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Using Scrum to Increase Flexibility and Effectiveness in an Agile-Research Experience for Undergraduates (A-REU)

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Abstract**—**The National Science Foundation (NSF) supports Research Experiences for Undergraduates (REUs) that attract undergraduate students into various research fields. REUs are valuable experiences for students, allowing them to engage with advanced topics they wouldn't typically encounter in the classroom. However, these programs, especially when delivered over the summer, have a very short time frame to develop undergraduates from novices to advanced researchers, especially when the field involves cutting-edge research. On top of these constraints, many participants are novices to the research practice itself. This work addresses the need to mentor novices in research and domain fields while allowing them the autonomy to explore and enjoy the research process. Thus, Agile-REU (A-REU) was developed. A-REU uses a Scrum-inspired mentorship framework to engage faculty and graduate students in guiding undergraduates through the research process. A-REU redefines traditional Scrum roles and processes to fit the unique temporal, spatial, and cognitive demands of a summer intensive REU. This work leverages the Scrum framework, synchronous and asynchronous communication practices, and the existing REU structure to improve the student mentorship experience at REUs.

This A-REU was deployed to a singular mentorship team at the REU Site: Cybersecurity Research of Unmanned Aerial Vehicles at Embry-Riddle Aeronautical University. Following the informal implementation of Scrum for research mentorship, this pilot evaluation involved 3 REU participants, a graduate student researcher, and a faculty mentor. Researchers received a one-hour Scrum orientation and a concise introduction to their project topic. Students participated in one-week Sprints (Monday-Friday) in which they set goals for their progress each week. Students met with the graduate student 3 times a week and the faculty mentor at least once a week to provide updates on their progress. In addition to REU activities that allowed them to share their progress with the other REU participants, the A-REU students participated in Scrum-inspired reflection sessions at the end of the week. The outcomes of this pilot program were positive, with all students successfully completing some level of research in the REU. This pilot study presents the initial framework, an evaluation of the A-REU process's success, and suggestions for future adaptations.

Keywords**—** Scrum, Agile, REU

Introduction

The National Science Foundation (NSF) supports undergraduate research through a funding program known as Research Experiences for Undergraduates (REU) [1]. This is one of the most prominent vehicles for encouraging undergraduate research, which in turn improves students' experience and success in STEM fields, whether they continue on to graduate school or find work in STEM industries [2, 3]. As part of running and participating in the REU program, faculty must focus on finding the most effective way to ensure that undergraduate students achieve a positive outcome from the REU.

One main challenge in implementing an REU is that students enter the REU program with an eagerness to learn, but very little knowledge about what research looks like [4]. The process of training undergraduate students to accomplish effective research, when they are starting out as novices, takes time and resources, such as dedicated and structured mentorship [5, 6]. There are established behaviors that lead to greater REU success, e.g., constant communication, positive mentor-mentee relationships, and encouraging student autonomy and ownership over their projects [7, 8, 9]. This is particularly challenging when the REU is a summer program, as the time constraints of a 10-week program mandate careful planning to implement it effectively.

In response to these challenges, this work utilized Scrum (a project management framework known for its success under constantly changing conditions) to manage undergraduate students during their REU [10]. The use of Scrum was inspired by the successful use of Scrum in academic settings [11, 12, 13] as well as informal experimentation done by the authors to mentor undergraduate researchers. This paper addresses a mentorship group that was a subset of the NSF REU Site: Cybersecurity Research of Unmanned Aerial Vehicles at Embry-Riddle Aeronautical University. Inspired by previous efforts that use Scrum to increase efficiency while struggling to get students up to speed in cutting-edge technologies, A-REU was developed to improve the quality of mentorship within an REU [11]. While the entire REU focuses on a variety of developmental and team-building exercises, this work focuses on the relationship and development of research within a single project group.

Background

This section provides background on (1) Scrum, an Agile method used in both industry and academic settings, and (2) the successes and challenges of undergraduate research.

Scrum

Scrum was first begun in the 1990s as a framework for software product development but has since spread to other domains [10]. In Scrum, a small team consisting of the Product Owner, the Scrum Master, and Developers works together towards a single objective, known as the Product Goal. All work needed to achieve the goal is broken down into tasks in the Product Backlog, which is under the control of the Product Owner, who is responsible for representing the needs of all stakeholders. The Scrum Master oversees the Scrum process and guides the rest of the team towards effectively and correctly using Scrum. The Developers are the ones actively working on the Backlog items. Work is organized into 1–4-week periods, known as Sprints. At the beginning of each Sprint, Developers choose the most pressing work from the Product Backlog and commit to completing it during the Sprint by placing it in the Sprint Backlog. Each Sprint has an overarching goal that is supported by the tasks assigned to the Sprint Backlog. Throughout the Sprint, several regular meetings take place. At the beginning of the Sprint, the team meets for Sprint Planning to decide what work

