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Improving Student Self Efficacy in High-School Extracurricular STEM Activities through Implementation of Agile Workplace Practices (RTP)

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Abstract

A leading reason that high school students do not pursue careers in engineering fields is lack of confidence with STEM concepts and scientific thinking. In addition, teachers of engineering courses often report uncertainty in communicating complex STEM topics to high school students. Even if both teachers and students feel comfortable working within a scientific paradigm, inflexible high school curricula do not provide opportunities to utilize modern digital engineering tools. All of these issues, and others, result in students who graduate unprepared for college and the workforce. However, extracurricular activities taught by experienced Career and Technical Education instructors provide students exposure to project-based, workplace-like environments that can build self-efficacy in the complex communication and organizational tasks that underlie systems engineering. Teachers of these extracurriculars often have connections to local professional networks and are allowed more control over the structure and pedagogy of their instruction. In addition, students in these programs are exposed to real-world systems thinking and technical communication challenges as they work on a project. Therefore, incorporating digital engineering tools meant to formalize and promote systems-level thinking into extracurricular STEM activities may increase student and teacher self-efficacy in STEM and workforce behaviors. Following an Agile model, these tools must be cloud-native, interdependent, and computationally supported processes in order to promote student control and continual improvement of their digital environment.

In this mixed-methods case study, researchers and systems engineering professionals partnered with the teacher of a local high school engineering extracurricular to implement Agile workplace management tools. These tools were designed to encourage self-efficacy in systems-level thinking and improve technical communication as students designed and built a solar powered race car for a national competition. Students were surveyed for two academic years on their feelings of self-efficacy and their knowledge of how Agile workplace tools support digital engineering concepts. The survey instrument was created for this study based on workplace self-efficacy measures, and to capture changes that were made in year two of the project to reduce attrition. In addition, educators on the project and a subject-matter expert on systems thinking were interviewed for their experience designing and introducing these tools to students and professionals, as well as for confidence in teaching engineering concepts at a high-school level. Survey results indicate that implementing Agile workforce management tools improves student

self-efficacy. However, benefits are most clearly seen when implementing these tools within a project management system students are already familiar with. Analysis of interview transcripts reveals this is likely due to student inability to simultaneously familiarize themselves with a new project-management system and new workforce readiness skills. In addition, educator and professional interviews reveal improved teacher confidence in communicating systems thinking and improved quality of technical communication from both teacher and students. These results highlight the need for future research on which Agile digital engineering tools most improve student and teacher self-efficacy in experiential engineering projects, as well as the importance of collaboration between basic and applied researchers and educators in developing students' workforce readiness skills.

Introduction and Motivation

Nearly 40% of adults in the US have achieved a bachelor's degree or higher. This achievement is similar for residents of California, with 4-year college graduation rates hovering around 37%. However, state averages do not always reflect differences between urban and rural populations. For example, Los Angeles Air Force Station in El Segundo, California, is in an urban area of Los Angeles county with demographic information showing bachelor's degree achievement rates of 56.6%[1], well above the state average. On the other end of the spectrum, Edwards Air Force Base is situated in a mostly rural area on the northern edge of Los Angeles county, colloquially referred to as California's "Aerospace Valley". The communities that comprise the Aerospace Valley surrounding Edwards AFB have rates of bachelor's degree attainment of approximately 20%[2], which is well below the state and national averages. Communities surrounding many other Air Force Bases that are situated away from major metropolitan areas report similarly low rates of college degree achievement. It is this disparity in college-going rates between urban and rural communities surrounding Air Force Bases that helped to motivate this research.

In some areas, the military base is the only employer requiring employees with technical credentials and Bachelor's degrees. In rural communities which lack qualified people to do these jobs, recruiting and retaining skilled engineering degree holders is challenging. Recruiting and retention challenges underscore the importance of investment in college education and engineering degree attainment in the communities surrounding Air Force Bases. Air and Space Force Outreach efforts at all installations attempt to create the educational attainment rates required to maintain base effectiveness by encouraging students from the local populations to pursue STEM careers. AFSTEM, The Department of the Air Force's Science Technology, Engineering, and Mathematics outreach enterprise-level program, helps to develop the talent needed for the future workforce by engaging both students and teachers with relevant STEM content. Supplying high school students with tools and behaviors commonplace in the professional work environment helps them develop confidence in pursuing engineering or career-technical occupations in the STEM-centric Aerospace industry[3].

