Life Skills students in the STEM classroom: robotics as effective project-based learning

Introduction

Science, Technology, Engineering, and Mathematics (STEM) courses in American K-12 schools have been traditionally reserved for a select group of high-achieving K-12 through higher education students to develop their career path in order to aid in American competitiveness in STEM fields (Jolly, 2009). These students are often expected to be self-motivated, to possess an intrinsic desire to learn, and be able to demonstrate high achievement in mathematics and science coursework (Means, et al., 2017). It is broadly believed that to be successful in STEM requires specific personal characteristics (e.g., aptitude) and higher-level thinking skills such as problem solving, critical thinking, and analysis. Researchers have defined these skills (e.g., communication, collaboration, critical thinking, and creativity) as 21st century skills supporting successful employment outcomes in the modern workplace (Partnership for 21st Century Skills [P21], 2008). Research suggests that Project-Based Learning (PBL) is a hands-on and collaborative means for students, especially low-performing students, to develop STEM understandings and 21st century skills in the K-12 classroom (Han, Capraro, & Capraro, 2015). Hence PBL opportunities (with a foundation of hands-on and collaborative learning) may be a potential avenue to facilitate inclusive STEM instruc-
tion, meaning, "educating students with special educational needs, such as [those with] specific learning disabilities, alongside students without special needs so that they may have the right of participation in the science classroom" (McComas, 2014, p. 48). If students with disabilities are afforded equal access to PBL STEM activities, including differentiated instruction and accommodations, it is likely that they, among all students, can meet defined STEM learning goals (Basham, Israel, & Maynard, 2010; Han, et al., 2015).

To garner a better understanding of how students with disabilities may access the STEM curriculum if afforded the experience (e.g., PBL) and resources (e.g., cooperative learning with peers), this article describes an engineering-focused PBL involving seven middle school classrooms with two distinct groups of students: one group identified as Gifted and Talented (GT) and the second group as Life Skills (LS). A GT student is defined as, “a child or youth who performs at or shows the potential for performing at a remarkably high level of accomplishment when compared to others of the same age, experience, or environment” (Texas Education Agency [TEA], 2017a, para. 2). LS is a program designed for students with learning or developmental disabilities to provide them functional skills to operate at a basic level in society (TEA, 2017b). For the purposes of this study, we use Life Skills (LS) to refer to students who are enrolled in and participating in the Life Skills program as defined by the Texas Education Agency. All students were enrolled in a Grade 8 course titled Engineering Robotics. The purpose of this course is to introduce the fundamentals of robotics, including writing programs and building a robot to accomplish a specific task. The maximum enrollment for these robotics-based engineering classes using the LEGO Mindstorms Robotics kit was 6 LS students and 12 GT students, for a total of 18 students.

Standards

For this specific robotics lesson and activity, it was imperative to recognize the educational level of the students as well as determine if they were properly exposed to the necessary Texas Essential Knowledge and Skills (TEKS) state standards in their earlier grade levels. Though some scholars believe that teaching 21st century skills should not begin until middle school (Assefa & Gershman, 2013), most participating students had previously been exposed to 21st century skills (e.g., critical thinking and problem solving). In kindergarten and first grade, the supporting Science TEKS K.3 and 1.3 state that, "students know that information and critical thinking are used in scientific problem solving" (TEA, 2017c). By the time they reach the third grade, the wording changes slightly, as the Science TEKS 3.3 states...
that, “the student knows that information and critical thinking are used in scientific problem solving, and the contributions of scientists are used in making decisions.” Due to early exposure to 21st century skills, students starting at the kindergarten level are trained to ask questions and find answers by conducting investigations—a requirement for being successful in this robotics lesson and activity.

In addition to the TEKS identified above, this activity incorporated TEKS in Math (7.8, 8.7), Career and Technical Education (130.402, 130.408), and Technology (126.16). Cross-curricular by design, this engineering-focused PBL centered on the Alamo because of its historical importance to Texas. Additionally, all students in the class had completed a year-long course in Texas State History in Grade 7.

