Project Health as a Capstone Rubric Element

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Work in Progress: Project Health as a Capstone Rubric Element

Abstract

Senior Design capstone programs help students develop many skillsets, including the ability to successfully manage a project. Students struggle transitioning from small assignments with clear instructions to large projects with less defined short-term activities and deliverables. As students have little to no experience managing large projects, the curriculum must provide tools and templates to help students manage their projects. A common method is to introduce 'gates' with specific deliverables for each gate, as typically used in industry stage gate project management. Students naturally convert the gate deliverables into discrete assignments they are accustomed to, and do not see them as tools to help them manage their projects. When this happens, the students focus on the specifics of the assignments and then view their grades as being subjective and unfair. A vicious cycle is set up where more specific and detailed rubrics are provided by the instructors to help remove the subjectivity in an attempt to provide fairer grading. However, this results in students treating the deliverables increasingly like an assignment and less like a guide to help them successfully manage their project.

A "Project Health" element is introduced in the grading rubric as a method to force the students to realize there is more to the deliverable than the specific requirements in the rubric. This change provided a method to reward the project teams who were paying attention to managing their projects, in addition to providing the requested specific items in the rubric. Initially, students struggled to understand how they could prepare specific items to check off this new rubric line item. In reality, there is no specific deliverable for this rubric item other than shifting focus from the specific checkpoint assignments to the whole project. The impact on their overall grade is small enough that the course was not viewed as excessively disorganized and subjective, but large enough that the students would constructively ask how to improve their scores. The results of this change were analyzed and compared to literature.

This paper details the downward spiral caused by increasingly specific rubrics and the start of the journey to dig out of this hole.

Introduction and Literature

Capstone Design or Senior Design is the culmination of students' undergraduate experience and knowledge. The high-level purpose is to provide students with an experience of the design development cycle during their education. They sharpen their technical and theoretical skills by taking a design from conception to completion. Evaluating various project deliverables, achievements, and overall project success in line with the learning outcomes of the capstone design class can be arduous for design instructors, especially considering each capstone project has different challenges, difficulty levels, and expected outcomes. Most Capstone Design programs have team-based projects, adding another layer of grading complexity to ensure each individual gets a fair and deserving grade while maintaining cohesiveness within the team. Capstone Design classes also have learning outcomes on intangible project aspects such as teamwork quality, communication skills, project management, professionalism, etc. Creating

rubrics to evaluate these aspects objectively while providing individualized feedback to each team requires a good balance between depth and simplicity in a rubric [5], [14]-[16].

Literature suggests the following key components are generally included in a Capstone Design course or program to assess student projects [3-5], [17], [19], [20]. These elements might vary slightly depending on the discipline (e.g., engineering, business, healthcare) or the specific objectives of the capstone program. These aspects match very closely with expected ABET outcomes [18]. We compiled the following list of key components for use in our Capstone Program:

1. Problem Definition & Understanding: This includes clear identification of the problem or need and evidence of understanding the technical, practical, and/or societal context of the problem.

2. Project Planning and Management: Clear project objectives and milestones, time management and adherence to deadlines, and resource allocation and management.

3. Technical Design and Innovation: Creativity and innovation in solving the problem, application of appropriate engineering or technical principles, and use of effective and relevant methods or tools.

4. Prototyping and Implementation: Prototype development, testing, and evaluation. Evidence of iterative design and continuous improvement, and proper documentation of technical work and decisions made.

5. Results and Analysis: Evaluation of outcomes relative to objectives, quality of data analysis and interpretation, and identification of limitations and areas for further improvement.

6. Communication Skills: Quality and clarity of written reports (e.g., project documentation, technical papers), oral presentation skills (e.g., pitch presentations, stakeholder meetings), and ability to communicate technical concepts to a non-technical audience.

7. Teamwork and Collaboration: Ability to collaborate effectively with team members, evidence of leadership or active contribution to team efforts, and communication and conflict resolution within the team.

8. Ethical and Societal Impact: Consideration of ethical implications of the design or solution; assessment of environmental, societal, or economic impacts; and compliance with relevant regulations or standards

9. Reflection and Self-Assessment: Ability to reflect on the project and its outcomes. Identification of personal strengths and areas for improvement, lessons learned, and future directions for the project or design.

