projects and programs across universities, the authors were unable to find any for determining the overall efficacy of projects and programs. A leader in the field of capstone design was consulted for help in finding the sought references and confirmed the lack of tools or studies seeking to develop tools to that effect. PAR seeks as a project to allow direct comparison between different capstone projects run in the same program and between the same or different capstone projects at separate institutions.

Methods

This study gathered faculty experiences and anecdotal insights from mechanical engineering capstone instructors through interviews to inform PAR project selection, identify key questions to be answered, and document approaches used to inform the development of a capstone design metrology tool. The following questions were developed and asked of veteran mechanical engineering senior design instructors in an open-ended interview format both as an opportunity to share thoughts and experiences and to inform the creation of PAR. Approval for the questions and interview protocol were obtained through Elon University's IRB before interviews were conducted.

1. How do you source projects for capstone?
2. How far ahead are you locking in projects?
3. What do you look for in a good project?
4. How do you scope projects?
5. Approximately how many unique projects are managed per semester?
6. Do you perform any skills assessments of students prior to grouping?
7. What size groups do you use?
8. How do you form groups?
9. Do you take prior experience or participation in relevant activities when forming groups?
10. How are projects assigned? (If multiple projects are available)
11. Are groups assigned an expert or mentor other than the instructor from the University?
12. How is student success tracked and evaluated?
13. How often do you meet with teams for coaching?
14. How often do you meet individually with students for coaching?
15. What are the main project performance problems that you observe in a capstone class?
16. What are the main group performance problems that you observe in a capstone class?
17. What interventions have you implemented in the past to address these concerns?
18. How did those interventions turn out?
19. What facilities do the students have access for manufacturing?
20. What external resources are students allowed/encouraged to use for manufacturing?

Six instructors were interviewed in this study. Three hailed from a large ABET accredited public land grant R1 university with established ME capstone program, 1 came from another large ABET accredited public R1 university with an established ME program, and 2 came from a medium sized private liberal arts university with a more recently ABET accredited engineering program. Each professor interviewed has taught a capstone course at least 3 times. These Universities were selected to obtain the profile of the programs where future PAR studies will be tested.

Results

The interviews yielded three main themes and challenges that emerged with those themes: 1) Physical capabilities, 2) Programmatic capabilities, and 3) Group capabilities and selection. Each theme will be described in more detail supported by interview comments from the interviewees.

Of the programs represented by the interviews, most had machine shop facilities for students to use, or they have someone on campus to build their parts at a central shop. Due to machine time and skill constraints, some programs still decided to outsource parts to online custom shops such as SendCutSend or to local machine shops. The latter option to off campus production was usually more costly for the instructor.

At the two universities included in the study that were large R1 institutions with legacy engineering programs, the students had access to a wide range of experts on every topic that could be pursued over the course of the capstone project but were often not directly connected to those experts. The main expertise constraints came for the newer engineering program at the medium sized private liberal arts university. While all engineering disciplines are represented among the faculty in the department, the engineering faculty there is a tenth the size of R1 peers. The result is experts in all topics were not always available for students to consult. Over time, projects were scoped to reflect this reality, reducing the variety of projects offered. All the universities struggled to run capstone classes due to the workload of the class being higher than a typical lecture class with the same credit for the instructor. The management of sourcing projects was a large time sink for many of the professors, especially the ones that sought unique projects for each group, whether they came from industry, the local community, existing design competitions, or internal needs. One of the universities has abandoned this all-unique project approach to maintain some consistency and reduce the workload towards a manageable level.

Group capabilities and selection are where the programs most diverged. The methods for group selection were as follows: 1) random, 2) skills-based assessment, 3) performance based, 4) self-selection, and 5) a mixture of skills assessment and project preference. For the randomly selected groups, professors set group size and then used a random number generator to assign students to groups. This approach led to predictably gaussian results. For the skills assessment approach, a class skills matrix was harnessed to maximize the prescribed skills distribution across each group within the class. With this approach, multiple versions were used across the programs. One approach used a student's reported self-perception of competency in core engineering skills (Statics, CAD, Writing, Machining, etc.) on a 0-5 scale with zero being no ability and 5 being an industry expert. The highest competencies viewed were in the 3-4 ranges for most skills. This approach was Gaussian in performance also, and an observed drawback was students got collared into working on tasks related to skills they already possessed. This outcome led to poorly distributed and inequitable student workloads as well as limited opportunities for students to learn new skills in capstone. Another skills assessment method deployed for team selection was application of the CliftonStrengths top 5 skills assessment to form student groups [8]. This process was developed internally based on a department member's experience in industry and running companies. CliftonStrengths classifies all talents into four major categories; strategic thinking, how people "absorb, think about and analyze information and situations"; relationship building, how people “build and nurture strong relationships"; influencing, how people influence others; and executing, how people “make things happen” [9]. These 4 are then broken down into a total of 34 specific themes with learner being an example of a theme in the strategic thinking category. According to one interviewee, use of CliftonStrengths to inform group selection has worked well because it ensures formation of groups that are well rounded in both personalities and skills while not explicitly saying that a specific student is the best at a specific engineering skill. Some positive observations from using this method included separating “influencing” individuals into different groups and ensuring each group had more than one “executor” to make sure there was a driving internal force to accomplish tasks and goals.

