2023 Annual Conference & Exposition
Baltimore Convention Center, MD | June 25 - 28, 2023
The Harbor of Engineering Education for 130 Years
Paper ID #38243

Implementing Systems Engineering with Elementary School Students

Rachel Brennan, Tufts University

Rachel is a senior at Tufts University, studying mechanical engineering. She has had several years of experience in both teaching and research, including tutoring in science and math, as well as working with and teaching special needs children. Her research has been focused in molecular biology and material science.

Mohammed Tonkal, Tufts University and King Abdulaziz University, Saudi Arabia

Mohammed is a Ph.D. candidate in mechanical engineering with a research focus on teaching systems engineering to k-12 students. He has completed a master's degree in mechanical engineering at the University of Southern California. He also holds another master's degree in engineering management at King Abulaziz University. Mohammed has previous experience in working on large projects in various engineering fields.

Prof. Chris Buergin Rogers, Tufts University

Chris is a professor of Mechanical Engineering at Tufts University with research in engineering education, robotics, musical instrument design, IoT, and anything else that sounds cool.

Work-in-Progress: Experimenting with a Systems Engineering Project in Elementary School

Abstract

If we take a look at innovations around us, we will rarely find that they are the work of an individual. Instead, they are the result of multidisciplinary teamwork. If we apply the same concept to classrooms, and get a whole class to work on a project, it would allow for more complex, realistic, meaningful projects to be completed. In this research, we gave a complex project to a 5th grade science class at a private elementary school. The task assigned to them was to construct a smart LEGO city. We split the class of 15 children into five teams of three, and each team contributed a part to the overall city. Initially, the instructors provided outlines of the work sessions as well as assign tasks that need to be done, but as the project continued, the kids became responsible for selecting and forming their own assignments. Each group had different engineering problems they need to solve, making the learning experience varied from one group to another. Observations were taken and interviews were conducted to give qualitative information on how the students approach the overall problem, and how they felt about the systems engineering practices they used. In our study we provided the mechanisms through a planning board with set tasks, pacing, and teams. In six 45-minutes sessions, the students were able to build a city with semi-autonomous cars, a train that moves across the city, interactive power plants with motorized wind turbines, buildings that light up when the train comes by, city roads that are interconnected, and more. All the students had fun in this project, and most of them felt proud of their work, according to out post-project survey. Ultimately, the scaffolding helped the students achieve their goal of a complex group engineering challenge.

Introduction

Introducing a large scale, complex engineering project to 5th graders can seem like a daunting task for both the students and the teacher. However, giving elementary school students structure through systems engineering tools to a multifaceted large problem appears to help reduce the ambiguity and encourage participation in the group project. By using techniques such as team management, multi-team communication, and self-pacing in STEM activities, the children become more adapted to working in settings commonly found in the real world. Systems engineering practices are applicable to most if not all future classes, careers, and situations that the students will experience in their coming years; allowing them to become comfortable with these tools early on improves the chances they will succeed in the future.

Systems engineering is an integrated part of Project-Based Learning approach (PBL); this is a teaching tactic where students work with real-world practices, define goals, and execute a project along the way[1]. Project-based learning also helps students learn soft skills and experience leadership roles[2,3]. Additionally, educators have found PBL inspires collaboration between students and allows teachers to just intervene when students ask questions during projects[4]. The students enjoy project-based learning classes, and it increases motivation to complete the assignment among students[5]. Though there are some set backs, as with any type of teaching approach, researchers have addressed the various challenges in applying project-based learning when it comes to complex projects that requires multi-team collaboration and interactions[6]. We took into account these various issue in the process of developing our project.

Tools Development

In general, implementing a systems engineering project requires using project management tools to allow teams to plan, execute and monitor the project through its life-cycle. People have adopted different methods to manage projects, including waterfall and agile methods[7,8]. For physical products, companies use the waterfall method, where a project goes through a distinct processes that takes a product from a concept to testing to launching[9]. Alternatively, the Agile method does not use such clear boundaries between planning and building but instead requires the user to plan their next move without extensively organizing the whole project. Each module has advantages and limitations, and both methods are currently used frequently in businesses[7,8].