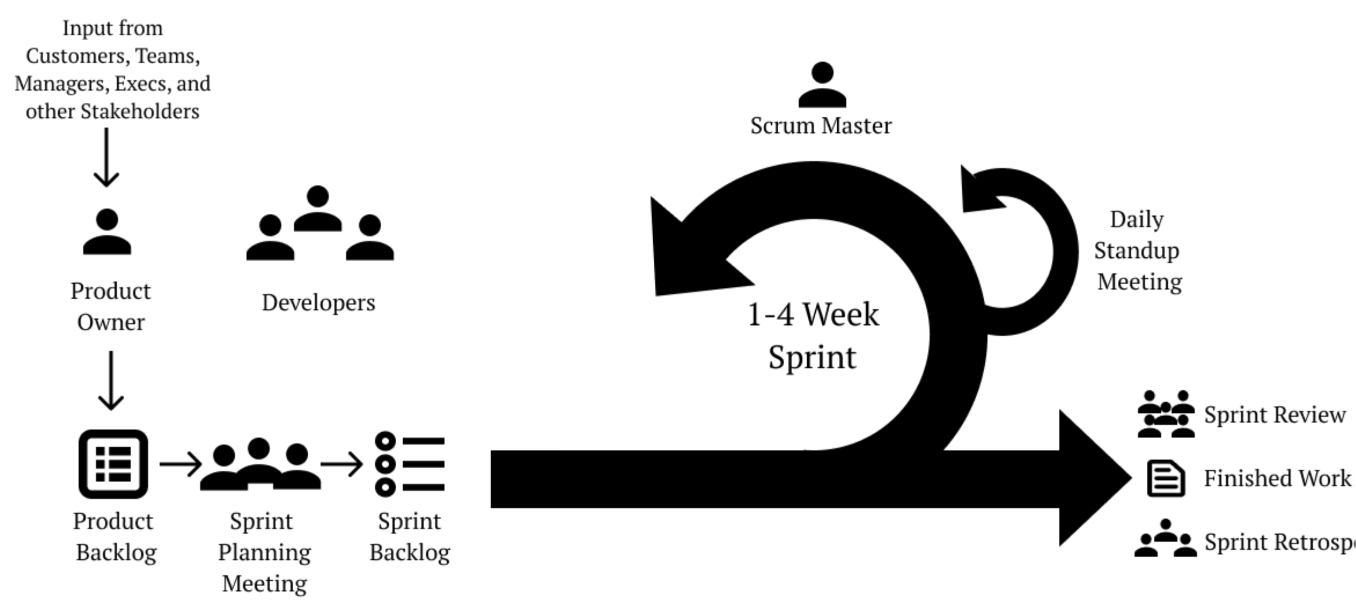

Figure 1. The Scrum Process

will go into the Sprint Backlog and who is responsible for each Backlog item. A 15-minute meeting, known as the Daily Scrum, is when the team meets to discuss their progress and any roadblocks they are facing. At the end of each Sprint, a Sprint Review and a Sprint Retrospective are held to reflect on the Sprint's outcome and the quality of the Scrum process, respectively. The Scrum process is depicted in Figure 1.

Implementing the Scrum process in an REU setting is supported by findings in the literature that Scrum is beneficial in academic settings. Scrum has been used in the classroom to support project-based learning [14], in the implementation of academic research [11, 12, 13], and non-project-based work to encourage consistent progress in overwhelming tasks [15]. Specifically in research groups, Scrum allows students to take ownership over new projects while still receiving appropriate mentorship [11, 13]. Scrum encourages student productivity, allowing for more progress to be made in less time [12]. These benefits uniquely position Scrum to address some of the challenges found in undergraduate research and REUs.

Undergraduate Research

There are many different formats in which undergraduate research can occur. The REU site in this work follows an apprentice-style research structure, in which students learn from faculty and other mentors in a traditional research group setting [2, 16]. Other models include students working on industry research projects, course-based research, and student-guided projects [16].

Exposing students to undergraduate research has been shown to have numerous benefits, such as improving student retention within degree programs and encouraging students to seek graduate study opportunities [2]. In the field of computer science, integrating research experience throughout the curriculum has been implemented to provide students with the benefits of undergraduate research experiences [17]. In order to help students achieve these positive benefits, key design considerations involve making the knowledge accessible and interesting to the students' level, encouraging autonomy, emphasizing collaboration and teamwork, and helping students engage in proper reflection [2].

REU sites face the challenge of getting students up to date on niche, cutting-edge research topics [18]. Solutions to this include formatting the beginning of the REU to be lecture-intensive [18]. Alternatively, scaffolding the research projects so that the students can complete them successfully in small parts over time [19]. Additionally, the faculty workload needs to be considered. Faculty can feel that participating in the REU gains little benefit in the promotion and tenure process, and they lack the time to develop the project and training materials to keep undergraduates properly engaged [2].

This work discusses how using Scrum can not only provide a beneficial structure for REU design but also alleviate pressure points in the experience for both faculty and students.