With the known disparity in college degree achievement and its accompanying recruiting and retention issues, the purpose of this research was to investigate if improving ties between high school learning opportunities and desired workplace behaviors would improve student self-efficacy in STEM pathways and college degree achievement. Some of the most effective means of improving high school student perceptions towards and pursuit of STEM disciplines in college have been extra-curricular activities and outreach activities from engineering professionals that tie schoolwork to the workplace[4,5]. For example, a longitudinal study of Virginia public high school students using data gathered from 2007 to 2014 showed that exposure to engineering content in high school correlated to increased enrollment in engineering at four-year colleges[6]. This effort was a collaboration between engineering professional outreach activities and an extra-curricular experiential learning activity in a local high school whose demographics tended toward career technical education.

High School instructor confidence in and experience with STEM disciplines and professional workplace environments also correlates to improved pursuit of engineering in college. The National Science Foundation's Research Experiences for Teachers study found that middle and high school instructor encouragement was more influential to students pursuing STEM disciplines than both student aptitude and family recommendations[7]. A 2024 meta-analysis showed that increased STEM education improved teacher self-efficacy in teaching STEM disciplines[8]. In addition, further NSF funded Teachers and Researchers Advancing Integrated Lessons in STEM research concluded that teacher self-efficacy improved with interactions with researchers in relevant fields and working in a community of practice[9]. Mentorship and connection of students with professionals in the discipline has long been considered beneficial to outcomes in engineering disciplines. The belief that connecting high school educators with engineering professionals and utilizing extra-curricular activities to develop desirable workplace behaviors would help interest students in pursuing engineering in college and technical school motivated this study.

The goal of the current effort was to improve both teacher and student self-efficacy in "digital engineering" workplace practices by implementing systems engineering and Agile workplace methodologies in the pedagogy, providing internet-enabled support, and implementing professional consultation in a high school extra-curricular experiential learning activity. "Digital Engineering" has been a term of practice in the aerospace and defense industries since the early 2000's and implies the intersection of engineering analytical techniques with systems engineering discipline, model-based systems engineering, and citizen developer computational capability development. Because of its software reliance, Digital Engineering has adopted many practices of the Agile software development discipline. Agile development methodologies[10] are being employed in the Aerospace and Defense industries, not only for software development, but also in hardware research and development activities. Many principles of the Agile Manifesto, such as frequent interaction with customers, "single sources of truth" for a given project, and reflection on a researcher's own learning, overlap with strong pedagogical practices and are being incorporated into "Digital Engineering" practices in the workplace. It was these digital tools and practices that the professionals and High School instructor incorporated into the project-based activity (see Appendix).

By changing the online support for a project-based extracurricular from a traditional assignment-like Learning Management System to a more collaborative and student-led "workplace", the authors aimed to foster a learning environment which would encourage systems thinking and Agile practices. Systems Engineering, Systems-Level thinking, and Agile workplace environments are common in the Aerospace Industry and especially in the region surrounding Edwards AFB in California. These aerospace, Digital Engineering workplaces require higher level analysis and synthesis activities from Bloom's taxonomy[11] at all levels of the workforce, as well as significant communication and independent action. Active learning and project-based coursework tend to already engage higher-level skills[12] than testing and homework practice, making a project-based extracurricular a salient target for conversion to workforce-level Agile methodologies.

The extracurricular course targeted for this implementation was the Solar Car competition team at local high school. The Solar Car Challenge is a designing, building, and racing team event[13]. Started in 1993, the project structure and annual nationwide competition motivates students to learn and apply science and engineering disciplines by designing and building vehicles of several different classes to race on an annually specified course. Teamwork, communications skills, and professional criticism are required by the structure of the competition, for which there are participation milestones throughout the academic year. The final race event in July is supported by a website, workshops, rules, safety information and timeline from the race organizers. This website functions as an ideal "single source of truth" for an Agile project management system. The Solar Car Challenge requires the students to keep a website, document their processes, and report results in a heritage engineering design "build and bust" approach. The requirements for hardware development through a documented process, internet enabled documentation and reporting, and teamwork make the Solar Car project class attractive for implementing "Digital Engineering" methods and tools into the High School educational experience.

More generally, the Solar Car Challenge structure creates a learning environment similar to that of the Air Force Research Laboratory's Rocket Propulsion Laboratory. Both environments require higher level learning skills from Bloom's Taxonomy like analysis and synthesis. Both require self awareness, autonomy, and advocacy by their workers. Both require a willingness to seek out and assimilate new information. The similarity between the High School extra-curricular and professional research workplaces made the solar car project an excellent target of opportunity for investigating Systems Engineering and Agile workplace environments on team members' self-efficacy.