Each Capstone Design class will include several project deliverables, assignments, and milestones giving teams an opportunity to present their project status and be graded based on their performance [14], [15], [17].

Literature on assessing capstone projects is vast and spans the spectrum from detailed rubrics [1]-[4], [14]-[17], [8]-[10] for each deliverable [20] to completely moving away from rubrics [6],

[7], [12], [13], thus revealing contrasting perspectives on the purpose and application of engineering design rubrics [17]. Several educators/researchers have created rubrics for project assessment across interdisciplinary programs [5], [9], [10], and at the same time, many have reported findings that providing detailed rubrics shunts student creativity, as students view their project only through the lens of the rubric instead of thinking out of the box to improve project performance and health [7]. Some educators/researchers focus on integrating stakeholder considerations into the design process, emphasizing external perspectives and real-world relevance [5], [10]. Some studies highlight ABET-driven outcomes [19], which prioritize measurable educational standards over stakeholder integration. Structured rubric guidelines aim for clarity and consistency in assessment frameworks, but rejecting rigid grading rubrics can promote creativity and flexibility [6]-[8]. A balance is needed between standardization and adaptability to accommodate the diverse aspects of a capstone project.

Place of Rubrics and Checklists in an Assignment

Senior Design or Capstone Design classes are unique and differ in execution, operation, and assessment from other engineering classes students have previously taken. There is value in detailed rubrics because they are familiar to students, and they help teams understand a starting point for preparing project milestones and how to effectively communicate these to the instructor. Rubrics for intangible project aspects such as team cohesiveness, communication skills, and time management, are often based on student surveys and self-chosen ratings by students [9], [10]. The results of these surveys are influenced by the survey questions and students answering with what they perceive to be the correct answer rather than their own input. After observing several classes and analyzing project reviews, we have experimented with adding a “Project Health” item to rubrics. We hypothesize this new item will enable instructors to provide tangible feedback on intangible and perceived aspects of the project, to improve the project health. Other items on the rubrics will stand alone and continue to help students prepare in the form of a checklist. The Project Health item also provides needed subjectivity to the grading rubric. Each project in a class is different and needs to be assessed through the subjectivity of its own requirements and challenges, which other checklist items on the rubric cannot address.

Project Health Introduction

We are instructors and directors of a large (235 student, 58 project) ECE Senior Design program and believe in continuous improvement of the course. When we see gaps in the course or when students identify unclear expectations, we attempt to correct these issues. Naturally, this results in clearer and clearer instructions for deliverables, which translate to more detailed rubrics. We expected the student questions and complaints to decrease and understanding to improve as the deliverable instructions became more detailed, however, the opposite occurred. Instead, students now had a very clear list to pull their grade to pieces. The intangible quality of the projects decreased while the students became sharper and sharper at delivering precisely what was requested in the rubric. Students were demanding more feedback, however, not feedback on how to improve their projects, rather, feedback on why they received the grade they did. Grading and

feedback became a defensive position for us, rather than a learning experience for the students. We were moving in a direction counter to the purpose of capstone programs.

Project Health was introduced as an additional element in the rubric in an attempt to counter this trend. The intent was to have a mechanism to push students to focus more on the global health of their project, rather than trying to turn every project deliverable into a tightly defined assignment.

The definition of Project Health provided to the students in the rubric is:

"Does the project design demonstrate maturity, applicability, and quality? Has the project made sufficient progress relative to what could be reasonably expected. You cannot prepare for this other than running your project well and spending time with your team/mentors in design exploration and experimentation."

For the major reviews, Project Health was worth 10% of the grade, which is not a large percentage of the assignment grade. However, if graded aggressively, it would have a significant impact on students scoring over 85% on the reviews. From an instructor grading perspective, it was not difficult to provide feedback and justification to the students for the Project Health grade, even when it was graded aggressively.

We wanted two outcomes from introducing Project Health to the rubric:

1. Ability to reward or penalize teams based on how well they are managing their projects, so the overall grade more closely represents the subjective assessment of progress based on the learning outcomes and quality of the team and project.
2. Modification of student behavior away from focusing on the specifics of the rubric and toward managing their project from a technical and project management perspective.

The definition of Project Health was deliberately left at a high-level. Clear examples were not provided for what would constitute a high or low score. The goal of the Project Health item is to focus the students on managing their projects, rather than managing their grades.