Related Work

Existing work has highlighted how Scrum can benefit productivity in research and improve the outcomes of the research process. Aggrawal and Magana, while using Scrum in a course-based REU, found that it improved the amount and quality of feedback that students received [20]. Tomás supports this finding, suggesting that both feedback and the frequent deadlines implemented by Scrum were important components of Scrum, enabling students to complete their Master's theses [21]. Ramos et al. also found that Scrum could benefit the research production of students in time-restricted scenarios [12]. A multidisciplinary research case study done by Hidalgo shows that agile processes, i.e., Scrum, benefit the coordination and teamwork aspects of research [13]. Franco et al.'s work on doctoral research groups in the social sciences found that utilizing

Scrum not only helped with organization and time management, but also was a structure for peer-to-peer support [22].

Not only has Scrum increased productivity in academic research, but it has also enabled faculty to grow their research groups more effectively and use time more efficiently. Previous work by Ochoa and Reynolds introduced Scrum into managing research groups where undergraduates, graduate students, and faculty collaborate on a wide assortment of projects [11]. Their work highlights how information sharing, enabled by the Scrum framework, has allowed the research group to operate at a larger scale. Hicks and Foster also relied on Scrum to manage research groups of graduate students, finding it to be more time-efficient for faculty [23].

This work supports the effectiveness of implementing Scrum as a research management technique for a 10-week summer REU program. As it stands, upon completion of this work, no other work has specifically adapted Scrum for the summer REU scenario, in which this is the students' only focus for a 10-week period. The Scrum implementation discussed in this work presents preliminary results on its benefits, as determined during the summer REU.

Approach

This study involves a quality improvement initiative to evaluate Scrum's effectiveness in managing an undergraduate research team within an REU setting. This section details both the implementation of Scrum within the team and the means to measure its effectiveness as a research management framework.

The goals of this approach are:

- To ensure the research success of undergraduate students, enabling them to have measurable output to reflect their effort.
- To create an efficient method for state-of-the-art knowledge acquisition for research novices.
- To encourage flexibility and autonomy in undergraduate research.
- To provide a framework that allows faculty and graduate students to serve as effective mentors.

Roles and Leadership

In a Scrum Team, the three major roles are the Developer, Scrum Master, and Product Owner. In A-REU, these roles are altered, as described in Table 1, to Researcher, Primary Guide, and Research Advisor.

Table 1. Scrum Roles for A-REU

<table>
<tr><th>Traditional Scrum Role</th><th>A-REU Roles</th></tr>
<tr><td>Developer: Completes the work in the Backlog</td><td>Researcher: Completes the Research Project according to items in the backlog</td></tr>
<tr><td rowspan="2">Scrum Master: A steward for the Scrum process</td><td>Primary Guide: Guides the day-to-day Scrum process</td></tr>
<tr><td>Research Advisor: Holds weekly reflection sessions</td></tr>
<tr><td rowspan="2">Product Owner: Maintains the Project Backlog</td><td>Primary Guide: Provides more granular control and updates of the Research Backlog based on Researcher progress</td></tr>
<tr><td>Research Advisor: Controls the direction of research activities and manages resources; mentors Researchers and Primary Guide</td></tr>
</table>

In Scrum, the Developer is responsible for the work items in the Backlog. During each Sprint, they decide which work should move from the Product Backlog to the Sprint Backlog and assign it to themselves. In A-REU, the Researcher follows the same process as the Developer, but the items in the Backlog are aligned with the research project.

The biggest difference between Scrum and A-REU is the transformation from Scrum Master and Product Owner to the Primary Guide and Research Advisor. Whereas the Scrum Master manages the Scrum process and the Product Owner manages the Product Backlog, the Primary Guide and Research Advisor share both responsibilities, with the Primary Guide handling day-to-day, granular issues and the Research Advisor mentoring the Primary Guide and defining the overarching goals and logistics.

The goal of the Scrum Master is to relieve the team of the pressure of the process. They are responsible for ensuring that the process is followed correctly. Through the proper utilization of a Scrum Master, students can succeed in the Scrum process without extensive training [24]. The Primary Guide meets most regularly with the Researchers. Therefore, the Primary Guide manages the Sprint Planning Meeting, the Stand-Up Meetings, and the Sprint Review and Retrospective each week as a Scrum Master would. However, in weekly meetings with the Research Advisor, the Researchers are encouraged to reflect on their progress in ways that mimic the Scrum Master's role in the Sprint Review and Retrospective.

The goal of the Product Owner is to maximize product quality by managing the items in the Product Backlog, their priorities, and ensuring that the Researchers understand them. The Primary Guide controls the items in the Research Backlog and is responsible for ensuring they align with the Research Advisor's goals for the project. The stakeholders in the research project are two-fold. The Primary Guide and Research Advisor have knowledge and experience in the field of research and are therefore responsible for having the ultimate say in the Research Backlog in order to encourage continuous progress. However, the Researchers should maintain autonomy and be able to follow paths of interest, in which case the Primary Guide and Research Advisor must consider the Researcher's personal desires when creating the Research Backlog.

