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Integration of Agile Project Management in an Engineering Capstone Course

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This paper outlines the integration of an Agile Project Management approach in a capstone engineering design course at Washington State University (WSU). The mechanical/materials engineering capstone course at WSU emphasizes interaction with industry customers and a drive for completion as teams of 4-6 students complete a semester-long project for various nonprofits and industry sponsors. Historically, the course has been highly unstructured, giving students space to manage their own time. While this approach is helpful for developing agency among students, many teams end up scrambling at the end after falling behind schedule early on. By teaching students the Agile Scrum framework, instructors provide students with a tool that can be used to map out their project, prioritize tasks, and manage project deliverables with the drumbeat of two-week sprints. This approach is applied to a single-semester mechanical and materials engineering senior design course at WSU, but is applicable for other disciplines and course layouts.

Keywords: agile, scrum, mechanical, industry

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Introduction

Culminating the engineering curriculum, capstone design courses are intended to provide students with opportunity to apply their acquired knowledge and skills to a real-world engineering challenge. In order to satisfy ABET student outcomes[1], this experience should facilitate innovation, teamwork, problem-solving, and incorporation of relevant codes/standards and environmental considerations. To provide such an experience, many capstone programs seek out partnerships with engineering industry companies. These relationships are mutually beneficial as industry sponsors receive low cost engineering services while students benefit from meaningful work, interaction with a real customer, and exposure to an industry sector. The importance of providing capstone projects with real customers and real implications cannot be emphasized enough as this forces students to be honest with their skills and take responsibility for delivering a quality product[2,3]. Industry projects must, of course, be scoped properly such that they are able to be completed within the timespan of the course as handing students open-ended projects is a recipe for incompletion[4,5].

Another factor affecting the success of industry capstone projects is the structure of the course. The level of structure involved in engineering capstone courses varies significantly between departments and universities. The most unstructured courses essentially assign projects to teams at the beginning of the semester with instructions to manage their time well and complete the project by the end of the semester, offering minimal guidance, check-ins, and feedback from the instructor throughout the semester. Other programs have found success from implementing more rigid scaffolding with regularly scheduled assignments, meetings with faculty advisors, and other requirement[6,7]. Both ends of the structured vs. unstructured course spectrum have advantages and drawbacks. The ability of students to solve problems and make decisions based on their own judgement are major learning objectives for the capstone courses. In an unstructured course environment, students have the space and freedom to develop agency and own the responsibility for their decisions whereas students in more structured course environments tend to rely on course structure to "catch them if they fall," often expecting their instructor or mentor to check their work. However, without structure, teams tend to fall behind on their projects, underperformers fail to contribute, teams skip prototyping cycles and neglect getting early feedback, and project outcomes suffer from these mistakes.

In this paper, a model for an Agile capstone course structure is presented with logistical details for implementing this model in a single-semester mechanical/materials engineering capstone course (ME 416). The tradeoffs between the existing, unstructured course and the new Agile structure are discussed along with results from surveys and prior projects. Finally, critical messaging for communicating the framework to students is discussed.

Challenges with Unstructured Course

For at least the last decade, the mechanical/materials engineering capstone course at WSU has been taught with minimal class structure. Students choose their own teams, are assigned to an industry project, then are expected to manage the project timeline and deliverables on their own from that point onward (with help from the instructor when requested). This class format has some benefits compared with more structured regimens:

1. Students learn to manage their own project schedule.
2. Students are not burdened with tedious class assignments.
3. Students enjoy the freedom of not being told what to do and develop the ability to make decisions on their own.
4. Minimal administrative burden for instructors.

Each of the above outcomes are highly beneficial to the students and align well with the course objectives. However, several obvious challenges are presented by this unstructured approach:

1. Most teams fall behind on their projects early on.
2. Important prototyping and validation steps are often skipped.
3. Many teams neglect to solicit early feedback.
4. Non-contributing students can slip under the radar.