This effort was a collaboration between the instructor of the project-based Solar Car extracurricular, researchers, and engineering professionals. It was intended to improve students' and instructors' self-efficacy surrounding both systems-level thinking and Agile workforce management tools with the end goal of increasing the likelihood of participating students enrolling in engineering in college or pursuing career technical occupations in the local aerospace industry. Questions being asked in this investigation are: can changing the structure of technology use within a high school experiential learning activity help develop student self-efficacy in workplace skills and behaviors, and does experiencing that environment lead to improved awareness and understanding of systems thinking and Agile methodologies?

Methods

The experiential educational activity targeted for this effort was the Solar Car extracurricular course at a local high school. An engineering technology instructor teaches the academic year-long course to mostly career technical students in grades 9 through 12 of the school's engineering program. The Solar Car activity does not include classroom content or require specific math or computer science pre-requisites. Since the Solar Car project class is voluntary and the specific skills used in “Digital Engineering” are broad-ranging, the specific learning outcomes for this effort needed to be carefully targeted. While Model-based Systems Engineering (MBSE) was originally recommended for implementation, MBSE was considered too broad and academically intense for an experiential course with no classroom support. In addition, purchasing an MBSE software platform as used in the industry, such as Cameo, would be cost-prohibitive for the project, maintenance would not be sustainable for the few students using it, and implementation would stress the school’s IT infrastructure.

Since direct application of MBSE to the Solar Car project was not considered appropriate for developing student learning outcomes, a more general learning outcome of awareness of "Systems Thinking" practices was targeted. The foundational scaffold of the Systems Thinking learning outcome is desired by ABET in accrediting Baccalaureate Engineering degree programs. It focuses on holistic understanding of product requirements, as well as interfaces between sub-systems and systems that enable product function. Systems Thinking provides a more foundational learning outcome that is applicable to a wider spectrum of students. Systems Thinking focuses on understanding complex entities holistically through internal and external interfaces, tracking interfaces through abstraction layers that view interactions and functions one lens at a time, and relying on common accountable data sources[14,15]. This project targeted the extra-curricular activity’s online support and instructor perspective to create a Systems Thinking -based learning environment for the students.

For a voluntary experiential learning class like the Solar Car project, the course’s online support was considered a feasible target of opportunity to implement more workplace-like procedures and student accountability. In the beginning of the project, this was facilitated by implementing a novel Learning Management System (LMS) with an Agile structure.

Traditional LMS software like Google Classroom, Canvas, and Blackboard present and house course materials, support online testing, and enforce semester deadlines. However, they often focus almost exclusively on teacher-student didactic interactions, which does not leave room for team collaboration or develop student agency. Other tools that may be used in a similar manner, such as workplace collaboration tools (e.g., Confluence and Salesforce) offer different user interactions, including team member activity logs, document repositories, and pointers to other resources. While information repositories, contact lists, and user surveys are common between the two systems, workplace systems have a more web-content look and feel, and place less emphasis on deadlines. However, they do not offer instant feedback on homework problems or built-in online exams. Many features of a traditional LMS can be mimicked in workplace systems and vise versa, if the specific use of the feature is understood. A third option for LMS implementation are elaborate, interconnected packages like the Salesforce Customer Relationship Management software. However, these software rely on subscriptions for individual users and a certified developer network to customize installations for specific customers, and are therefore expensive to maintain. While embedded interconnections between software functions, such as connecting available inventory to needed item purchase requests, would be useful to automate a workplace and for the solar car team, the fact that neither the students nor the instructor could see or control that interconnection makes developer dependent software packages unsuitable for a Systems Thinking learning environment, regardless of the cost. All of the above options, while advertising a wide array of functionality, have impracticalities that make it difficult to implement Agile structures using their platforms.

On the other hand, the Microsoft Office Suite is ubiquitous in administrative environments and offers a “sandbox” approach to specific functional development that can be accomplished by “citizen developers” on a SharePoint backbone with a significant online community of support. Because the School District and AFRL’s Rocket Lab had the Microsoft Office suite available and the “citizen developer” approach lent itself to customizing functions for the Solar Car project “workplace” that the students and instructor could control, MS Office’s SharePoint functions were the first target developing the project’s online collaboration environment. Once the Agile functions needed to encourage a Systems Thinking thought process were developed, a solar car team SharePoint channel was implemented and released for student use (see Appendix). This design was developed primarily by the instructor of the course, with regular feedback about standard workplace use and learning objectives provided by engineering professionals.