The irony of introducing an additional rubric element to reduce the dependence on detailed rubrics is not lost on us.

Our capstone program attempts to mimic project management in industry by implementing a stage gate process. The class reviews are very similar to the gate reviews found in industry. Where industry practice and the class differ is, in industry, a project may not pass a gate. In industry, funding is not released for a project until open items are resolved, and the gate review is then repeated. In a class setting, holding a project back is very difficult because project timing and resources are fixed. The Project Health item can be used as a way to measure if the project would pass the gate in an industry setting.

Our class project teams are required to maintain a project time plan with tasks broken down by week and further broken out by subsystem. Emphasis is placed on planning the individual tasks, coordinating the tasks within the project team, identifying the percentage completion of each

task, identifying the project timing critical path, and keeping the time plan up to date. Less emphasis is placed on the absolute progress. We want the students to use the time plan as a planning tool rather than a way to admonish them on their progress. The rubric reflects this approach, as the time plan is not a perfect measure of how well the team is doing on the project. We all know there are tasks that, in spite of the best planning, take longer than expected. Students should not be penalized for changes to a time plan through no fault or lack of effort on the student's part. Previously, we have found it difficult to grade the time plan as both a planning tool and a measure of how well the project is doing. The Project Health item has helped to effectively grade both aspects of the time plan.

Feedback on the Project Health

The Project Health item was initially introduced to a new group of students who did not know about the capstone course or know what to expect. It was explained in class as part of the preparation for upcoming reviews and was briefly discussed as part of the rubric review with the class.

Approximately a week before the first gate review with the Project Health item, we received the following question on the class forum from a particularly well-prepared student:

"*In terms of "Project Health and Design Quality", is the expectation that each group gives a reflection on how the project is progressing up to this point? Should we be basing this off of our progress of events in our timeline? What information are we delivering for this particular part? What is the expectation of each individual member?"*

Our response to the question was:

"*There is no expectation and no need for you to directly address "Project Health and Design Quality" in your PDR presentation. We will take into account your full PDR presentation and any questions to determine how well you are running your project and if you are demonstrating maturity and quality in your designs, choices, and decisions.*

The level of thought put into the timeline and the progress indicated on the timeline tasks is one of many ways we will use for the score for this element.

If you have been putting in the time to focus on your project and are using the assignments and reviews to demonstrate your progress and journey, you will have no problem with this element. If you have been only focusing on completing the assignments and not your project, this element will be challenging to do well on."

This question is interesting because the student is trying to morph the Project Health item into a concrete and verifiable deliverable. They want to know how to check off this box and make sure they are prepared. There was a little more discussion in class on this topic.

Some teams received very low Project Health scores, for example the Preliminary Design Review (PDR) overall average was 90% with a minimum of 67%, whereas the Project Health average for PDR was 84% with a minimum of 40%. During the reviews, students received ample feedback on how to improve the health of their projects and received less feedback on the

other rubric elements. While there were a number of students unhappy with their Project Health scores, very few students complained compared to the number of students who complained about other rubric element scores.

Data analysis

Our capstone program is a two-semester class. In the results below, 'A Class' is used to denote the first semester and 'B Class' is used to denote the second semester. Both classes have the same students on the same project teams, and the data is maintained for each individual student across both semesters. The class size is 235 students on 58 project teams and most projects are unique. We performed an analysis of Project Health implementation over both semesters (A&B Classes). Project Health was graded for three deliverables in A Class; Preliminary Design Review (PDR), Status Review (SR), and Critical Review (CR), and for four deliverables in B Class: Critical Design Review (CDR), Alpha Demo, Beta Demo and Design Day (DD). The data attempts to answer the following questions:

1. Are we already measuring Project Health, and are there any predictors of Project Health?
2. By scoring Project Health, was there a change in behavior?

Is using Project Health simply measuring something already covered in the class rubrics, or is it a unique measure of a necessary learning experience? To answer this, a regression analysis was performed to calculate the coefficient of determination (R^2) on all measured student grading data against the average Project Health score. Typically, R^2 ranges between 0 and 1, a value of 1 indicating the regression predictions perfectly fits the data.

