Effect of Sophomore Cornerstone Course on Senior Capstone

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I. Introduction

Over the last six years, we have developed and refined our approach to teaching a second-year cornerstone course in electrical and computer engineering. The purpose of this paper is to evaluate the effect of this cornerstone course on our senior capstone students.

We developed the cornerstone course for two main reasons. The first is that students did not have sufficient preparation for a demanding fourth-year capstone project. Apart from a light team project in their freshman introductory class, students in their sophomore and junior years generally only work with a lab partner. Without the experience working with larger teams, students in capstone often find their projects suffer due to teamwork issues they are unprepared to deal with. In addition, while some sophomore and junior labs are project-oriented, they tend to be much better defined and structured than capstone projects. Students go into capstone lacking experience in defining, documenting, scheduling, reporting and in general managing a large project.

The second reason is that students need to repeatedly practice complex tasks such as teamwork, project management, and communication. While the first term of our capstone sequence addresses these issues, students need to see them more than once. Having them go through a project cycle twice, once as sophomores then again as seniors, reinforces these skills.

In this paper, we will examine the effect of this cornerstone course on our capstone students, specifically looking at ABET outcome 5, "an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives" [10]. After providing some background on the courses in section II, and an overview of the assessment tools used in section III, in section IV we will provide assessment results and discuss two comparisons of student performance:

1) in their sophomore cornerstone course vs. senior capstone course, and
2) in their senior capstone course before and after introduction of the cornerstone course.

II. Background on capstone and cornerstone courses

A. Capstone

Every senior in the ECE department at Portland State University must do an industry-based senior capstone project [1], as is also required by ABET. The purpose of these projects is to give students the opportunity to: (i) apply their knowledge to solving real-world problems, (ii) gain experience working as part of a multidisciplinary team, and (iii) become actively involved in a company or other community organization. Students are expected to practice a systematic and

thorough design methodology, do detailed and thorough documentation of all work, work at developing more effective oral/written communication, and make a serious effort to complete the project.

A primary element of the ECE capstone program is the participation of our community partners, that is companies or community organizations participating in these projects. We try to ensure that each student is afforded the opportunity to work as part of a design team on a real-world project of value to the sponsoring organization. In surveys, our students consistently cite their capstone projects as one of the most rewarding and formative experiences of their undergraduate education.

The three-quarter capstone sequence starts in fall term with a first class, Industry Design Processes (ECE 411), which covers design documentation standards, building and managing effective teams, product development steps, developing and presenting project proposals, design processes, project scheduling and management, and design to meet desired needs. The class consists of lectures and a small team-based practicum project that allows the students to immediately apply and practice the course content. At the end of this first term, projects from community partners have been gathered. Students submit their preferences for a project using rank choice voting, and are assigned to a project team using their voting preferences and technical and personal strengths shared through an updated resume. For the next two terms (ECE 412 and 413), teams work independently on their projects with guidance and feedback from their project sponsor, faculty advisor, and the capstone instructor. At the end of the spring term, project teams present their results, write a report, and participate in a poster session.

B. Cornerstone

As discussed in the introduction, students frequently were unprepared for this complex team project, having had little to no team project experience. For this reason, we introduced the cornerstone project in 2018 to provide intermediate project experience before their senior year [2],[3]. The cornerstone sequence consists of two classes (ECE 211 and 212), preferably taken fall and winter terms of the sophomore year, but also offered in compressed form in summer term for transfer students. These classes have two overarching goals: (i) teach students engineering design and project management well before the fourth-year capstone projects, and (ii) teach electrical and computer engineering topics through hands-on experiential learning.

The first class, Introduction to Design Processes (ECE 211), discusses the design process, needs, requirements, functional decomposition, testing and project management. Students are assigned to teams and define and propose a project of their choice. The projects must address some specific need, and meet some other technical constraints such as being microcontroller-based (e.g., ESP32) and employ at least one sensor and one actuator. In the second class, Introduction to Project Development (ECE 212), teams work on their projects. Scrum [4],[5],[11] is used for project management, including daily stand-ups for team communication and accountability, two-

week sprints for time and task management, and sprint reports for documentation. Students use a Gantt chart and Trello board [12] which also enhance planning, time management, and accountability. Teams present and demonstrate their projects, and write a report at the end of this class.