Instructor self-efficacy was assessed through semi-structured instructor and professional collaborator interviews. These interviews revealed that including Agile practices in the course pedagogy improved instructor confidence in communicating systems concepts and underscored the benefits seen from collaboration with researchers and workforce professionals. Student engagement with learning outcomes was measured through a novel survey instrument during the academic year. The survey reported acceptable internal consistency and results indicated that students felt high levels of self-efficacy throughout the investigation. Feedback from the first year’s survey showed that the Solar Car team students were distracted from content of the solar car project by having to learn SharePoint mechanics and switch back and forth between SharePoint and the school’s typical Google Classroom learning management system. Despite having all the needed features, students reported feeling like the SharePoint platform was unintuitive and the instructor reported a lack of adoption for the system. In the second year of implementation, since the instructor now had experience developing tools and features that supported systems thinking outcomes and desired Agile practices, re-creating the useful features into a more traditional LMS (Google Workspace) allowed for students to engage more meaningfully with Agile methodologies and systems-thinking concepts, although it did not impact self-efficacy in other workplace skills.

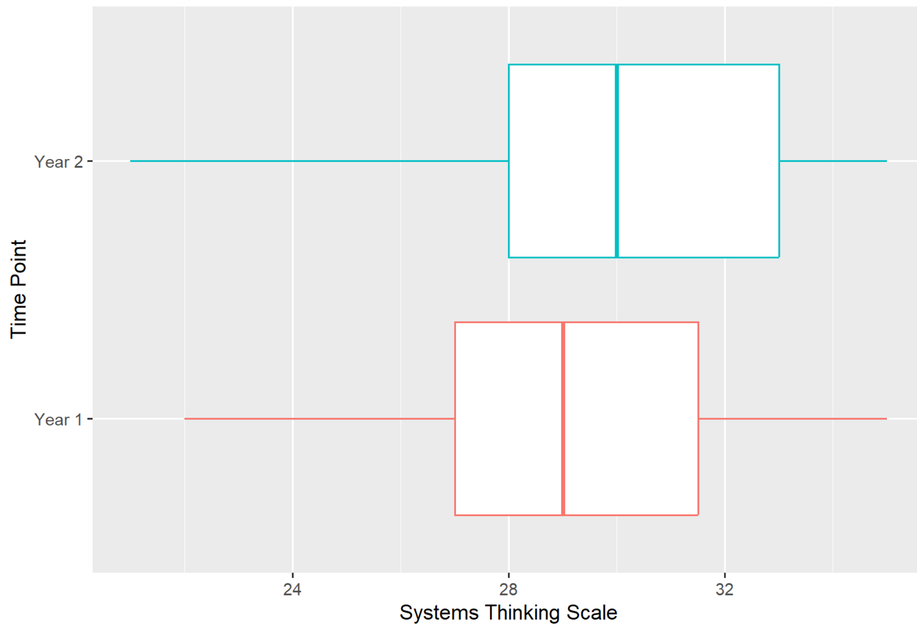
Results

This study aimed to measure student self-efficacy in two domains of importance for workforce development: systems thinking skills and navigation of Agile project management platforms. While some measures for measuring self-efficacy for certain workforce skills in the high school environment exist[16,17], there is no current measure that focuses on skills related to systems thinking. Therefore, a novel survey measure (the Systems Thinking Scale) was developed, drawing from prior work and utilizing the learning objectives from this investigation. The Scale consisted of questions focusing on background familiarity with online learning management systems, as well as seven Likert-scaled questions, such as "I understand how systems engineering helps ensure that requirements for product quality are met." Students rated each statement from one to five, with a highest possible self-efficacy score of 35.

Table 1: Descriptive Statistics for Scores on Systems Thinking Scale (/35)

	Total (N=60)	Year 1 (N=27)	Year 2 (N=33)
Systems Thinking Subscore			
Mean (SD)	29.5 (3.52)	29.1 (3.40)	29.8 (3.65)
Median [Min, Max]	30.0 [21.0, 35.0]	29.0 [22.0, 35.0]	30.0 [21.0, 35.0]

Figure 1: Scores on Systems Thinking Scale by Year



Students in the Solar Car course responded to the Systems Thinking Scale (STS) once during both years of the study, as well as a single-question survey in between the two survey implementations for the purpose of validating student responses to the STS. In Year One of this study, there were 27 students in the Solar Car program. In Year Two, there were 33 students in the program, nine of whom had also participated the previous year. All students responded to the STS (n = 60). In efforts to protect participant privacy, no demographic or identifying information was collected from students.

Scores on the STS were similarly high during both years (see Table 1, Figure 1). The mean self-efficacy score was 29.5 out of 35, with a slight but not significant increase from Year 1 to Year 2. Cronbach's alpha was calculated for year 1 (7 items; $\alpha = .68$, $N = 27$) and year 2 (7 items; $\alpha = .72$, $N = 33$) and demonstrated acceptable internal consistency, although the smaller sample size in year 1 may have resulted in increased error. In addition, responses to the validation question were also promising, with 25 of 35 students who responded in between STS implementations reporting that they agreed or strongly agreed with the statement "I know what I'm supposed to be doing and how to do it" (see Table 4).