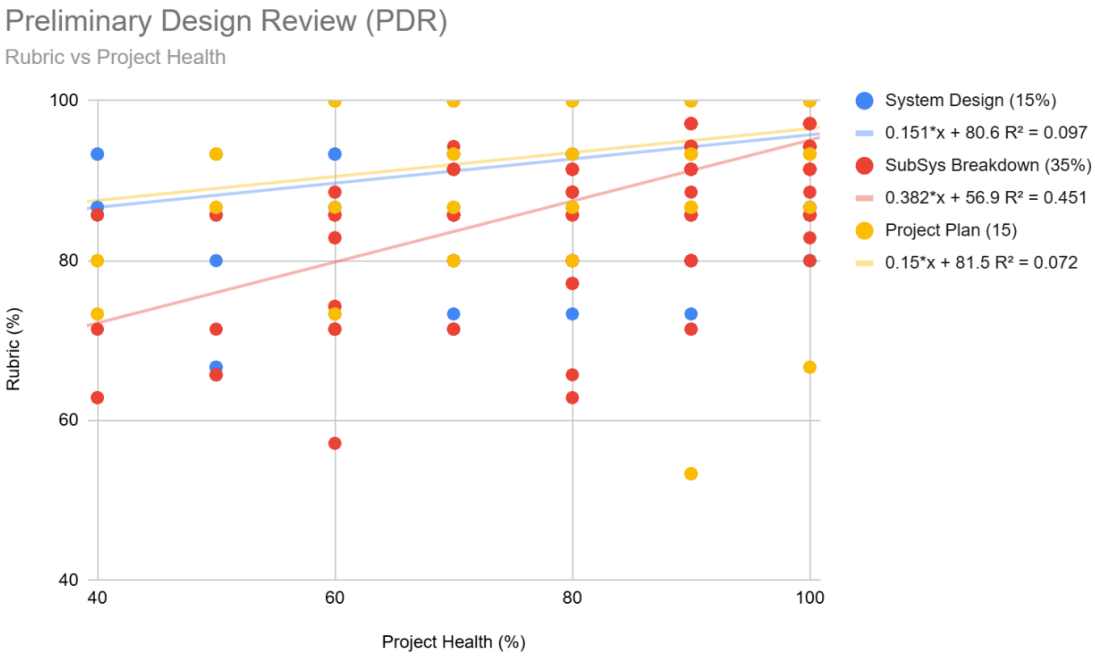

Figure 1 - *PDR Scatter Plot Rubric Element vs Project Health*

A scatter plot of three of the PDR Rubric Elements vs Project Health is shown in Figure 1 to visualize the relationship and to identify patterns. Only three PDR Rubric Elements are shown for clarity, representing the full range of R^2. Project Health is discretized as it was graded as integer values between 0 and 10. A linear trend line was selected, as higher order trend lines did not result in higher R^2 values. There is a high scatter in the data, the discretization in the data makes it difficult to see the 235 data points per series, the low slope of the line indicates Project Health is graded more aggressively than the other Rubric Elements. Ultimately R^2 was selected as the best measure of the relationship between Project Health and other Rubric Elements.

R^2 A Class Deliverables vs Average Project Health	
Class Deliverables	**R^2 vs Avg Proj Health**
First Concepts	0.090
Product Requirements	0.046
Market Study	0.016
System Architecture	0.141
Preliminary Design Review (PDR)	0.531
Status Review (SR)	0.383
Critical Review (CR)	0.396
Average Teamwork and Professionalism	0.090
Lecture Attendance	0.039
Guest Lecture Attendance	0.005
Assessments (Individual & Team)	0.001
Other Deductions	0.000

Table 1- R^2 A Class Deliverables vs Average Project Health

R^2 B Class Deliverables vs Average Project Health	
Class Deliverables	**R^2 vs Avg Proj Health**
Critical Design Review (CDR)	0.430
Program Review 1	0.033
Program Review 2	0.130
Program Review 3	0.226
Pre-Design Day Review	0.103
Alpha Demo	0.417
Beta Demo	0.368
Design Day	0.195
Lecture Attendance	0.016
Guest Lecture Attendance	0.003
Assessments (Individual & Team)	0.000
Other Deductions	0.027

Table 2 - R^2 B Class Deliverables vs Average Project Health

From Table 1 and Table 2 for A Class and B Class there is a very low correlation to Project Health on graded attributes where Project Health is not included. Even for deliverables that include Project Health (italics) in the rubric the correlation is not very high, (R^2=0.383 to 0.531) and (R^2=0.195 to 0.430) respectively.