Previous papers [6],[7],[8] presented assessment results on these cornerstone courses. Overall, the main conclusions are 1) students do well in successfully completing and demonstrating their projects, are enthusiastic about the hands-on project-based class, and gain satisfaction from designing and building their own projects, 2) teams can deliver decent presentations, but written reports are more challenging, and 3) teams improve over the course of two quarters in the use of project management tools, but at this stage need significant monitoring and feedback.

III. Assessment tools used in this paper

For course assessment in both cornerstone and capstone courses, we developed rubrics that were applied to several of the ABET and related student learning outcomes. For this paper, we will concentrate on ABET outcome 5 (Teamwork and Project Management). The assessment processes for each course are described here with complete rubrics in appendices at the end of the paper.

A. Cornerstone assessment process

Assessment of our cornerstone course was described in detail in [8]. The process is summarized briefly here, and the rubrics themselves are in Appendix A at the end of the paper. Our rubrics are based on a 4-level performance scale: Beginning (1), Developing (2), Proficient (3), and Exemplary (4). In most cases, we allow intermediate levels, such as “Developing/Proficient”. Most rubrics have more than one major criterion and each criterion usually has more than one performance metric.

Assessment of outcome 5 (Teamwork and Project Management) is done using two tools. One is a set of reports from the Scrum leaders - peer mentors in the class assigned to each team – who fill out reports for their team every two weeks. The instructor’s assessment is based on reading these reports and adding their own observations. The second assessment tool is peer evaluation using a survey in CATME [9]. There are three main criteria for outcome 5: Planning, Implementation, and Teamwork. Each of these criteria has several performance metrics used by the instructor to evaluate it. For example, for Teamwork, there are five performance metrics involving defining team members’ roles, having a team contract, communication, members contributing equally, and conflicts. The complete rubric is in Appendix A. A more detailed discussion of how these criteria were assessed, especially interpretation of the CATME survey data was presented in [8]. The translation of CATME data, which used a 1 – 5 scale, to our 4-level performance scale was somewhat complicated, but the process is described in this previous work.

For Teamwork, the Scrum leaders scored their teams on the five performance metrics in the rubric, and completed a report for every 2-week sprint. Only the final report, which was also evaluated by the instructor, was used to calculate the average scores reported in the following section. In the CATME survey, two questions were used to assess teamwork, one on contributing to the team's work, and one on interacting with the team.

For Planning and Implementation – sometimes grouped under Project Management – Scrum leaders scored their teams on two and six performance metrics, respectively. As with Teamwork, only the final Scrum leader report was used to calculate the average scores. In the CATME survey, three questions were used to assess project management, one on keeping the team on track, one on expecting quality work, and one on having related knowledge, skills, and abilities.

B. Capstone assessment process

1. Student Survey

To get a sense of how students evaluate the impact of the cornerstone course on their preparedness for capstone projects, we developed a survey for students at the end of their first quarter of capstone. This survey was given for the first time in Fall 2024. There were three prompts, each with a 1 – 5 scale answer for 'strongly disagree' to 'strongly agree' and a section for optional comments. There was an additional optional section for further feedback at the end. The prompts were:

1. The project management experience in ECE 211/2 helped prepare me for the project management needed for the practicum project in ECE 411.
2. The team experiences and training in ECE 211/2 helped prepare me for the team experience in ECE 411.
3. The presentation experiences in ECE 211/2 helped prepare me for the project presentation in ECE 411.

2. Student outcome assessment

To explore the effect of our cornerstone course on capstone, we looked at assessment data from the first capstone class, ECE 411, only. By the end of the capstone sequence (ECE 412 and 413), any effects of the cornerstone course would be overshadowed by the capstone experience itself. In ECE 411, students work on a quarter-long team practicum project. We looked at data from a year before students had taken the cornerstone course (Fall 2019 – cornerstone was first offered to sophomores in 2018) and a more recent year (Fall 2022) where we now require all capstone students to have taken cornerstone.

There are a few differences between the two years. In 2019, there was a smaller, separate capstone section for power engineering students. We have not included that here, but

concentrated on the main section for computer engineering and all non-power electrical engineering students. In 2022, there is no longer a separate section for power students; all computer and electrical engineering students are in the same class. The capstone sequence is now being led by a different instructor. Other than these small differences, the assessment methods, assignments, and rubrics are essentially the same between the two years.

Outcome 5 (Teamwork and Project Management) was assessed by the instructor based on two team-based assignments. The assignments evaluated were:

1. creating the project design specification document (i.e., the requirements document) and
2. the project schedule.