The other domain of self-efficacy measured by this study was that of confidence with Agile methodologies. Due to the transition from SharePoint to Google Workspace between Years 1 and 2, which was necessary for the instructor to engage students on the online platform, the

Table 4: Agreement with the Statement: 'I know what I'm supposed to be doing and how to do it'

	Total (N=35)
I know what I'm supposed to be doing and how to do it.	
1 (Strongly Disagree)	1 (2.9%)
2 (Disagree)	2 (5.7%)
3 (Neutral)	7 (20.0%)
4 (Agree)	10 (28.6%)
5 (Strongly Agree)	15 (42.9%)

Table 2: Belief in the Efficacy of the Platform Used (Sharepoint/Google Workspace) by Year

	Total (N=60)	Year 1 (N=27)	Year 2 (N=33)
Belief in the Efficacy of Agile Platform			
Mean (SD)	3.80 (1.09)	3.26 (0.984)	4.24 (0.969)
Median [Min, Max]	4.00 [1.00, 5.00]	3.00 [2.00, 5.00]	5.00 [1.00, 5.00]

assessment for this domain was limited to one Likert-scaled question. Students' self-reported their confidence in appropriately utilizing the Agile project management system to assist with their Solar Car tasks (see Table 2, Figure 2). An independent-samples t-test was used to determine if responses to this question were different between year 1 (hosted on SharePoint) and year 2 (Google Workspace). Students reported significantly higher self-efficacy while using Google Workspace (M = 4.24, SD = 0.97) than while using SharePoint (M = 3.26, SD = 0.98), t(58) = -3.88, $p < .001$.

Student reports and instructor feedback after Year 1 indicated that the low self-efficacy scores in Year 1 for working with an Agile methodology was due to the students' lack of familiarity with the SharePoint platform. In an interview with the instructor, he stated that he felt students had limited time in the extracurricular and were unwilling or unable to transition to a new LMS. Students could either focus on the novel learning objectives or figure out how to adopt a new platform, but not both. Therefore, the instructor states that he made the decision to transition to using Google Classroom and the Google suite of products for the course, which the students were already using for other courses. Due to the background familiarity questions included in the Systems Thinking Scale, this analysis was able to empirically test the instructor's beliefs.

The results of an independent samples t-test show that students felt significantly more familiar with Google Workspace (M = 12.8, SD = 1.43) than with SharePoint (M = 7.11, SD = 2.29), t(58) = -11.717, $p < .001$. In addition, Table 3 shows a split between students who scored 10 or less out of 15 on this measure (indicating low familiarity with the platform) and students who scored 11 or higher out of 15 (indicating high familiarity). A final independent samples t-test indicated that, independent of which platform they were using, students who had a low level of familiarity with that platform were significantly less likely to report a high level of self-efficacy while using Agile tools to prepare for competition (M = 3.36, SD = 1.04) when compared to students with a high