In summary, both the Primary Guide and the Research Advisor are involved in the Researchers' progress throughout the A-REU. However, the Primary Guide role is intended for a graduate student. They have the time to guide a single team of students through the process day to day. Alternatively, the Research Advisor is a faculty mentor who may be responsible for multiple Researcher teams and has other responsibilities that constrain their time. This structure enables greater scalability, allowing Research Advisors to share their expertise with multiple teams of undergraduate Researchers while keeping the workload manageable by employing a graduate student as a Primary Guide for each team.

Sprint Schedule

In an industry setting, the Scrum Stand-Up meetings occur daily. In academia, the fact that the Scrum project is not an individual's entire workload has led to the reduction of meetings to 1-3 times per week [11, 14]. In these cases, it is understood that, due to other responsibilities a student may have, spacing out the "Daily" Stand Up meetings allows students to make meaningful progress on their work while still being frequent enough to catch and address roadblocks before they occur.

Alternatively, the REU is structured in a 5-day, 40-hour-per-week structure. This aligns more closely with industry practice, as REU students are expected to spend their entire week focused on their research and to be compensated appropriately. The Primary Guide and the Research Advisor, despite their other obligations throughout the summer, remained available to the Researchers during the REU work hours. In addition to scheduling meetings, the Primary Guide and Research Advisor maintained in-person and virtual availability.

Table 2. Weekly Scrum Event Schedule

<table>
<tr><th>Monday</th><th>Tuesday</th><th>Wednesday</th><th>Thursday</th><th>Friday</th></tr>
<tr><td rowspan="3">Sprint Planning Meeting</td><td rowspan="3">Virtual Stand Up</td><td rowspan="3">Stand Up</td><td rowspan="3">Virtual Stand Up</td><td>Stand Up</td></tr>
<tr><td>Sprint Review</td></tr>
<tr><td>Sprint Retrospective</td></tr>
<tr><td colspan="5">Sprint Check In</td></tr>
</table>

By balancing in-person and virtual events, Researchers were given the space to exercise autonomy and self-efficacy in solving problems while still maintaining access to the Primary Guide and Research Advisor as helpful resources. Based on these considerations, the Weekly Scrum Schedule was made as seen in Table 2.

The Primary Guide meets with the Researchers each day. These meetings occur in person three times a week (Monday, Wednesday, and Friday). On the other two days (Tuesday and Thursday), the Primary Guide conducts a virtual Stand-Up to check in on progress with Researchers. The virtual Stand-Ups offer flexibility for the Primary Guide, who may have other responsibilities and projects throughout the semester. It also allows Virtual Stand Ups to be familiar to all participants and to occur in case of illness or conference travel throughout the summer.

At the beginning of each week, a Sprint Planning Meeting was held instead of a Stand Up. During these meetings, the Primary Guide helped the Researchers estimate their availability for the week, assign tasks, and estimate task complexity.

For synchronous virtual communication, all team members had access to University-provided Microsoft Teams accounts [25]. This enabled video calls. For asynchronous communication, documents were shared via the same Teams infrastructure. Although the Teams structure also allows asynchronous discussion via a message board, the team preferred to hold asynchronous discussions in a Discord server [26]. Successful communication can happen across many platforms; it is important to ensure that all team members have access to the platform and the experience needed to use it correctly.

The Sprint Review occurs each Friday, following the group presentations (which were a part of the overall REU structure). The Sprint Review is time-blocked to no more than 1 hour. The goal is for the Researchers to evaluate their performance over the weeks Sprint in regard to achieving the Sprint Goal. Therefore, the Primary Guide would ask questions about how they felt they accomplished tasks and the amount of progress they made.

The Sprint Retrospective also occurs each Friday, following the Sprint Review. This event is time-blocked to no more than 1 hour. During the Sprint Retrospective, the focus switches from reflecting on the work done to reflecting on the Scrum process. Researchers were asked to reflect on whether they assigned themselves an appropriate amount of work from the Backlog, how they responded to roadblocks, and were encouraged to provide feedback on the Scrum process.

The Researchers meet once a Sprint with the Research Advisor. This meeting, referred to as the Sprint Check-In, occurred sometime in the middle of the week, with the day and time varying according to the Research Advisor's schedule. These meetings are time-blocked for at least 1 hour, and unless requested, the Primary Guide is not present. This gives the Researchers the freedom to reflect on their experiences freely with the Research Advisor. The goal of these meetings is to be flexible to the needs of the Researchers. During this period, the Research Advisor shall provide technical and research expertise, encourage Researchers to reflect on their progress, and address any academic questions the Researchers might have.