These assignments were chosen for assessment because they directly examine the team's abilities to establish goals and plan tasks. There were three performance metrics for the schedule and five for the requirements document. These are in the rubric in Appendix B. A 4-point scale is used as in the cornerstone course.[1]

IV. Assessment results and discussion

A. Results of cornerstone assessment - what students have learned at this point

A summary of assessment results for outcome 5 (Teamwork and Project Management) is shown in the histogram in Figure 1 for four years of teaching the class from 2019 – 2023. The vertical axis is the performance score on a scale of 1 (Beginning) to 4 (Exemplary), and the horizontal axis is the main criteria for this outcome. Abbreviations used are "TW"= Teamwork, "SL" = Scrum Leaders, "PM" = Project Management, "Plan" = Planning, "Impl" = Implementation. The first two groupings are related to Teamwork and the next three are related to Project Management. The first grouping in Teamwork, and the first two groupings in Project Management, are based on average scores from the Scrum leaders. The last grouping in each category are the students' own evaluations from a CATME survey.

For Teamwork, students consistently scored their teams in the developing/proficient range. Scrum leaders generally scored their teams a little higher, in the proficient range. The higher score in 2023 may be partly because the Scrum leaders were somewhat new and inexperienced, and more prone to grade generously. We are working on improving Scrum leaders' training, including consistency in grading.

[1] The labels used in the rubric were originally Proficient (4), Acceptable (3), Needs Improvement (2), and Unacceptable (1). To avoid confusion, results from these rubrics are re-labeled as Exemplary, Proficient, Developing, and Beginning which carry the same numeric score.

Similarly, scores for Project Management are consistently in the developing/proficient range. Here there is little difference between the scrum leaders' scores and how the teams scored themselves in CATME.

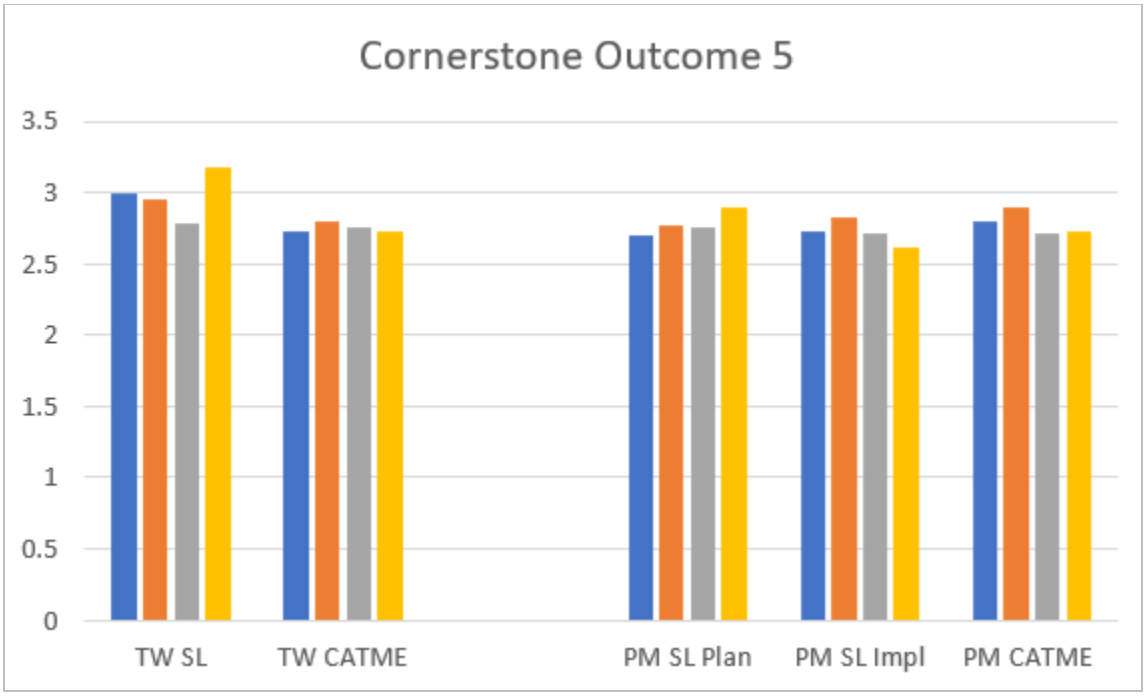

Figure 1. Assessment of Outcome 5 in ECE 212 for four years 2019 - 2023. Teamwork (TW) assessment on the left and Project Management (PM) on the right.