While these challenges are common in capstone courses, they can have detrimental effects on project outcomes, and successful project completion is essential to building students' confidence and maintaining industry clients.

Benefits of Agile Course Structure

The Agile project management approach is known for improving customer satisfaction, promoting team efficiency, and pushing frequent design iterations, all while minimizing extraneous tasks[8]. While the Agile paradigm was initially centered around software development, the same values provide benefit to design work in many engineering disciplines, both in industry and in the educational realm.

When applied to a mechanical/materials engineering capstone design course, the Agile approach has the potential to address each of the challenges presented by the unstructured approach without compromising the benefits. Figure 1 illustrates the potential benefits of the Agile approach in improving time management and prototype completion among teams in the capstone course. Major milestones essential to typical project completion were mapped out across the semester with target completion dates (shown in black) reflecting a linear completion rate throughout the semester. The actual completion dates for those implicit milestones were then plotted (in color) for the 5 teams from the Fall 2023 semester, prior to the implementation of the new Agile framework which makes the milestones explicit. From this chart it can be seen that all of the teams fell behind schedule at some point, and many of the teams have a significant stalling phase in the middle of the semester where no milestones were being met. Data points marked with an "x" indicate deliverables that were simply skipped due to lack of time or due to the teams perceiving those steps as unimportant. Two teams skipped the beta prototyping altogether, and other teams neglected important testing of their prototypes.

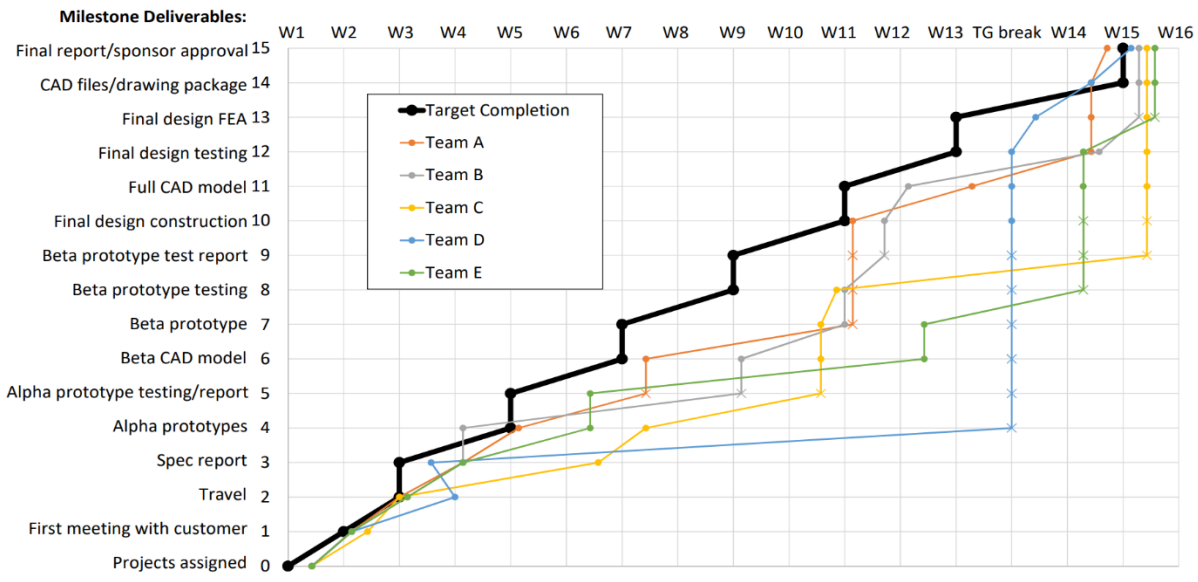

Figure 1. Milestone tracking from unstructured course in Fall 2023 compared with target completion dates for new Agile course layout.

Scrum is a methodology widely used for implementing the Agile paradigm in project management. With an Agile Scrum framework implemented in the ME 416 course, students map their projects into a series of two-week intervals (called sprints) where each sprint has clearly defined project increment/deliverable. With this approach, teams agree in advance on a number of prototyping cycles and are encouraged to stick to the schedule as they navigate one sprint at a time with clear goals for the end-of-sprint deliverables.