Classroom and Instructional Design

The Positive Interdependence, Individual Accountability, Equal Participation, and Simultaneous Interaction (PIES) Classroom management technique by Kagan and Kagan (2015) was selected for this activity. PIES was chosen with the understanding that all four components are to be utilized in order for the classroom activity to be successful. To facilitate PIES and satisfy student accommodations, the classroom was designed to ensure that all students could observe and participate in the activity during all phases. Therefore, the classroom work area was wheelchair accessible, and all materials used during the assignment were safe and easy to use in order to facilitate use by students with motor-control impairments. A center lane or aisle was available for moving large objects, including wheelchairs, from the front to the very back of the classroom. For the first part of the Alamo PBL, the classroom was arranged so that students were seated in table groups around a central arena—close enough for them to practice collecting data to write a short program. These short programs allowed students to evaluate the performance of their robots before placing them on the arena in the back of the classroom where the main Alamo map was set up. Interaction, a key component of the Froebel classroom, is the use of the materials (Froebel gifts). Froebel gifts are a series of sets of specially designed materials that provide hands-on explorations of lines, rings, and points. For this lesson, students used rulers as well as different-colored yarn to explore principles of length, distance, and movement, while utilizing math to construct an algorithm and program to move the robot. The students, both LS and GT, were shown that they could use yarn and markers to trace and measure the distance that the robots had to travel.

Students were split into groups of three and assigned one of three roles. The roles were predetermined by the teacher based on each student’s present abilities using pre-assessment data generated through discussion with the students and the teacher’s observation of the students’ in-class performance. These individual accountability roles were Field Engineer, Mechanical Engineer, and Computer Programmer. Each group had to contain at least one identified LS and GT student. The decision to mix both LS and GT students was intentional; research has shown that including a diverse group of students in the learning process better mimics the natural educational environment, supports the idea of group work, and encourages all students to embrace the diversity that naturally exists in the real world (Lam, Doverspike, Zhao, Zhe, & Menzemer, 2008). For most of the robotics classes, LS students took on the role of Field Engineer. Field Engineers were responsible for: (1) surveying the land map and (2) sketching out the path that the robot was to travel. Each Field Engineer was given a scale drawing of the map—resembling a slightly distorted maze. These Field Engineering students had to: (1) first determine if their map was either the same or different than the large-scale field map at the center of the arena; (2) orient the map properly for analysis and then, using a crayon, they were to (3) sketch the path from the entrance of the maze to the exit. In addition, LS students who could use a computer...
successfully were given the opportunity to program the robot or place and run the robot. The Mechanical Engineer student would then take the measurement data provided by the Field Engineer along with pictures of the map and string to convert the data into a process-flow diagram algorithm. After completion of the algorithm, the teacher would then approve the work and allow the Field Engineer and the Mechanical Engineer to return to the maze and take measurements to determine displacement. The two engineers would return to their group, and the Computer Programmer was now responsible for the development of the program based on the notes and measurements provided by the Field Engineer and the Mechanical Engineer.

Having LS students take on an active role in the learning environment ensures not only improved knowledge retention but increased self-confidence and motivation to learn more about STEM (Lam, et al., 2008). In all classes, LS students started the Alamo PBL by acting as the Field Engineers responsible for providing the initial set of data about the terrain the robot needed to travel. As the Field Engineer studied the Alamo data, the Mechanical Engineer was responsible for performing calculations that included the circumference of the wheel and the number of rotations required for the vehicle to travel successfully to the required spots on the map. Data was exchanged routinely throughout the duration of the activity. The computer programmer was responsible for interpreting the Field Engineer’s map and writing the PFD. The PFD can also be thought of as the algorithm that will be used for determining which direction the robot’s wheels should turn as well as the direction the robot should travel.

The PBL Development and Implementation

The development of this PBL was grounded in various inquiry-based and constructivist educational theories, which state that knowledge is gained through social interactions and experience with the physical world in the form of hands-on activities. This would be met by utilizing the techniques of Vygotsky (1978), where social interaction was vital to meeting the goals of the PBL. Froebel’s (1895) philosophy of play-based learning was also leveraged in the lesson design to aid student engagement and interest. Students played with colorful plastic construction bricks, axles, and wheels so they could engage, manipulate, and create functional structures small enough to complete the robotics lesson’s objective. The Alamo PBL activity is considered a main course project due to the sustained duration of the PBL and students’ continued involvement in this single project activity (Larmer & Mergendoller, 2010).