Figure 2: Student Perception of Effectiveness of Agile Platform

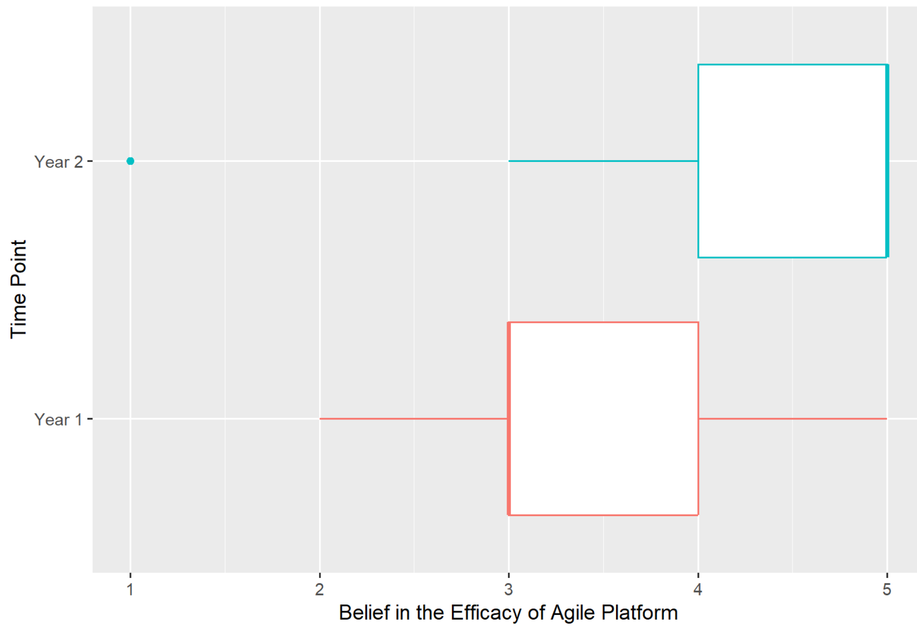


Table 3: How Familiar Students Felt with Learning Platform by Year

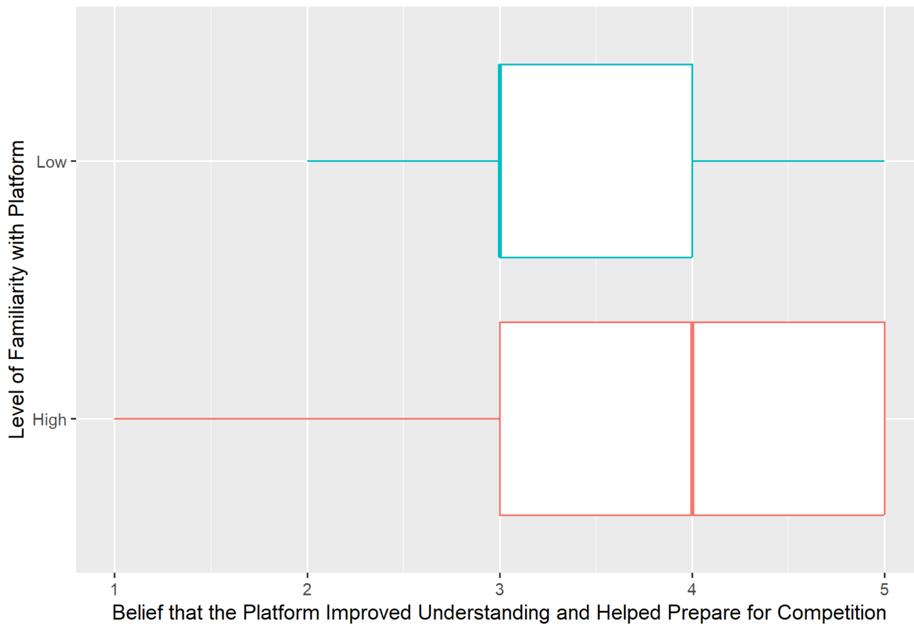
	Total (N=60)	Year 1 (N=27)	Year 2 (N=33)
familiarity			
Mean (SD)	10.2 (3.40)	7.11 (2.29)	12.8 (1.43)
Median [Min, Max]	12.0 [4.00, 15.0]	7.00 [4.00, 12.0]	13.0 [9.00, 15.0]

level of familiarity with the platform (M = 4.11, SD = 1.02), $t(58) = 2.8018$, $p = .006$. These results are visualized in Figure 3 and support the conclusions made by the instructor in his interview.

Discussion

This study attempted to improve high-school student self-efficacy in systems thinking practices and Agile workplace practices in a workplace-like, project-based extracurricular activity. The introduction of a novel Systems Thinking Scale and the utilization of interviews with the instructor of the Solar Car program provided innovative, responsive, and consistent methodologies for measuring student self-efficacy. Students reported high levels of confidence in systems thinking during both years of implementation, and improved understanding and utilization of Agile methods when using a familiar LMS platform in year 2. The instructor reported improved self-efficacy in his own teaching, pedagogical development, and professional engineering communication due to implementing Agile strategies and collaborating with workforce professionals. He also recognized a critical limitation affecting the efficacy of the SharePoint platform and was able to correct it based on feedback from students and researchers. His initiative and the success of this intervention as a whole highlight the benefits seen from

Figure 3: Percieved Efficacy of Platform by Student Familiarity



research-industry-education partnerships for students, educators, and professionals.

However, this study does have several limitations. Primarily, it is a case study of one classroom in one school over two years. The sample size is small. It is also possible that some results in Year Two were affected by what the instructor had learned and changed in Year One, although the instructor had already been teaching the Solar Car class for several years prior to the introduction of Agile methods and systems thinking pedagogy to his curriculum and was very familiar with the structure and function of the team. In addition, the Systems Thinking Scale has never been used before and it is unclear how well it generalizes. While the STS is relatively internally consistent, it is not incredibly so, and it is possible that the small number of students who took the scale twice (students who were in Solar Car in both Years 1 and 2) affected its consistency in Year Two.