Agile Scrum Integration in Capstone Course

Sprint Map

To implement an Agile approach in ME 416, the course is mapped out into a series of 2-week sprints, following the first week of the class which is reserved for team formation and Agile training. The sprint map is the "big picture" plan designed to help teams stay on track with delivering prototypes and documentation throughout the semester. At the end of each sprint, the team will have made a specific product increment.

A sample sprint map, as shown in Figure 2, is provided to teams when projects are first assigned. While the sample sprint map fits many projects quite well (especially those projects involving design/build of some sort of widget), teams are encouraged to modify the sprint map as needed to fit their project. For example, one team's project might not require Finite Element Analysis (FEA) but would benefit from motion studies, so the team would modify the map accordingly. A team that is tasked with performing tests on an existing device (rather than designing a device), might struggle to integrate their project with the sample sprint map. However, they may decide that prototyping sprints can be used for prototyping their test apparatus.

Sprint #	Week #	Weekly Activities	Sprint Deliverables
	1	Team formation, Agile training	Scrum leader schedule, first email to customer
1	2	Customer visit, problem definition	Trip report, spec report
	3		
2	4	Ideation, alpha prototypes	Three alpha prototypes (cardboard or CAD), alpha prototype report
	5		
3	6	Beta prototype construction	Functional prototype and CAD model, beta prototype report
	7		
4	8	Beta prototype testing	Beta prototype test report
	9		
Spring break			
5	10	Final design construction	Fleshed out CAD model with FEA, component selection, BOM
	11		
6	12	Final design construction & testing	Finished product, test plan
	13		
7	14	Project documentation	Final report, drawings, CAD files, etc.
	15		

Figure 2. Sample sprint map for a single-semester ME/MSE capstone design course

Sprint Backlogs

At the start of each sprint, the team develops a list of tasks (called a backlog) that must be completed during the sprint to reach sprint deliverables from their sprint map. The sprint backlog is posted on Basecamp, the project management software used for the class. As students take on tasks from their team's backlog, they drag the tasks between 5 organizational bins (as shown in Figure 3): Sprint Backlog, Being Worked Today, In Progress, Blocked, and Done.

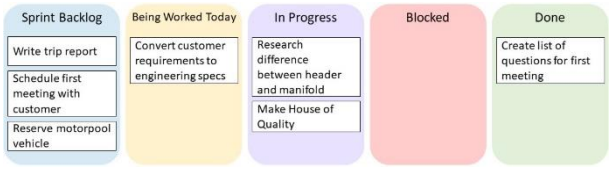

Figure 3. Sample Backlog Management space

Scrum Master

Each sprint is managed by a designated Scrum Master who tracks progress throughout the sprint and leads the Scrum meetings described in the next section. The Scrum Master is also responsible for keeping the team on track with a linear task completion rate and must report a Backlog update to the TA after each lab. Students take turns serving as Scrum Master throughout the semester.

Sprint Events

- **Sprint planning (< 30 mins):** At the start of each sprint (Tuesday in lab), the team meets together to create a backlog for the upcoming sprint. Backlog items are tasks that must be completed by the end of the sprint. Task due dates should reflect a plan to complete tasks in a linear progression over the 2-week sprint period. Finally, the team decides on which tasks each member will take on that day, marks the owner of the tasks on Basecamp, and moves the tasks to the appropriate column in the Backlog Management space.
- **Daily scrum (< 10 mins):** At the start of each lab period, the team meets together to review the status of the Backlog. The team discusses any blocked tasks and makes a plan to resolve them or escalate to the instructor. The Scrum Master shares insights from his/her sprint tracking to inform the team on whether the tasks are on-track with a linear completion rate or not. Finally, the team decides on which tasks each member will take on that day, marks the owner of the tasks on Basecamp, and moves the tasks to the appropriate column in the Backlog Management space.