The results show overall satisfactory performance in the developing/proficient range for both criteria. No results are in the exemplary range, but this is as expected for sophomore students. This is generally students' first exposure to a structured team project, and developing/proficient performance is expected and acceptable. Over the years we have used this assessment data to find problem areas and improve the course. What we have not examined so far though is whether student performance improves in their senior capstone project, and whether this capstone project performance has improved since we introduced the cornerstone course. These questions are addressed in the final section of this paper.

B. Student survey on effectiveness of cornerstone in preparing them for capstone

The results of the three-question survey given to capstone students at the end of the Fall 2024 term are summarized in Figure 2 below. On the horizontal axis, 5 is 'strongly agree' and 1 is 'strongly disagree'.

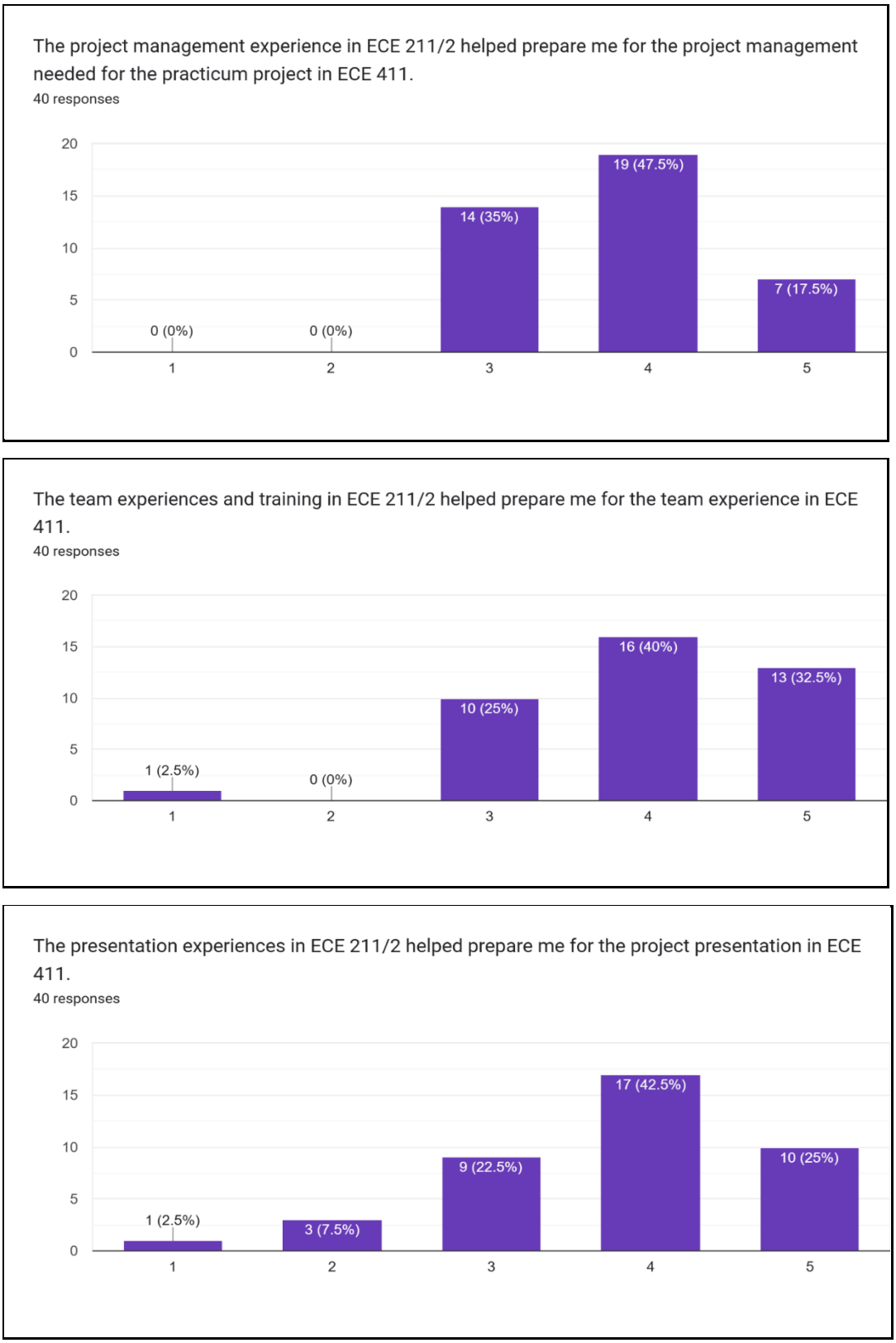

Figure 2. Results of student survey done in Fall 2024 in ECE 411. There were 40 out of 70 possible respondents. A Likert scale from Strongly Disagree (1) to Strongly Agree (5) was used.