Future studies on this topic should attempt to replicate systems thinking and Agile competency benefits in other engineering extracurricular courses. Because the learning objectives are content-neutral, other team activities for high school students such as Science Olympiad or Robotics may benefit from implementing similar structures. In addition, research that includes pre-test self-efficacy measures would allow for a control group measuring improvement in self-efficacy. Similarly, testing the Systems Thinking Scale in actual engineering workplace environments might lend insight into its general applicability. The STS should also be modified to improve consistency while maintaining items developed from standardized measures and keeping systems thinking learning objectives in mind. Other investigations on the relationship between teacher connectedness to workforce practices and professionals and student outcomes should be conducted.

The benefits of this study lie in its unique solutions to several problems faced by members of rural communities surrounding Air Force Bases and the engineering employers who would like to hire them. This investigation emphasizes individual solutions developed through collaboration between engineers, researchers, and educators. It draws attention to the reasons high-school students gain or lose confidence in their STEM skills and knowledge, and proposes solutions that can be implemented in almost any high school with an existing career-technical or engineering program. As shown by the necessitated change in LMS platform in this study, the best ways to improve self-efficacy in high school students are often not the most complex or detailed, but the ones that allow them to build on skills and knowledge they already have.

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Appendix: Examples of Agile Implementation in LMS