- **Sprint reflection (< 15 mins):** At the end of each sprint (Tuesday lab), the team meets together to reflect on the completed sprint. The Scrum Master shares insights from his/her sprint tracking to inform the team on how linearly tasks were completed and how many tasks each member completed. The team then fills out a Sprint Reflection sheet, documenting any changes to the product specifications. The team also discusses their effectiveness as a team, noting any problems they encountered and proposing solutions or improvements for the next sprint.

Sprint Schedule

The capstone course at WSU is structured with a 50-minute lecture every Monday and two 3-hour lab sessions on Tuesdays and Thursdays. Each sprint begins on a Tuesday at the start of lab. Sprint deliverables are posted to Basecamp by Monday night at the end of the sprint.

Important Messaging

When teaching the Agile Scrum framework in the class, students can become overwhelmed by the terminology procedures, especially if it is their first exposure to Agile. Instructors should emphasize the following messages to avoid confusion and misconceptions:

- **Agile is a simple approach to project management.** Agile involves mapping the project into a series of two-week chunks (called sprints), then tackling those sprints one-at-a-time by making a task list (backlog) for the two-week sprint. Teams then use the backlog as a guide for what they should be working on and work to complete all the tasks by the end of the sprint in order to keep their project on schedule and produce frequent prototypes to their customer for feedback.
- **Teams manage their own projects.** Although instructors provide training on the Agile Scrum framework, students are the ones responsible for using this tool to manage their project. The instructor will not manage the project for them or tell them what they should be doing each day.
- **Teams should invite feedback.** Students tend to hide their work until it is finished and perfected for fear of criticism. With the Agile framework, every product increment should be shared with the customer for feedback. Early prototypes will undoubtedly have flaws, but early feedback is essential to customer satisfaction in the end.
- **Primary goal is to get the work done.** Students should not become overly focused on the Agile Scrum methodology such that they lose sight of the overall goal of completing their project. The Agile framework should support this goal, not get in the way of real work.

Conclusion

The Agile project management approach is widely used in engineering industry to improve team productivity, encourage early prototyping, and invite customer feedback. By bringing these values into the classroom, students are exposed to the Agile Scrum framework and provided with a tool to better manage their class projects. This framework is currently being implemented for the first time in the ME/MSE capstone course at WSU in response to a need for better time management and more frequent prototyping and customer feedback as students work to complete their semester-long industry projects.

References

1. "Criteria for Accrediting Engineering Programs," ABET, 2023-2024. [Online]. Available: https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2023-2024/.
2. A. T. Chamillard and K. A. Braun, "The Software Engineering Capstone: Structure and Tradeoffs," ACM SIGCSE Bulletin, vol. 34, no. 1, p. 227–231, 2002.
3. Y. J. Joo and K. Y. Lim, "Project-based learning in capstone design courses for engineering students: Factors affecting outcomes," Issues in Educational Research, vol. 29, no. 1, pp. 123-140, 2019.
4. C. Pezeshki, J. Leachman and S. Beyerlein, "Managing project scope for successful engineering capstone projects," *The International journal of engineering education*, vol. 33, no. 5, pp. 1442-1452, 2017.
5. M. J. Traum, S. R. Niemi, M. W. Griffis, N. A. Thomas and W. G. Sawyer, "Implementing an Effective Large-Enrollment Engineering Capstone Design-and-Build Program," in *Proceedings of the 2020 American Society for Engineering Education Southeastern Section Conference*, 2020.
6. B. Nassersharif, "A Structured Approach to Capstone Design," in *Proceedings of the 2022 Capstone Design Conference*, Dallas, TX, 2022.
7. S. W. Trimble and A. N. Shuaib, "Structure as a Key to Successful Capstone Design Projects," in *Proceedings of the 2022 Capstone Design Conference*, Dallas, TX, 2022.
8. U. Waqar, Agile Scrum Crash Course, Amazon Digital Services LLC - KDP Print US, 2020.