A hypothesis could be that Project Health was just a reflection of how students were doing in the class overall. For example, if poorly performing students were not attending class, then maybe this would be amplified in Project Health, however the analysis in Tables 1 & 2 does not show this. The analysis does show Project Health is mostly an independent measure of learning outcomes for the class that are not measured in other ways.

The data is further broken down to determine if the Project Health item has overlap with other measured elements for the deliverables where it is measured, PDR, SR and CR for A Class and CDR, Alpha, Beta, and DD for B Class. Tables 3-5 show all the rubric elements for each of the PDR, SR and CR where R^2 is calculated between Project Health and each of these rubric elements. All students are graded individually for all deliverables; this analysis is performed at the individual level rather than the team level.

PDR R^2 Rubric vs PDR Project Health	
Rubric Element	**R^2 vs PDR Proj Health**
Project Intro (5%)	0.063
System Design (15%)	0.097
SubSys Breakdown (35%)	**0.451**
Tech Demo Plans (5%)	0.027
Project Plan (15)	0.072
Mockup (15%)	0.163
Project Health and Design Quality (10%)	1.000
PDR Total	0.615

Table 3 - A Class PDR R^2 Rubric vs PDR Project Health

SR R^2 Rubric vs SR Project Health	
Rubric Element	**R^2 vs SR Proj Health**
Project Intro (15%)	0.015
Subsys Timeplan (10%)	0.130
Subsys Status (15%)	0.214
Technical Milestone (20%)	0.280
Proj Budget (10%)	0.107
Issues and Help (10%)	0.102
Lessons Learned (10%)	0.291
Project Health (10%)	1.000
SR Total	0.538

Table 4 - A Class SR R^2 Rubric vs SR Project Health

CR R^2 Rubric vs CR Project Health	
Rubric Element	**R^2 vs SR Proj Health**
Project Intro (5%)	0.107
Subsys Timeplan (5%)	0.106
Subsys Status (10%)	0.107
Technical Relevance (27%)	0.130
Quality of Functionality (27%)	0.207
Quality of Presentation (6%)	0.263
Project Budget (5%)	0.001
Issues and Help (5%)	0.021
Lessons Learned (5%)	0.078
Project Health (5%)	1.000
CR Total	0.374

Table 5 - A Class CR R^2 Rubric vs CR Project Health

The immediate observation is there is a very low correlation between Project Health and other rubric items, except for the Subsystem Breakdown in the PDR Technical Milestones in SR. This makes sense, as these specific rubric elements are an indication of the project's core work. Both SR and CR have low correlation to all elements, with Lessons Learned in SR and Quality of Presentation in CR having the highest, which is a little surprising. This indicates Project Health is a unique rubric element in these deliverables. Similarly for B Class, Tables 6-9 show all the rubric elements for each of the CDR, Alpha, Beta and DD where R^2 is calculated between Project Health and each of these rubric elements.

CDR R^2 Rubric vs CDR Project Health	
Rubric Element	**R^2 vs CDR Proj Health**
Project Intro & Background (3%)	0.027
System Architecture (10%)	0.001
Design Elements (50%)	**0.455**
Lab Bench Demo (20%)	**0.435**
Product Req and Test plan (5%)	0.015
Project Plans (2%)	0.049
Project Health and Design Quality (10%)	1.000
CDR Total	0.590

Table 6 - B Class CDR R^2 Rubric vs CDR Project Health

Alpha R^2 Rubric vs Alpha Project Health	
Rubric Element	**R^2 vs Alpha Proj Health**
Subsystem Functionality (60%)	**0.430**
As Per Project Plan (30%)	**0.370**
Project Health (10%)	1.000
Alpha Total	0.585

Table 7 - B Class Alpha R^2 Rubric vs Alpha Project Health

Beta R^2 Rubric vs Beta Project Health	
Rubric Element	**R^2 vs Beta Proj Health**
Subsystem Functionality (60%)	**0.397**
As Per Project Plan (30%)	0.271
Project Health and demo quality (10%)	1.000
Beta Total	0.562