Scrum Training and REU Preparation

Student exposure to Scrum began on the first day of the REU, with no prior knowledge expected. After general onboarding for the overarching REU program was completed, the Primary Guide met with the Researchers and provided an overview of the Scrum process. This overview lasted approximately one hour, with the goal of exposing the Researchers to the general Scrum format and terminology. This minimal training relied on the idea that participants in a Scrum Team can learn the process through immersion in the practices [24].

Following the Scrum training, the Researchers and the Primary Guide discussed the REU research topic. The Scrum process started immediately as described in the rest of this session.

Evaluation: Learning Scrum

One important outcome of this process is for Researchers to become adept at the Scrum process. This is not because Researchers need to be experts at Scrum to be successful, but because by effectively implementing the Scrum process, they gain the benefits of incremental progress, self-efficacy, flexibility, and quality reflection. To gauge the Researchers' performance within the Scrum process, the rubric shown in Table 3 was used for evaluation.

The Primary Guide and Research Advisor meet at least 1x/week after the conclusion of the Sprint to discuss the Researchers' progress and to adapt the process for the following week to ensure consistent progress. While the Scrum Process Quality Rubric was available to the Primary Guide and Research Advisor throughout the process, it was formally used only after the REU was completed. Researcher performance was evaluated as a group using the rubric in Table 3 for each Sprint, after reviewing meeting transcripts and Sprint histories logged in Scrumwise [27].

Evaluation: Research Progress

Evaluating research progress is more difficult to standardize. Though the REU is an intensive program intended to allow undergraduate students to conduct research, students enter at different levels, and there is no standardized expectation upon completion beyond a project report. Therefore, to evaluate research progress, the Research Backlog in Scrum is analyzed to assess the completion of various research activities.

The success of each student is encompassed not only by the research tasks they completed, but also by the qualities and experiences gained throughout the REU process and the impact the REU has on their career. This type of evaluation was out of scope in the pilot study but is intended to be implemented through longitudinal studies of future A-REU process implementations.

Table 3. Scrum Process Quality Rubric

	5 (Excellent)	4 (Very Good)	3 (Good)	2 (Fair)	1 (Poor)
Sprint Goals	The Sprint Goal is clearly defined. The tasks chosen align with the goal.	The Sprint Goal is clearly defined. The tasks chosen mostly align with the goal.	The Sprint Goal is defined. There is a correlation between tasks and the goal.	The Sprint Goal is vague or ambiguous.	No Sprint Goal is defined.
Task Selection	Tasks are decomposed, concise, fully actionable, and sized appropriately to be achievable within one day or less.	Tasks are clearly decomposed, actionable, and well-sized.	Most tasks have been adequately decomposed, though minor ambiguity remains. Tasks may lack consistent clarity or sizing.	Tasks are partially decomposed, but many remain unclear or overly large.	Tasks are not clearly decomposed, and the Sprint Backlog is not actionable.
Effort Estimation	Effort estimations are accurately sized.	Effort estimations are mostly accurately sized with minor discrepancies	Effort estimations are present, but there are noticeable inaccuracies or inconsistencies	Estimates are often inaccurate or missing for several tasks	No effort estimations are provided for tasks.
Definition of Done	Clearly defined, comprehensive, and consistently applied	The DoD is clearly defined and mostly applied	DoD is defined, but incomplete or inconsistently applied	The DoD is vague, incomplete, or rarely followed	No definition is established
Burndown Chart	The burndown chart follows a consistent downward trend, and all	The chart shows a generally downward trend with minor deviations.	Some progress is seen, but there is notable stagnation	The burndown chart is incredibly inconsistent.	The burndown chart provides no useful information.
Capacity Estimation	The capacity estimation was accurate, with all tasks completed on time, leaving a few left over.	The estimation was mostly accurate, with only minor errors.	The estimation was somewhat accurate, but notably under- or overestimated.	The estimation was largely inaccurate.	No attempt was made to estimate team capacity.
Sprint Review	All completed work is addressed, thorough feedback is provided, and next steps are outlined.	Most work is discussed, and feedback is provided. Next steps are discussed.	Some work is discussed, and feedback is limited, or the next steps are unclear.	The Review is perfunctory, with no meaningful discussion of the work completed.	No Sprint Review is conducted.
Sprint Retrospective	The Sprint Retrospective leads to actionable improvements, with the team identifying and implementing solutions, while simultaneously recognizing their successes.	The Sprint Retrospective identifies areas for improvement, and some actionable steps are taken.	The Sprint Retrospective identifies issues, but the proposed solutions are vague or difficult to implement.	The Sprint Retrospective is conducted, but offers little meaningful discussion or actionable outcomes.	No Sprint Retrospective is conducted.
Stand Up Meetings	The stand-up meeting is concise and effective, with all team members clearly communicating progress, upcoming work, and blockers, resulting in strong team alignment and timely follow-up.	The stand-up meeting communicates progress and upcoming work for most team members, with blockers identified but follow-up or clarity occasionally lacking.	The stand-up meeting shares some status information, but updates are vague, uneven, or overly detailed, and blockers are inconsistently identified.	The stand-up meeting is conducted but lacks structure, clear updates, or meaningful value for team coordination.	No stand-up meeting is conducted