To build a project-based learning environment in classrooms, where students work together on one project, we introduce a project management tool that would enable students to define their roles in the project. We chose the agile approach because it sounds more appealing to students since it requires little planning time before each class, compared to higher planning times when adopting the waterfall method[10]. One major aspect of agile product design is the idea of sprints. A sprint is a short period of time that is designated for all people involved in the project to finish a set of tasks[11].

Usually, an agile board consists of multiple columns, each representing a task status. A task, that can be written on a post-it note, can be moved to the different columns once its status has changed. A sprint board can be a physical board or digital. The agile method is exceedingly flexible so it can even be implemented in various project times, as the board is scalable to any project size[12]. In the case of this project, we have designed it to fit in a limited number of classes (6 classes, that is translated to 6 sprints) and aimed to present this idea in our board as well. Thus, we chose the columns of the agile board to show the number of sprints to make it easier for students to comprehend. We also divided the board by teams. Each row represents different teams, and they were distinguished by colors: orange for team city power (referred to as the Power Team), pink for the Roads Team, green for the Buildings Team, blue for the Trains Team, and yellow for the Vehicles Team as shown in Figure 1.

Unlike typical agile projects, this project has no official client that would define requirements (which is called ”User stories” in agile)[12]. Instead, we formulated them as pre-written tasks. These pre-written tasks were placed in the “tasks bank” section of the board. Each team had their own tasks bank, to minimize confusion between students. Initially, we (the instructors) defined all tasks, but as the project progressed, the students were incentivised to come up with their own