Students were mostly positive that the project management experience in cornerstone was helpful, with 2/3 either agreeing or strongly agreeing, and no one disagreeing. While students found the cornerstone course helpful, they did find that there was a lot more to learn in capstone. Some comments to this question were:

> "The project management experience in ECE 211/212 helped prepare me for the project management required for the practicum project in ECE 411. ECE 211/212 taught me how to stay organized, break projects into sprints, and manage my time effectively. These skills were incredibly helpful when tackling the more challenging project in ECE 411."
>
> "ECE211 and 212 helped me overcome Impostor Syndrome. I was able to manage and deliver a quality project and I am proud of it."
>
> "I feel like I took more of a leadership role this term and I didn't do that in 211/12 so it was helpful but I definitely had to learn more this term than before."
>
> "ECE 211/212 taught me a good amount of project management skills, but it was only one kind of project management."

Students were similarly positive about the previous teamwork experience, with over 70% either agreeing or strongly agreeing. One respondent did not find it useful. Some comments to this question were:

> "Having taken ECE 211/2, I had an idea of what to expect from working on a team-based project when going into ECE 411."
>
> "The team experiences and training in ECE 211/212 helped prepare me for the team experience in ECE 411. It was helpful because everyone in both the 211/212 and 411 groups participated actively, and we did not spend much time in the 'storming' phase, which made it easier to get everyone working together."
>
> "The critical failure of my group in 212 helped me learn how to keep everyone on track and accountable, and not to pick software or hardware that was stupidly unreasonable for the task."
>
> "Helped me prepare for teammates with different levels of effort."
>
> "I have enough experience and exposure to working on a team that 211/12 felt mostly like another exercise/degree requirement."

Students were a bit more mixed on the usefulness of presentations in cornerstone. While 2/3 agreed or strongly agreed, there was 1/3 who were neutral or disagreed. Some comments to this question were:

> "I think the ECE 411 presentation was more in depth in comparison with the ECE 211/212 presentation, but it did prepare me for how it would go."

"The 211/2 was not an actual presentation, we just were required to demo/showoff our project!"

"Presentation was shorter and more informal"

Some general comments:

"I found having the experience of 211/212 to be very helpful. Not only with the projects and project presentations, but with learning industry methods to dealing with problems."

"ECE 211/2 was a great introduction to ECE 411 and provided a smooth transition in terms of difficulty. I am glad to have taken ECE 211/2 in the past."

In general, students mostly agree with our intention, that the cornerstone experience helps prepare them for the capstone project. This is mainly true for introducing them to project management and working on a team project, with less benefit from the less formal presentations required in the cornerstone course.

C. Student outcome assessment for capstone

The results for outcome 5 in 2019 and in 2022, as assessed from two team-based assignments, are shown in the histogram in Figure 3 below. Data for 2019 is on the left and 2022 on the right. The horizontal axis shows the four performance categories from 1 (Beginning) to 4 (exemplary), repeated for each year. The vertical axis shows the percent of students in each category. In 2019 there were 70 students in the class, and in 2022 there were 43.