Table 4. A-REU Scrum Evaluation Results

	Sprint 1	Sprint 2	Sprint 3	Sprint 4	Sprint 5*	Sprint 6	Sprint 7**	Sprint 8	Sprint 9
Sprint Goals	3	3	3	2	4	3	3	2	3
Task Selection	3	4	4	3	N/A	2	2	3	4
Effort Estimation	2	3	3	4	N/A	4	2	3	4
Definition of Done	1	3	3	3	N/A	2	2	3	3
Burndown Chart	3	3	4	2	3	4	3	3	3
Capacity Estimation	3	3	3	4	4	4	4.	4	4
Sprint Review	4	3	4	3	3	4	3	4	4
Sprint Retrospective	3	2	3	4	3	3	3	3	4
Stand Up Meetings	3	3	4	3	N/A	4	4	4	4

*Data is missing due to the Primary Guide being out of town for a conference.
**Researchers ran the Sprint Planning without the Primary Guide.

Results

This section of the paper contains the information regarding Scrum proficiency of Researchers, research outcomes, and reflections after the completion of the A-REU. The overall trends of this rubric tell a story. In most aspects, the Researchers improved in their knowledge of Scrum and had either positive or improving performance during the first half of the A-REU. However, common research impediments caused them to feel like they were falling behind, and the Scrum efforts became more disjointed due to competing interests. Despite never achieving expertise (scores of 5), the Researchers still relied on the Scrum process, which guided them through some of the challenges of conducting research.

Scrum Proficiency Trends

Table 4 shows the rubric results of Scrum proficiency that were evaluated by the Primary Guide and Research Advisor after the completion of the A-REU. These trends are also depicted in Figure 2.

<u>Sprint Goals</u>: Throughout the process, the Researchers defined 1-2 goals per week. At times, the goals were highly specific, and all tasks were aligned with the goal. However, the alignment of tasks with the goals struggled as the Researchers balanced the other requirements of the REU. For example, the desire to complete a project and turn it in at the end, along with many tasks taking longer than expected, led to the development of multiple, non-cohesive Sprint Goals in some Sprints.

<u>Task Selection</u>: Overall, the Researchers were mostly successful at choosing tasks that aligned with the goal and properly decomposing them. However, once the experimentation got more hands-on, the tasks became less clearly defined. Researchers struggled with insufficient knowledge to properly decompose tasks. Despite struggles in the final weeks to implement the experimentation as planned, the knowledge gained from their failures helped the Researchers to properly define the tasks related to experimentation.