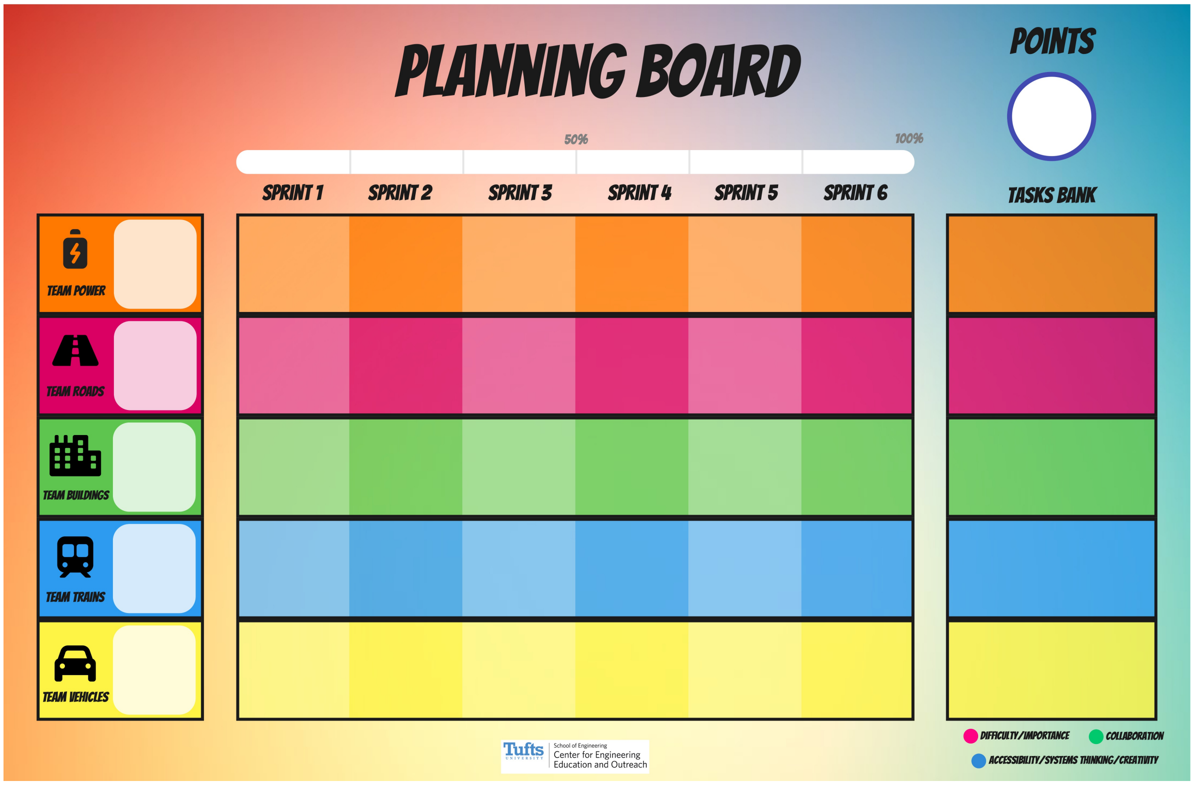

Figure 1: Planning board template

tasks they found useful to the project.

Another structural element of the project and the planning board was the scoring system. One of the goals of the project was to emphasize the idea of collaboration. Each task held a value that would contribute to the overall class score when accomplished. At the end, points were collected from completed tasks and were calculated toward a total score for the project. The students were told they would get a prize if they got a score of 200 points or more. We were interested in seeing how a score could help motivate the students and if they would select tasks to accomplish based on high point values.

Procedure

The researchers designed this study to evaluate the integration of the planning board and tasks with elementary school education to take place in a fifth grade science class at private school in Massachusetts. This particular class was made up of 15 students of multiple races, ethnicities, and genders. The overall goal assigned to the class was to construct a LEGO smart city using LEGO® Education SPIKE™ Prime Set[13], along with other LEGO kits and parts. The project was further split into five groups that would contribute to the construction of the city: the power team, the train team, the roads team, the buildings team, and the vehicles team. The students ranked their preferences for their groups and members to work with and were ultimately put in groups of three by the teacher. The class took place in the school's makerspace with separate areas, tables, and two LEGO® Education SPIKE™ Prime Sets for each group. The project itself (the city) had a designated area right outside the makerspace, in an open space in the school building.

On the first day, sprint 1, the board was introduced to the students. The concept of the teams were shown on the left hand side of the board and the children had time to identify which team they were on and where their categories were on the planning board. Next, we explained the concept of the six sprints. We emphasized that there were six 45 minute sessions in which the kids would become familiar with, build, and present the final project. After explaining the sprints, we deconstructed the idea of the tasks and the task bank for the class. The tasks showed the main instruction on them, the scoring system, and how they would be marked complete. We called special attention to how the different points were assigned: pink for difficulty of the task, green for collaborative efforts, and blue for creativity and systems-based thinking. Additionally, we explained how the tasks could be selected from the task bank and placed on the sprint that was currently active; if the task was complete it could be marked and left on the appropriate section. If the task was incomplete, during the following sprint, it should be moved to that day to keep an accurate account of what was being accomplished in which sprint. Finally, we ended the introduction by encouraging the students to use the board. Besides this, the role of the researchers and the teacher were limited in the process. We only provided mentoring on problems such as coding or finding additional materials. The goal was for the students to self-discipline themselves through the multi-step project with the aid of the planning board. At the end of each sprint, two students were selected based off the discretion of the researchers to give brief interviews about how the day went, what they thought of the project, the board, and the collaboration. We chose which students to interview based on what we saw them complete in class, if we saw them collaborating with others, or if they appeared to be struggling with a concept. On the following five sprints, there were no further explicit directions given to the students regarding their progress or their use of the board. Near the beginning of each sprint, we would call their attention to the number of points they had gained and give a brief message of 'good work' and 'keep going'. During sprint 4, the researchers introduced the idea of writing their own tasks to the students and made it available to all. They would need approval of their task and the researcher would assign points to it before placing it in their task bank. The study and project continued as such until the last day, sprint 6, when they were in a more structured timeline to present the final project by the period's end. In the last 15 minutes, each of the 5 groups showed what they had accomplished and demonstrated the 'smart' aspects of their designs.