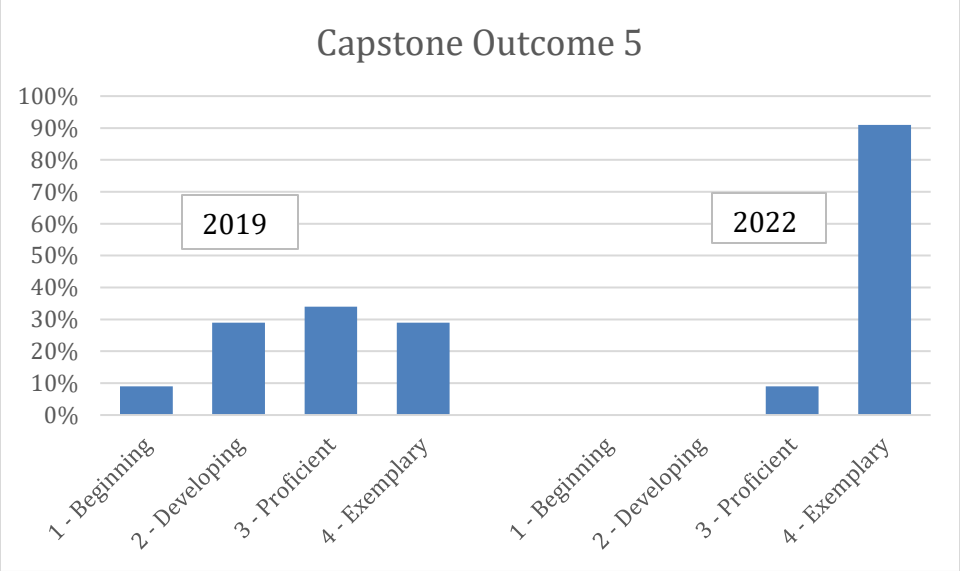

Figure 3. Assessment of Outcome 5 in ECE 411 in 2019 on the left and 2022 on the right.

In 2019, the results were somewhat low for a senior class. For comparison with cornerstone, the average score for outcome 5 over all four years of cornerstone data is 2.80 out of 4. For 2019 capstone data, the average is 2.83 out of 4. This suggests that in 2019 there was no improvement in teamwork skills, as judged by these limited assessments, between sophomore and senior years. This is not that surprising, as senior students at that time had little to no teamwork experience before capstone.

One other consideration is that the two assignments used for assessment of outcome 5 in ECE 411 came early in the quarter when students were still working out the expectations for themselves and their projects. Other outcomes assessed in the class which were based on the final project report and demonstration at the end of ECE 411 tended to have higher scores.

In 2022, as shown in Figure 3, we saw a dramatic improvement in the outcome 5 assessment compared to 2019. The average score is exemplary, 3.95/4. While there may be several contributing factors, such as a different instructor teaching the class and assessing the assignments, it is certainly plausible that the teamwork experience in cornerstone taught some skills that students are using in capstone. This would agree with the results of the survey of ECE 411 students in Fall 2024 reported in Figure 2.

Finally, we compared outcome 5 for students in cornerstone in 2020 and capstone in 2022. While there may be some individuals with different schedules, these should be mostly the same students. However, we do have students who transfer into our program as juniors, which makes this difficult to estimate. Figure 4 below shows these results superimposed, with the 2020 cornerstone class in blue and the 2022 capstone class in red. The vertical axis is the percent of students in each of the performance categories (1 = Beginning to 4 = Exemplary) on the horizontal axis.

It can be seen that there is significant improvement in the outcome 5 assessment scores for these students in their capstone as compared to their cornerstone class. We realize that there are many factors involved here, in particular that different performance metrics were used for assessment in these two classes, as well as having different instructors. In cornerstone we allowed intermediate scores, e.g., 2.5, while in capstone we did not. In spite of these differences though, we think that it is quite promising to see this improvement in the same students' teamwork and project management skills between the two courses.

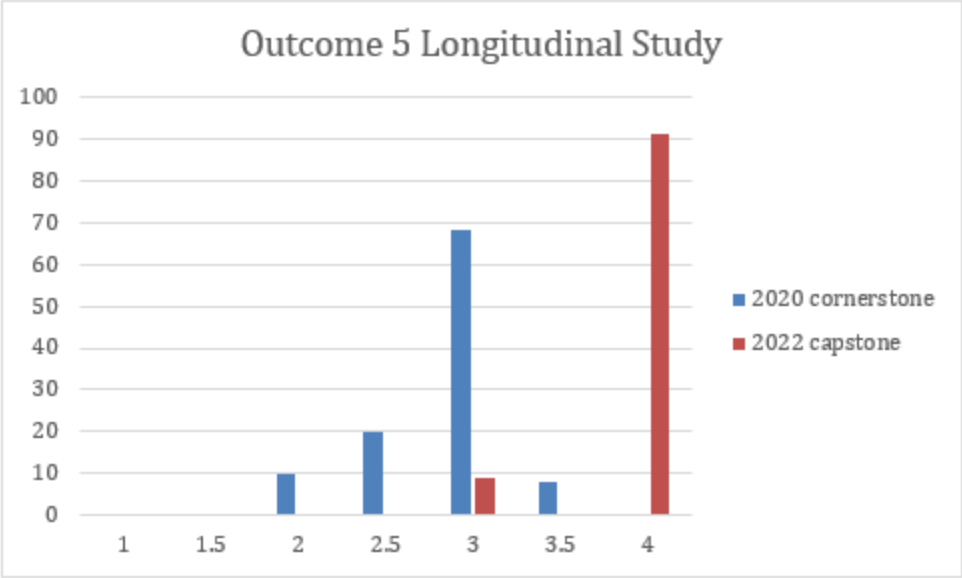

Figure 4. Assessment of Outcome 5 in ECE 411 in 2019 in blue and 2022 in red. Vertical axis is percentage of students and horizontal axis is the performance scale from 1 (Beginning) to 4 (Exemplary).