A less effective skill assessment that based group selection on measuring skills was performed in earlier prerequisite classes. Problems arise in groups using this approach because they tend to catalyze high-performing students all being grouped together while historically poor performers also all get grouped together. In these instances, groups with high performers generally do well in accordance with their prior grades. On the other hand, groups of low performers return an exceptionally poor performance because no one in the group does anything. In the worst situations, groups of low performing students will fight and require continuous instructor intervention. Sometimes, however, these groups surprise instructors because they realized someone must engage with the project and ultimately, they achieve a satisfactory result. The authors cannot condone this method of group formation as it is punitive from the start but is an interesting take on group formation and thus worth sharing.

Discussion

From the qualitative analysis of interview transcripts, common problems as well as solutions emerged. These testimonies illuminate important situated knowledge unique to the experience of teaching capstone that guides future data collection endeavors and the overall PAR project. While this study identified qualitative factors appliable across projects and programs, it was found that the viability of the potential project passing the instructors’ intuition is a very efficient method for screening projects initially. Another consistent factor that leads to successful projects was scoping the project properly, making sure that the desired final product from the student group was ambitious enough to push and challenge students but not out of reach that capstone teams are predestined to fail. For those initially ambitious projects to be successful, systems and expectations needed to be in place from project initiation to support the students in interacting with the stakeholders, prevent scope creep, and set agreed upon expectations and success metrics.

The findings of this faculty interview-based study reinforce and extend prior work on capstone pedagogy by highlighting that project success is driven by interplay and alignment between project characteristics, group formation strategies, and institutional capacity. PAR is conceived as a quantitative framework for comparing capstone projects and programs that can be inserted indiscriminately into any ME department’s capstone course as an evaluative instrument. What emerged from faculty interviews is the insight that, like a differential equation, the initial conditions must be given and considered in the quantitative program assessment. The effectiveness of senior design metrology depends critically on upstream decisions made by instructors and institutional conditions: project vetting, team construction, and fabrication capability availability.

The interviewed instructors identified team dynamics and project scope as dominant sources of capstone difficulty, often outweighing purely technical challenges. Although PAR is fundamentally a project-level assessment framework, its successful deployment is inseparable from the instructor's ability to anticipate and manage group behavior, stakeholder interaction, and scope evolution. As Paretti et al described, engineering faculty are rarely taught these skills, and they must be learned from experience [10].

One important implication is instructor's intuition as an early-stage project filter. While intuition is sometimes viewed as antithetical to quantitative assessment, the instructors interviewed consistently reported that an initial "viability check" based on professional experience was needed to weed out projects that did not fit their program's resources, capabilities, or cadence. For new capstone programs or new instructors without a senior mentor to give guidance, PAR provides immense value as a bridge. For those without experience in selecting capstone projects, PAR provides a known, vetted project that is accomplishable within the parameters of a variety of different programs. A new instructor could confidently run PAR projects for a few semesters to create for themselves time to learn how to teach capstone and select viable projects.

Group formation strategies emerged as the area of greatest divergence across programs represented and was consequential for outcomes. While skill-based methods produced predictable performance distributions, they often reinforced inequitable workload allocation and constrained student growth. In contrast, the use of CliftonStrengths-based grouping was viewed favorably by several interviewed instructors because it balanced leadership, execution, and interpersonal roles without rigidly assigning ownership to specific tasks or expectations. This approach appears to mitigate common failure modes identified in the literature, such as overdominance by "influencers" or paralysis in groups lacking "executors".

Conclusion

With a breadth of knowledge and experience, capstone instructors are a valuable source of information in developing PAR. From the small number of instructors interviewed at the three universities represented, five key factors were determined critical to the capstone project experience and end product: 1) passing a test of viability based on instructors' engineering intuition, 2) proper project scope, 3) facilities and support for the scope of the project, 4) adequate support for students in managing key stakeholders, and 5) not allowing scope creep. One university was using an unstudied engineering methodology to form balanced groups based on CliftonStrengths. This information will allow the development of PAR with a goal of providing students with consistent experiences across varied projects.

From the information gathered in this study, future work will include constructed group testing based on CliftonStrengths with implementation of the initial PAR project at the authors' institutions to determine the best baseline group composition. In addition, a follow-on study will be conducted to assess existing capstone projects to determine how they fit into PAR and a another study using updated questions with a wider range of capstone instructors to see if the qualitative analysis arising from the small sample size interviewed here holds true for the larger capstone project class experience and to include schools with a wider variety of sizes, demographics, and curriculum structures.

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