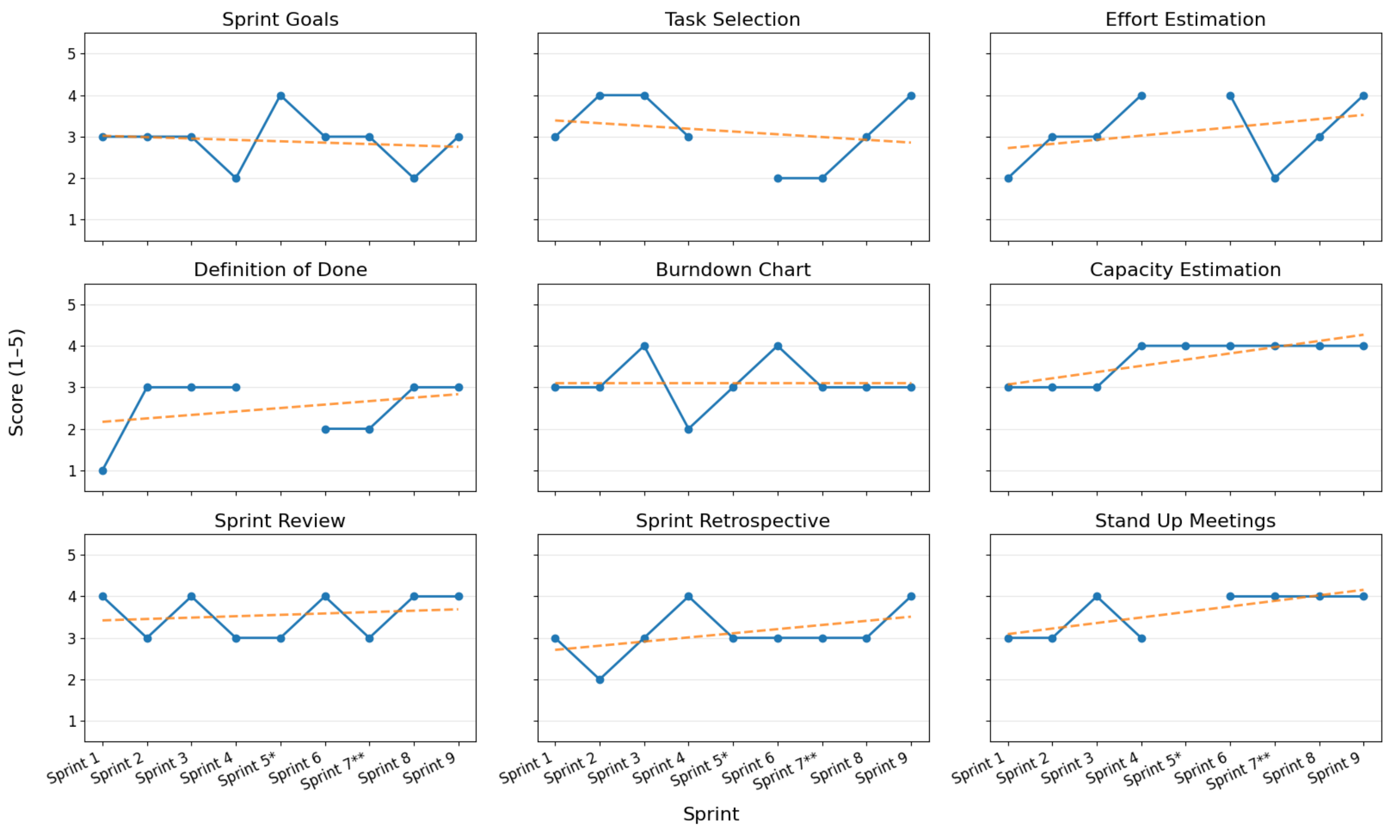

Figure 2. Trends in the results for each dimension of the Scrum Quality Rubric

Effort Estimation: The effort estimation was initially strongly guided by the Primary Guide, as the Researchers were intimidated by the process and tended to largely over-estimate. However, what began as a negotiation over appropriate effort estimates between the Primary Guide and Researchers evolved into the Researchers accurately estimating the effort required for each task. A dip occurred when the Researchers hit a major roadblock in implementing their project, as their lack of knowledge of the tasks themselves affected effort estimation.

Definition of Done: In determining the Definition of Done, the Researchers identified two improvement series. At first, when most of their tasks were related to reading and knowledge acquisition, they learned to better define when those tasks were completed. When the Researchers were exposed to new experimental tasks, they again struggled at first to determine when a task would be appropriately completed. At times, they thought a task met the Definition of Done, but later realized it was incorrect as they moved further into the research process.

Burndown Chart: Performance in terms of the Burndown Chart was largely consistent. Though there were slight dips and improvements in performance, the biggest issue was stagnation in the Burndown Chart, due to an inability to make progress on complex research tasks.

Capacity Estimation: To help Researchers learn about effort estimation, the capacity of a full workday was set at 5 points. This kept Researchers from the pitfall of tying effort to clock hours, which can be problematic as everyone accomplishes tasks at different speeds. However, this frame of reference, which was the formula used throughout all Sprints, was beneficial to Researchers' ability to perform Task Selection and Effort Estimation.

Sprint Review: The Sprint Review was a largely well-done Scrum ceremony. As the end of the REU approached, the Researchers' innate reaction was to spend the Sprint Review focusing on next steps rather than reflecting on the work completed. However, the Researchers used this time to improve cohesiveness in their Sprint Goals for the following week, preparing them to hit the ground running each Monday morning.

Sprint Retrospective: The Sprint Retrospective was another ceremony that the Researchers improved at throughout the A-REU. While Researchers consistently struggled to reflect upon the process rather than the product, by the end of the A-REU were able to make insightful judgments about their ability to complete goals and the roadblocks (both self-imposed and external) that prevented success. They also showed the ability to recognize their own accomplishments and reflect pride in their work.

Stand Up Meetings: The researchers quickly adapted to the flow of Stand Up Meetings. They participated fully and meaningfully. There were two main drawbacks to Stand Up Meetings. First, Researchers continually struggled to identify the causes of their roadblocks. This was tied to the fact that each week the Researchers faced new challenges in their research. Therefore, the roadblocks each Sprint were novel to the Researchers. Additionally, a desire to appear on top of their work and competent can lead Researchers to gloss over challenges. Despite this, Researchers were able to identify challenges when prompted.

Additionally, Researchers tended to save questions for the Stand Up Meetings, which at times made the meetings longer than intended. As the research material became more complex, the Primary Guide had to spend more time helping them troubleshoot.

Despite a minimal improvement across the Scrum rubric, the Researchers were still able to connect meaningfully with the Scrum process. Their performance was overall satisfactory throughout the A-REU. The research itself became more challenging throughout the A-REU. Where the students benefited from Scrum was that they had a framework to fall back on and a vehicle for continual progress, even as they struggled with the research.

Research Outcomes

The Scrum framework enabled the Researchers to quickly become involved in the research. Table 5 lists the research activities that were conducted each week. Additionally, certain tasks were not completed within the Sprint, as reflected in the table.