Texas students are familiar with the Battle of the Alamo, yet unclear regarding the details of the Texas Revolution where Mexican troops (under President General Antonio López de Santa Anna) launched an assault on the Alamo Mission. Students are presented with the challenge to imagine themselves as time
travelers who must use a robot to aid the survey engineers of the past in locating an alternate dig site for the original Alamo Mission. The students are charged with moving the Alamo to another location to avoid the fighting that occurred during the Battle of the Alamo.

After some research and debate, the students were introduced to the map of the Alamo site that they must use to successfully complete their tasks. Students quickly learn that the map of the modern-day Alamo is nothing like the maps of the past (where roads or paths for downtown San Antonio were not straight like those in modern day). They were also introduced to additional constraints, including losing points for running the robot off the road, in the rivers, or into bridges and buildings.

Typically, PBL uses driving questions that require students to search for authentic answers (Larmer & Mergendoller, 2010). In this PBL, students were tasked with determining What and How to keep Santa Ana from attacking the Alamo. This project led many students, all of whom had individually defined roles, to construct new ideas for evading an attack at the Alamo. To answer this question, students worked collaboratively in groups of three, to: (1) determine the path for the robot to travel; (2) write a project flow diagram algorithm describing the path that the robot would travel; (3) write a program for their team's robot to travel through the maze; and (4) test the robot to determine if their combined efforts were successful. Students' ideas had to be generated through a group consensus and then presented to the entire class. Therefore, students were graded individually and as a team based on the number of attempts that the robot was tested to travel through the maze. Students were not only motivated to get their robot to the end of the maze, but also had to understand the historical context of the location based on their knowledge of Texas and U.S. history TEKS to successfully complete the assigned task. While a strong knowledge of Texas history is not required to meet the learning objectives associated with this project, the students were asked to consider what they know about the Battle of the Alamo and the key players in this event. This was to cultivate their understanding of what transpired to create what they can use to prevent the battle from occurring. This project is an activity in which students learned the content from completing the project—and they also learned by playing with plastic construction toys used to build the robotic explorers that they build, program, and operate. To reinforce problem-based learning, the teacher assigned to each group robots with wheels of various diameters, with no two robots being the same. Due to this variation in wheel size, each group would produce unique calculations that were then used to program its robots.

In this PBL, students applied mathematics by calculating the circumference of the wheels. To develop 21st century skills, students collaborated and worked as a team. They communicated by listening to others and making their own ideas clear when speaking and writing. They needed to think critically by: problem solving; surveying and studying maps to distinguish differences; writing out steps for their calculations; producing thinking maps and process flow diagrams (PFD); and ultimately, using their creativity to try new approaches in calculating the circumference to get their robot successfully through a maze. Therefore, this PBL achieved its main course status, as the culmination of multiple smaller projects enabled students to gradually acquire the knowledge and skills to complete a more challenging task.

Specifically, students were learning how to use rulers, calculate circumference, calculate diameter, and use Microsoft Excel, PowerPoint, and email. The student-sent email is a culmination of the students' work, as it contained each group's calculations, photos of their maps in the form of jpegs, as well as their process flow diagram algorithms, all of which were produced using software tools. To assess 21st century skills, the Alamo PBL and supporting activities needed to be defined and approved by subject matter experts for authenticity (i.e., in the specific careers that the activity featured). The targeted or featured career paths included: surveying, physics, and computer science. Each of these career paths requires critical thinking, problem solving, collaboration, and various forms of communication, and each deliverable and objective of the activity had been defined by professionals in that field. The classroom teacher used input from professionals
in STEM disciplines to determine what key academic language should be used in the classroom; some authentic assessment tasks that can be used to evaluate the students’ success in completing the project; and to help troubleshoot programming or design issues when the students began to work on the robot-intensive portion of the project.