Table 8 - B Class Beta R^2 Rubric vs Beta Project Health

Design Day R^2 Rubric vs Design Day Project Health	
Rubric Element	**R^2 vs DD Proj Health**
Presentation Team (45%)	0.145
Functionality Individual (45%)	**0.581**
Project Health (10%)	1.000
Design Day Total	0.446

Table 9 - B Class Design Day R^2 Rubric vs Design Day Project Health

We see a very similar trend for B Class. In the CDR there is a very low correlation between Project Health and all rubric elements other than Design Elements and Lab Bench Demo, and even these elements do not have a strong correlation. For Alpha and Beta demos we see the strongest correlation between Project Health and System Functionality, this is somewhat logical because the stronger the Project Health is, the project technical achievements would reasonably be stronger.

Now, we explore the second question to see if there is a change in behavior. As A Class and B Class semesters proceed, the correlation between Project Health and the final score for each deliverable decreases. This is clearly shown in Figure 2 with the R^2 line. A desired hypothesis would be students use the Project Health score to modify their behavior by focusing less on rubric deliverables and focusing more on the actual project to improve the health of the project. If this were the case, we would expect the R^2 between the total points and Project Health to increase over time, indicating Project Health was more closely related to the other rubric elements. For the R^2 to decrease, either the other rubric element scores were improving without improving Project Health, or Project Health was improving without the other rubric elements improving. Neither of these are outcomes we would like. Since the R^2 analysis is looking at the correlation for each student, looking at the trends in the average Project Health score over time may paint a different picture.

Figure 2 looks at the trend difference between the average scores and R^2 across the deliverables in chronological order. The trend in Average Project Health and Average Overall scores is not clear. The ratio between these is also plotted to see if there is a trend, but there is no obvious trend. On the other hand, there is a very clear trend in R^2 decreasing during each semester (the A Class to B Class break occurs between CR and CDR). We would expect the R^2 correlation between Project Health and Overall deliverable scores to increase over time, indicating a 'healthy' project also resulted in a high score on the non-Project Health elements.