Methodology

We used data from videos, audio recordings, interviews, and surveys to review how the students used the board, approached the project, and interacted with one another. We placed four cameras around the room at key locations to observe the study. Two were in the main room where the majority of the building was completed. Another pointed directly at the board in a separate room to observe which students came to the board, which tasks they took, how long they were there, and if they talked to other class members. The final camera recorded the city's layout, where the final construction and LEGO plates were. We used recorders and extra cameras when particularly exciting moments were happening, such as a big task being started, several groups collaborating, or an interesting idea being discussed. The researchers conducted interviews on randomly selected students at the end of each sprint, during which we asked several questions about how they were feeling about the project, with whom they interacted, and how they used the tasks. We also interviewed the teacher at the end of the study to gain her perspective on her class and how the entire project went. Finally, we conducted an anonymous group survey with all the students at the end of the project where they ranked their feelings about the tasks, board, project, and collaboration on a scale of 1-5. All of the data was analyzed and grouped by type and activity after the sprint.

Smart city builds

Students were able to build multiple smart systems within the city. Figure 2 shows top view of the city taken on the last day of the project. We will be highlighting some of the builds created from each team.

Figure 2: A top view of the smart city

The Power Team was responsible for building models of different renewable energy sources that could be used in the city. We told the Power Team that they will not actually be powering the city, rather building models of how power would be generated in a smart city. In addition to the two LEGO® Education SPIKE™ Prime Sets they had, we provided the team with additional LEGO renewable energy kits that contain solar panels and wind turbine blades. The Power Team was able to build two motorized wind turbines that were controlled by a force sensor, a moving water wheel that was attached to a motor, a tilting system for a solar panel, another rotating solar panel on the top of a building (built by the building team), an automatic gate for their power plant, and small, motorized wind turbine beside the school.

The Road Team was responsible for the overall urban design and structure of the city. We designed and printed a suggested layout of the different LEGO plates, including roads, green, and grey plates, and handed them out to all the teams. Though the Roads Team followed the rough idea of our outline, they also took creative measures and came up with a new concept to include more space for the Buildings and Power teams. We gave the Roads Team LEGO city road plates, along with the two LEGO® Education SPIKE™ Prime Sets. As per our initial observations, the Roads Team was able to construct all city roads, build a bridge, and create a traffic light for the vehicles team. This involved a red and green LEGO brick attached to a motor that would switch positions to give different signals for the cars. Beside roads, the Roads Team also built an airplane and airport, which were not initially part of the city design.

The Buildings Team was responsible for creating different buildings within the city. The were given two LEGO® Education SPIKE™ Prime Sets, and other basic LEGO bricks from a large bin in the makerspace. The Buildings Team was able to build a rainbow apartment building with a person on a wheelchair outside of the building. This building held the electronics (the SPIKE™ Prime hub), and had a window that allowed the Power Team to get access to the button on the SPIKE™ Prime hub. Also, they were able to build a school that was programmed to ring its bell when a force sensor was pressed, a pedestrian draw bridge that was controlled by two motors, and a building that turned its light on when a train approached it.

The Trains Team was handed train track pieces, which were parts of LEGO train set, and they were asked to build a train using LEGO® Education SPIKE™ Prime Set. They built a bridge for train that allowed the train to go over the city roads and built a train that was strong enough to go up on the track.

The Vehicle Team was instructed to build a car and a truck that would navigate around the city. They built and programmed a car that could follow the path of the road, and they built a truck that used a color sensor to make turns when it detected different colored pillars that were installed around the city.

Findings: Use of Planning Board

Over the entire 6 sprints, each student excitedly participated in the project and interacted with our systems engineering tools, as the entire class worked steadily towards completing the overall goal of the smart LEGO® city. When we conducted the study, we were particularly interested in how the students would interact with the planning board. We wondered if they would utilize it throughout the sprints, if they would get bored of it, or if they would leverage it to their advantage. We found that the the students' interaction with the board help them in their design and in achieving the class's goal based on the number of students who utilized the board, the amount of time spent using it, and their reviews of the planning tool. The data collected from the study relied on both quantitative and qualitative analysis of the various fifth graders while they completed their task of building a smart city. Figure 3 shows there were 183 total number of visits with an average of 12.2 visits per student. On average, students visited the board 23 times each day.