V. Conclusions and future work

Our original hypotheses were:

a) students will show improvement from the sophomore to the senior course due to increased experience, and

b) that students will perform better in their capstone course since we introduced the cornerstone course.

We believe that the assessment data of outcome 5 in 2019 showed that, for this outcome at least, the first hypothesis was not true on its own. Senior students in capstone in 2019 had approximately the same average score for outcome 5 as sophomore students in cornerstone. In 2019, before seniors had taken the cornerstone course, their experience of classes before the senior year did not include team projects. Therefore, these students had no prior opportunity to learn teamwork and project management skills.

However, in comparing outcome 5 assessment data between 2019 and 2022, the second hypothesis does seem to be true. In 2022, we see a dramatic improvement in the outcome 5 assessment in the capstone course. We recognize that assessing learning gains due to a given intervention is notoriously difficult, especially across different years, and other factors may have contributed. However, we believe it is plausible that the cornerstone experience contributed to this improvement in teamwork and project management skills. Results from the student survey in

capstone this year also validates this belief, as students also say the teamwork and project management experience in cornerstone was valuable to them.

Comparing classes that are largely the same students, cornerstone in 2020 and capstone in 2022, further validates this hypothesis. This longitudinal study shows these students did improve their teamwork and project management skills between the cornerstone and capstone courses. This is a small study, only one class of students, and we have to be cautious and acknowledge that the assessments were not the same for the two courses. However, we believe the result is promising, and validates the conclusion that this cornerstone class is a useful learning experience. This conclusion is further validated by the survey results and student comments in capstone.

For future work, we plan to include more years of data in our longitudinal study. We now have the same instructor teaching both the cornerstone and capstone courses, which will give more certainty to future comparisons. In addition, we would like to look at other outcomes besides outcome 5. In particular, we plan to look at outcome 3, Communications. The capstone student survey indicated students found less value in the limited presentation experience in the cornerstone course. We began to introduce more formal presentations in cornerstone in 2023-24, and are continuing the emphasis in 2024-25. We plan to see if having more of a presentation component in cornerstone will provide value for capstone as well.

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Appendix A – Assessment Rubric for Cornerstone, Outcome 5

5. an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives				
Performance Indicator	**Beginning**	**Developing**	**Proficient**	**Exemplary**
A. Project planning (documentation, timeline, decomposition, requirements, specifications)	Superficial planning document	More thoughtful planning documentation	Project proposal provides full graphical and textual documentation for timeline, functional decomposition, requirements, specifications	Proficient + anticipates problems and potential solutions (plans B and C)
	Missing or incomplete timeline, decomposition, requirements and specifications	One or two components of plan are missing, not well documented or explained	All components of a plan are given, well documented and explained	
B. Project implementation (planning, tasks, deadlines)	Team meets irregularly	Team meets regularly	Team meets regularly	
	Plans are not updated as conditions change	Overall plan updated irregularly	Plans are updated regularly	Additional project planning and management features are used, e.g., burn-down charts for Scrum.
	Intermediate tasks are too broad, lack responsible person, deadline, and definition of "done"	One of the key components of intermediate tasks (who, when, what) is not specified	Tasks are specific, detailed, have responsibilities assigned with deadlines, and define when a task is done (who, when, what)	Adjusts effectively to unexpected events
	Activities driven by external deadlines - most activity just prior to some event	Activities follow a plan	Activities follow a plan	