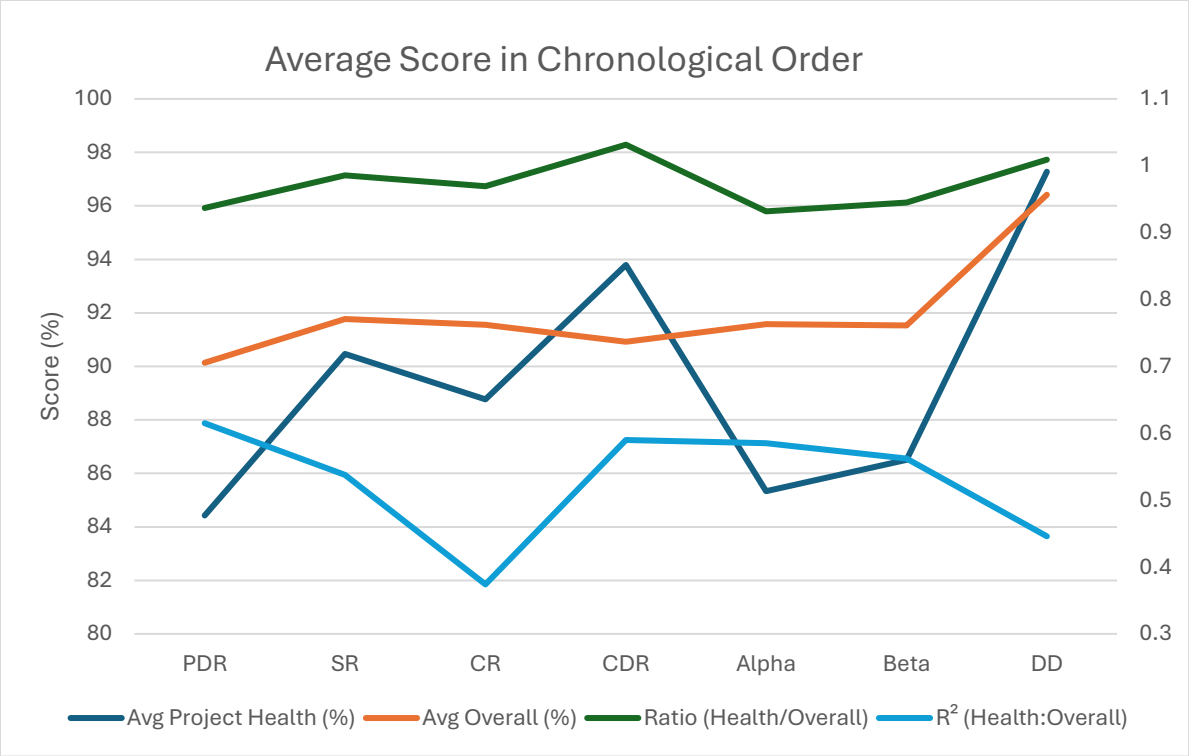

Figure 2 - Average Score in Chronological Order

Figure 3 plots the Project Health scores for each deliverable in chronological order to illustrate how the Project Health scores change over time. We do see a trend of mostly improving Project Health scores over time when we take into account the specific deliverables. PDR, SR1, CR1 and CDR are similar types of deliverables, and we see the Project Health scores mostly improving over time between these deliverables. Alpha and Beta demos are very technical and are reviewed differently than the previous deliverables, here we see Project Health improving from Alpha to Beta. There are three grading elements to Design Day, Team Presentation, Individual Functionality, and Project Health. In Table 9, we see a very low correlation between Team Presentation and Project Health and a moderate correlation between Individual Functionality and Project Health. For DD, the Project Health is a measure of how well each individual managed their part of the project, this is somewhat reflected in the Individual Functionality scores as a poorly managed project logically results in a poor technical outcome.