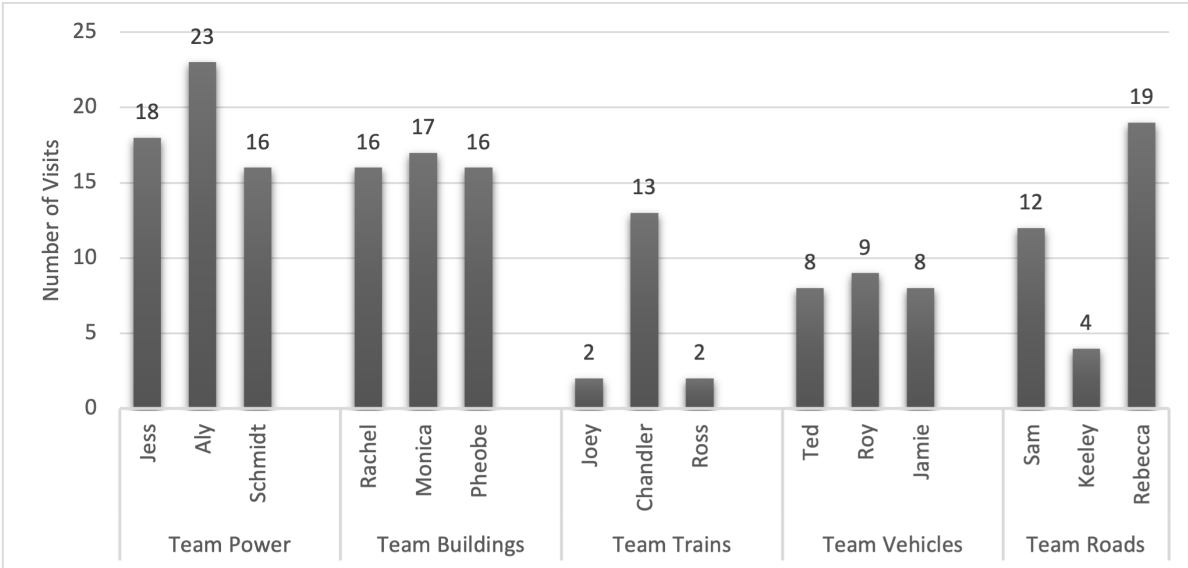

Figure 3: Total number of board visits per student

Over the course of six sprints, all 15 kids approached the board at least 2 times without direction from the research team or teacher (though there are two outliers of students who were absent for at least one day). The record number of visits to the board was 44 visits in one sprint, and the lowest amount was still 12 visits, as seen on figure 4. The repeated use of the board, whether it be to mark a task complete, to take a new task, or to gain clarification about what they were meant to be doing, indicates that the board provided help in structuring the project over the entire time. Also, the fact that multiple groups relied on the board suggests that it is beneficial to many types of learners. A total of 107 minutes were spent on the board by the students out of around 3,255 minutes of combined students' time.

As we can see in Figure 5 the two most common times in the sprint for the kids to look at the board was the first quarter and the last quarter of the 45 minutes actively dedicated to the project. The students would come in from their previous classes and immediately go to the board. They went there with no directions to do so and sometimes even had to be called back into the main room if an announcement needed to be made. The excitement surrounding going to the board and the logical use of it in terms of beginning and ending the sprint at it demonstrates that it provided support for the students when building a framework for the project.

The board also was used roughly on average for 40 seconds at a time when it was visited. There were three main reasons to go to the board for the students: choosing a task, revisiting and clarifying about a chosen task, and finally marking it as complete when appropriate. The first type of visit to the board was often the longest as it required discussions about where the plan was heading and what should be achieved next as well as potential collaboration with other teams. The second type was the fastest kind of visit. The students would approach the board and reread the task and ensure that the product they were building was satisfying all of the requirements, and if so they would then mark their task as complete. Following up on the different types of interactions with the board, a special note was made for the collaboration that was inspired by it.