The major accomplishments of the Researchers throughout the A-REU were founded on their ability to read and engage with advanced literature. Most weeks, the Researchers were reading relevant and cutting-edge research. The findings from this research were continuously applied to their research design, which adapted as they gained knowledge. At the end of the REU, the report included a strong literature review and a well-thought-out experimental plan, with prototypical experimentation using synthetic data.

The main challenges faced by the Researchers in the A-REU were common pitfalls. Waiting for the delivery of hardware parts altered their desired progress. They found that, through implementing their ideas in the physical world rather than relying on synthetic data, they spent many days troubleshooting issues. Despite these setbacks, the experienced researcher knows that that is when learning occurs.

Post completion of the REU, two of the three Researchers stuck with the project and, within six months, submitted it for publication.

Table 5. Research Outcomes

Sprint	Accomplished Work	Unfinished Work
Sprint 1	Read 1-2 relevant papers each. Shared notes and findings with the team.	
Sprint 2	Outlined project goals. Defined hardware requirements for the experiment design.	
Sprint 3	Read additional papers of related work. Training in Python.	Unable to build the system due to waiting on part delivery. Partially completed Machine Learning training.
Sprint 4	Presented progress. Researched Regulations.	Ran out of time to outline the report. Did not finish the data collection task.
Sprint 5	Additional reading. Assembled hardware. Began report writing. Presented progress.	Struggled with an advanced data processing task.
Sprint 6	Additional reading. Accomplished writing tasks. Completed experimentation with data collection.	Later discovered issues with the data they collected.
Sprint 7	Presented progress. Continued writing tasks. Began Machine Learning model coding.	Further hardware challenges.
Sprint 8	Created a progress poster. Additional reading. Finalized background writing tasks. Completed LSTM model.	Continued hardware challenges.
Sprint 9	Ran synthetic data. Completed and submitted their final report.	Attempted to get real data to test on the model.

Future Improvements

Based on the reflections and outcomes of the initial A-REU, Scrum is a legitimate management framework for REUs that can have a positive impact on both the undergraduate students and the faculty/graduate student mentors.

One notable weakness was the difficulty of determining Sprint Goals that respect the autonomy and choices of undergraduate researchers while still guiding them to achieve measurable outputs at the end of the program. One possibility is to pre-determine general Sprint Goals that align with known research steps to keep the students on track. For example, Table 6 presents a series of Sprint Goals for an REU focused on machine learning. Within the Sprint Goals framework, there is still ample opportunity for Researchers to pursue their interests.

The ability to align Goals with REU activities was limited because this A-REU was a single research team within a larger REU process. Implementing the entire REU as an A-REU would likely benefit the

Table 6. Projected Sprint Goals

Week	Sprint Goal
Week 1	Understand the project's high-level goals and set up the development environment.
Week 2	Gain proficiency in Python for data manipulation and begin exploring the dataset structure.
Week 3	Understand the fundamental workflow of an ML model and train a first model.
Week 4	Formulate a specific plan for the project based on a deeper understanding of the project.
Week 5	Develop a collection plan for more advanced data.
Week 6	Implement a more advanced, project-relevant AI model.
Week 7	Optimize the model's performance.
Week 8	Verify the model's behavior.
Week 9	Analyze experimental results.
Week 10	Finalize experiments.
Week 11	Draft the research report.
Week 12	Final Presentations and Program Wrap-Up.

cohesiveness of each week. Additionally, Researchers can benefit more from observing as other Researcher teams experience the Scrum process.

Quality reflection was difficult for the Researchers to achieve. This may be mitigated by allowing them to quietly consider prompting questions and reflect personally before sharing with the group. Admitting perceived faults can be difficult among peers, so effort should be made to keep this process comfortable for Researchers.

Limitations

This quality improvement initiative was conducted as a prototype within an existing REU framework. Therefore, the sample size is very small (3 students). As a result, future replication of the A-REU must be conducted with a wide range of students to determine the framework's overall strengths and weaknesses.

Conclusions

This paper presents the results of a pilot study of a quality improvement initiative that used Scrum to manage a 10-week summer REU program. This program adapted Scrum to work for small research teams, in which the undergraduate Researchers had control over the research progress but were guided by a graduate student serving as a Primary Guide and a faculty member serving as a Research Advisor. The 10-week process was split into 9 Sprints, during which the Researchers engaged in traditional research activities, including literature review, experimental design, experimentation, report writing, and presentations.

The success of the A-REU framework was continued engagement with the process, with the Researchers finding a suitable stopping point for their project despite encountering struggles inherent to the research process. Their continued effort lasted long beyond the REU, with two of the three students completing and submitting a publishable paper to a peer-reviewed conference.

Despite the initial success of the A-REU program, its structure must be refined to enhance benefits for REUs, and detailed longitudinal studies must be conducted to evaluate the program's true impact on undergraduates and undergraduate research.

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