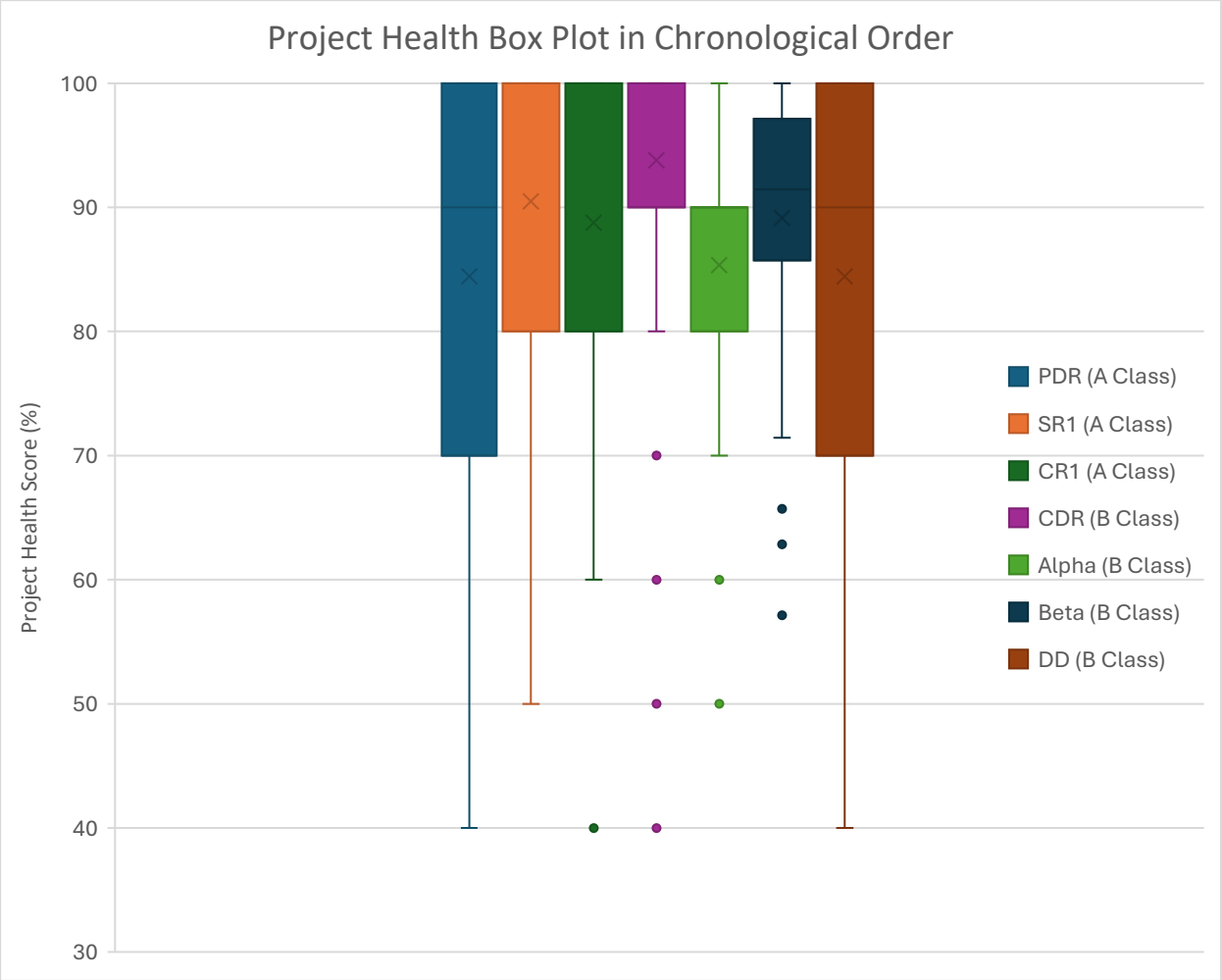

Figure 3 - Project Health Box Plot in Chronological Order

Conclusion

The Project Health rubric element had accomplished at least one of the two desired outcomes. For the first outcome, we believe the students' final grades now more accurately reflect the instructors' subjective overall assessment of each student. In regard to this first outcome, we believe the introduction of the Project Health rubric element was successful. Unfortunately, we have not been able to devise a good method to empirically prove this. One method might be to also record a subjective final grade in addition to the actual final grade for every class, however, we did not collect this data and it is difficult to complete retroactively.

The second desired outcome is to change students behavior over time to improve Project Health. A successful outcome is measured by the trend of R^2 (Project Health:Overall) increasing over time, however, R^2 (Project Health:Overall) actually decreased over time during each class, indicating the introduction of the Project Health rubric element had the opposite effect as desired. Students tended to follow the specific rubric elements even more closely, and focused

less on their overall project as the semester progressed. This matched our subjective observations.

The introduction of Project Health was not expected to solve all capstone grading challenges; however, it did provide us with valuable insights through observation and analysis:

1. More detailed rubrics tend to result in students focusing on the rubric elements rather than the overall project. For some of the rubric elements this is a good thing, and re-wording the rubrics to better match the desired outcome will help.
2. Including Project Health did not result in students significantly modifying their behavior toward focusing on their projects to improve their learning outcomes in the Capstone Program. Students highly motived by grades naturally search for a path to a secure outcome and thus tend to follow the detailed rubrics precisely. If the rubrics are created such that following them precisely does not create a 'healthy' project, then improved Project Health will not be the outcome. In our case, the way we added more specific detail to the rubrics was a step in the wrong direction. Detailed rubrics only help if the detail results in the desired learning outcomes, this is consistent with the literature.
3. Including Project Health does improve overall grade quality where the overall final grade more closely reflects the subjective evaluation of the overall project and learning outcome accomplishments.
4. While students did not fully understand Project Health, they were open to the feedback received on the respective Project Health scores and the overall project needs.
5. Project Health is an important measure of the learning outcomes, and there is little overlap between Project Health and other rubric element measures.
6. Detailed rubrics resulted in high workload for the instructors during grading, which did not translate well into improved learning outcomes. Feedback easily became defensive to justify the scores, rather than constructive to improve learning outcomes.

Project Health as a subjective measure of how well the team is managing the project as an outcome does have value and could be implemented on other project-based activities rather than just capstone programs.

Next steps

Implementing the Project Health concept was very valuable, and we learned a lot from the exercise, however, it is not the final solution to the problem identified in the introduction. We have continued the quest for continuous improvement and are trying the next evolution. Through the findings in this paper and research findings, including Nilson [13] and Blum [12], we are focused on providing constructive and implementable feedback to the students. The detailed rubric elements have been replaced with very high-level outcomes for each deliverable that are more aligned with what students will likely encounter in industry. Instead of the rubric being a list of compulsory elements, they are now a list of tools that can optionally be used to demonstrate the high-level outcomes. In concept, Project Health has been promoted to the

highest level and the other rubric elements are optional sub elements. Looking at it another way, the rubric is created to more closely reflect the desired learning outcomes. Data is still being collected for this most recent change and will be part of a future publication.

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