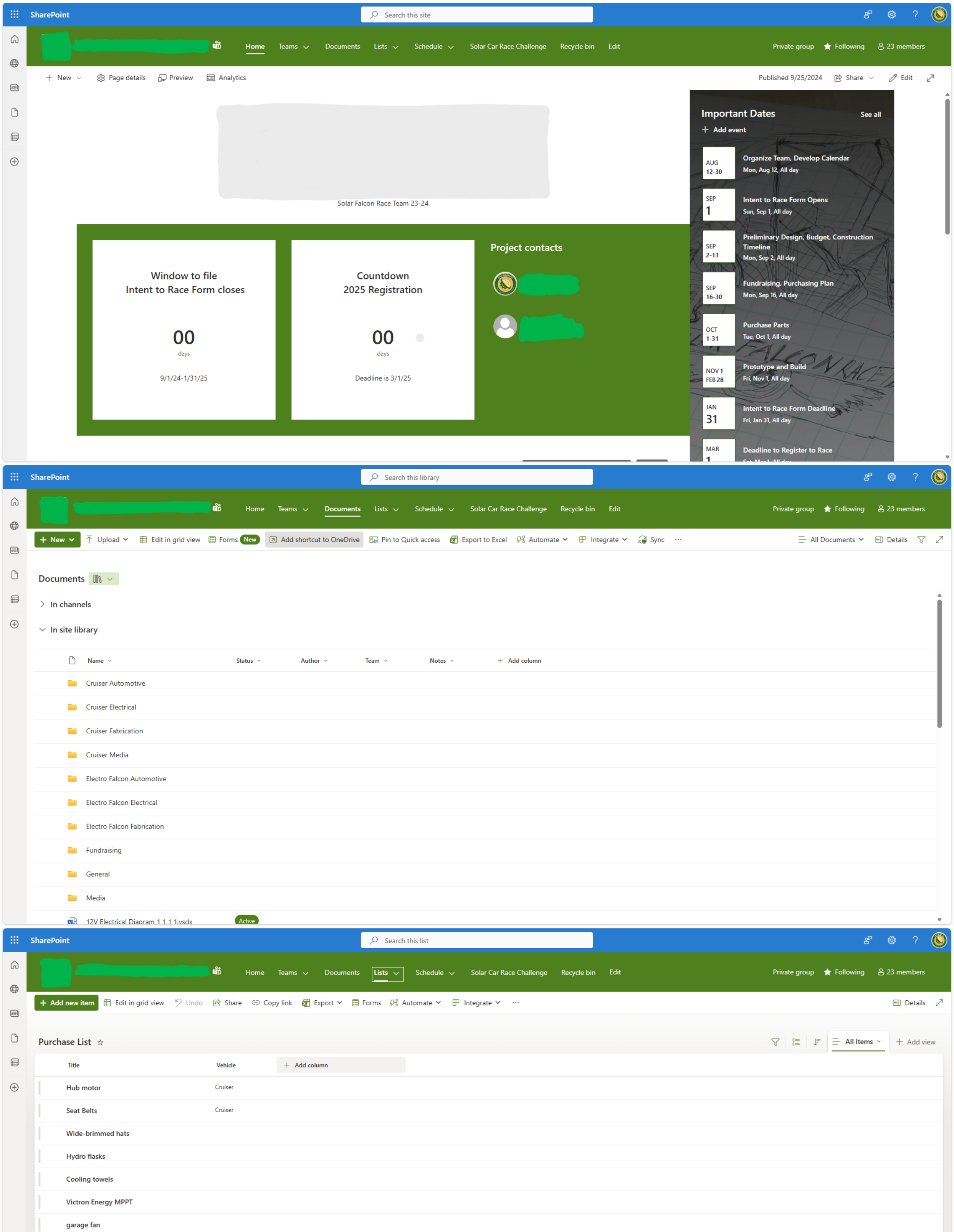

Figure 1: Year 1 (Sharepoint) Agile Implementation

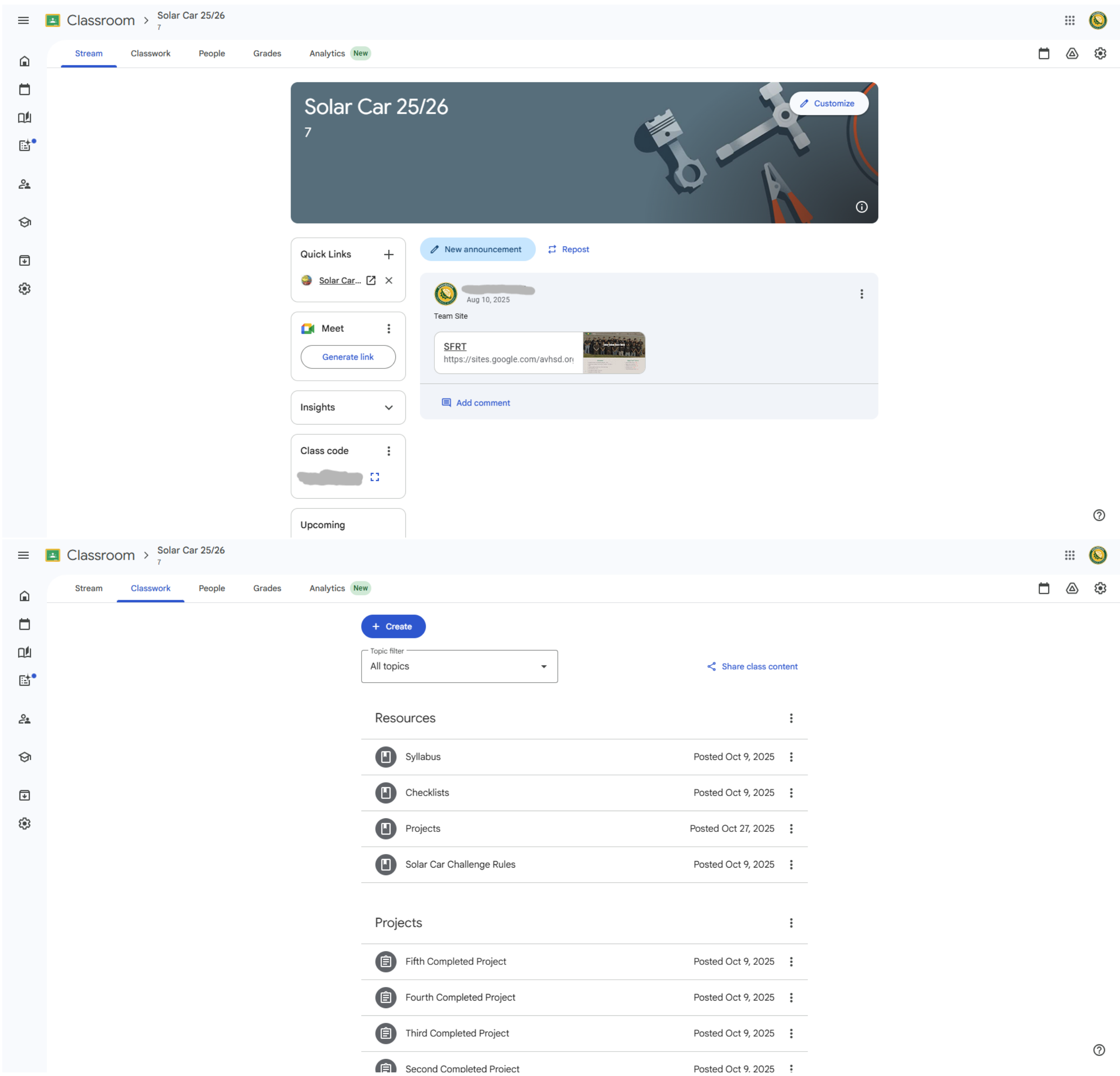

Figure 2: Year 2 (Google Workspace) Agile Implementation