	No systematic updating of tasks and project progress is very difficult to gauge	Tasks updated intermittently & project progress is difficult to gauge	Tasks are updated regularly and progress checked	
	No attention paid to deadlines	Team rarely misses deadlines	Team meets deadlines	
C. Team functioning (structure, communication, spirit)	Member roles and responsibilities are not clear	Member roles are clear but execution is problematic	Member roles and responsibilities are clear and effectively executed	
	Team does not produce a team contract	Team contract is superficial	Team contract is well written and team members stick to it	Team is cohesive
	Communication is poorly set up with frequent lapses	There are occasional lapses in communication among team members	Team communicates well and regularly	There is spirit of respect
	Several team members are not contributing enough	There is an imbalance in assigned tasks and responsibilities resulting in friction among members	Team members help each other	All points of view are considered
	Team is falling apart due to personality conflicts	Some evidence of friction but team manages to work through it	No evidence of friction	

Appendix B – Assessment Rubric for Capstone, Outcome 5
Requirements Document and Project Schedule

Rubric for Requirements Document		Create a requirements document (PDS) for your project			
Dimension	**Weight**	Proficient 4 - excellent	Acceptable 3- good	Needs Improvement 2- fair	Unacceptable 1- poor
General Documentation Guidelines	**10%**	Includes title (project name and "requirements"), authors, version number and date, page numbers (if more than two pages)	Missing only page numbers	Missing title, authors, version, or date	Missing two or more of title, authors version, date
Organization	**15%**	Includes concise summary of proposed project including background ("milieu"), objective, need statements. Individual requirements are grouped together logically with headings (e.g. functionality, performance, economic, etc). Includes marketing requirements	Incomplete or poorly written need or objective statements or background ("milieu") description. Missing at most one minor requirements category.	Missing need or objective statement, missing at most one or two minor categories or at most one significant category of requirements	Missing objective and need statements, missing significant categories of requirements
Attributes	**30%**	All requirements are abstract, verifiable, unambiguous, traceable, and realistic	At most two requirements missing at most one attribute	At most three requirements missing at most two attributes	More than three missing attributes
Completeness	**30%**	All externally imposed and identifiable project-specific requirements are captured	Missing at most one or two minor requirements	Missing numerous minor requirements or at most one major requirement	Missing two or more major requirements
Relevance	**15%**	All requirements are relevant to the proposed project	A requirement is not relevant to the proposed project	At most two requirements are not relevant to the proposed project	The requirements bear little to no relationship to the proposed project

Rubric for Project Schedule

Create a project schedule for your project

Dimension	Weight	Proficient 4 - excellent	Acceptable 3- good	Needs Improvement 2- fair	Unacceptable 1- poor
Work Breakdown Structure (WBS) ["modular decomposition"]	**40%**	Project has been successively broken down into meaningful concurrent hierarchical tasks relevant to the project, there are paths (where appropriate) for hardware, software, integration, testing). There are tasks for document and design reviews and revisions. There are tasks for test plan creation and review and test case description, creation, and execution.	Project has meaningful hierarchy and concurrent engineering relevant for the project but the plan is sometimes unclear or there are some missing tasks or a missing development path	Project hierarchiy is incomplete, there are multiple missing development paths, there is little concurrent engineering, there are numerous missing tasks, major missing tasks, or schedule is too "generic" -- not specific to the project at hand	Project lacks meaningful hiearachy, there is little or no current engineering, there are no tasks for document and design reviews and revisions. Testing path lacks stasks for test plan creation and review or test case creation and execution
Task Descriptions and Estimates	**40%**	Task names, though brief, convey an accurate description of the work to be performed using active "action" verbs, leaf level tasks all have durations assigned, leaf level tasks are no more than 5 days in duration, zero duration milestones are used for progress indicators, dependences between tasks have been identified	At most two instances in which as task: has a name that fails to accurately convey description of the work, has duration longer than 5 days, isn't described using "action" verbs, milestone is missing, is missing valid dependences	Three or more instances in which a task: has a name that fails to accurately convey description of the work, has duration longer than 5 days, isn't described using "action" verbs, milestone is missing ,is missing valid dependences	Six or more instances in which a task: has a name that fails to accurately convey description of the work, has duration longer than 5 days, isn't described using "action" verbs, milestone is missing ,is missing valid dependences
Resource Allocation	**20%**	All tasks have one or more team member assigned as resource, work load (as evidenced by Gannt view) is equitably distributed among team members, schedule (as evidenced by Gannt chart) has been load leveled (no team member scheduled for more than one task at a time unless duration of tasks has been	Schedule has been leveled and balanced but may still show some resources (team members) with disproportionate share of work load	No more than one or two tasks missing resource assignments, schedule has been balanced but not leveled or leveled and not balanced.	Schedule has numerous tasks missing resource assignments or hasn't been leveled or balanced.