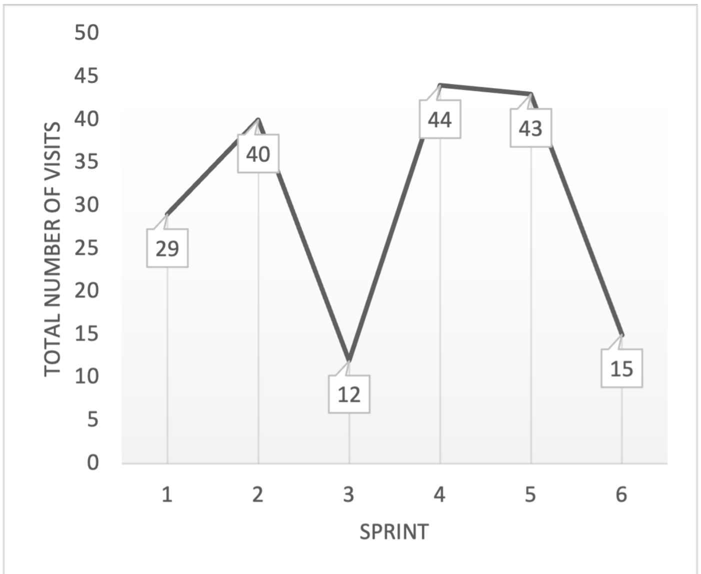

Figure 4: Total number of visits in each sprint

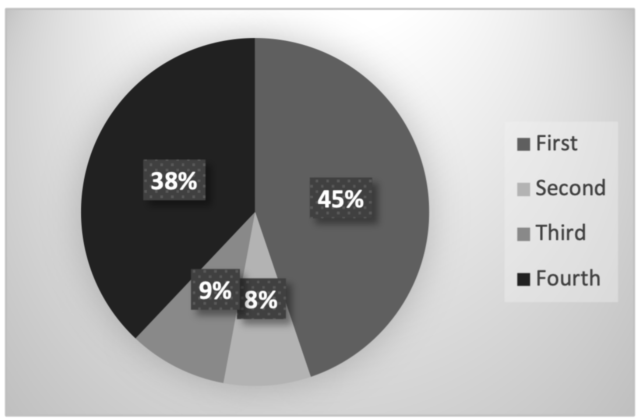

Figure 5: Time spent at the board based on the quarters of the class

Because of the collaborative nature of some of the tasks in the tasks bank, planning what to do next often required a discussion with another team about how and when that task could be completed. Thirty-eight inter-team interactions were documented over the six sprints.

In addition to the quantitative analysis of the planning board, we also interviewed the teacher about how the new tools helped her class approach this complex project. As a veteran teacher and someone who had been working with these students for over four months at the point of the study, the teacher was uniquely qualified to give a review of the entire process. When we asked her for her initial review with no prompting she said, "Oh, frankly, it exceeded my expectations, and I had pretty high expectations going in, and this was better than I thought it was going to be." She went on to elaborate that she has held the other studies as well as performed other projects with this class, and she believed that the the board helped them stay on task, whichever one it might be that they selected; additionally she commented on the autonomy that the board gave the students, noting that it was one of the more challenging projects that the students had taken on but required the fewest amount of questions directed at her. She said, "I felt like that worked really well. You had the tasks for them, but they were deciding which of those to do. They always had a sense that they were working on something they wanted to work on, and they were getting to decide how to do it, which doesn't happen that much in schools. So I think that sense of empowerment made a huge difference." The teacher also was impressed with the cooperation that was sparked and guided by the board. She specifically listed 'collaboration' and 'communication' as two soft skills that she saw her class developing over the course of the study. Overall, the project was deemed a success, but most importantly, the planning board and the systems engineering tools provided appear to aid the students in their individual development according to their experienced teacher.

Conclusion

At the end of the six sprints, the final project surpassed our imagination. The students appeared to find value in the planning board as it seemed to facilitate a self-motivated, self-guided, and successful collaboration in individual teams and across teams. The students completed most of their tasks, building a fully operational LEGO city with integrated robotics in every aspect of it. And most importantly, all the students were engaged in the process, and their enthusiasm was reflected in the final result.

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