Outcomes and Assessment

The Alamo lesson provided students an opportunity to use computers to type and perform research on the internet and use Microsoft products to perform mathematical calculations and make presentations of process flow diagrams and thinking maps. Participating students learned how to write programs on their computers using Graphic User Interface (or GUI) icons to control robots autonomously. However, before students could program the robots, they had to be introduced to the fundamentals of robot steering: tank drive and tank steer. Students were required to learn that tank drive is a steering technique that robots use; this was necessary to introduce in the beginning phases of programming motors. Students learned that robots steer by having either one wheel forward while the other wheel turns in reverse, or a robot can turn if one wheel continues to turn while the other remains stationary. They also learned that programmed robots tend to drift off course over great distances due to environmental factors. Yet many students struggled to grasp the tank drive steering concept. In fact, one LS demonstrated tank drive using the seat of his wheelchair. With this clever demonstration using a real-world example, other students picked up this technique immediately and demonstrated it at their seats.

Many LS students approached this project by first tracing out the path for the robot with string and by coloring their maps. This Alamo maze was challenging, as it presented more than one direction to reach the Alamo dig site finish line as well as several obtuse and acute angles for the turns, making it easy to make mistakes in programming. The students found that the robots tended to drift off course as they traveled long distances. This meant that the best choice for the students would be to choose the shorter and more complicated paths. Among participating classes, three of the six LS students chose the more complex path with the understanding that they would have better control over the operation of their robots. Overall, students quickly realized that they had to depend more on their math skills and guessing to find the correct solution.

Students in the seventh period class, with both LS and GT students, outperformed periods one through six, which were made up of a more traditional mix of students. Periods one through six struggled with their understanding of tank drive. One group in the seventh period class was so good that they programmed their robot to travel forward and then in reverse throughout the entire maze without error. Three of the six LS students remembered warnings regarding robots being programmed to travel long distances in a straight line and chose more complex paths. This demonstrated that they could follow the PBL directions and developed an understanding that they would have better control over the operation of their robots if they are programmed to travel short distances.

Beyond content understanding, Stichter (2008) recommends an evaluation of school belonging—the sense that a student feels that they are a valued part of the learning community. It was evident that LS students had found the robotics class to be a fun and thriving environment. The first notable observation was that they were willing to participate in class discussions by assisting in providing demonstrations of the motions of the robots. It was also observed that LS students appeared comfortable moving to the front of the classroom and demonstrating fundamental robotics functions like tank drive and tank steer. Regarding the academic learning experience and climate factor, it was observed that these LS students had developed a sense of friendly competitiveness and demonstrated an intrinsic drive to complete their task as quickly as possible, and notably before GT students. The LS students also were always smiling during class and happy about their work. GT students were more cooperative in working with the LS students. In turn, the GT students appeared happy to work with LS students, and this could also be observed by watching group interaction as well as the quality of the team’s work.

Conclusion

The purpose of this article is to present student performance in a mixed-ability STEM PBL unit focused on engineering. As they participated in the Alamo PBL unit, LS students were actively engaging in practices of math, cutting, measuring, or plotting directions in a real-world classroom without detailed teacher guidance. The LS students worked independently, and many could explain their choices and decisions regarding which direction the robot should travel through the city of San Antonio. Moreover, the students who struggled with the lesson were very motivated to make necessary changes after owning their mistakes and continued to produce high-quality navigation solutions.

Based on observations, it has been concluded that, due to the design of Alamo PBL and by using best practice and inclusion, all the students seem to demonstrate goal-oriented characteristics focusing on the opportunity to learn about engineering (robotics) in a relevant (i.e., Texas) historical context. Issues such as: (1) students not remembering how to log on to the computers; (2) forgetting the location of applications; (3) using simple word processing applications to perform simple calculations; (4) saving their work on their computers; and (5) using email all became nonissues, as it was noted the students were always ready to build something or program. Another positive outcome was an
increase in the number of parents visiting the classroom weekly. With the increase in parental visits, we observed a higher level of achievement and performance in the robotics class as well as in the students’ science and math classes. Overall, this article provides further avenues for research in the benefits for all students, especially those with disabilities in inclusive STEM environments, and provides insights on how students may develop empathy toward differently abled peers while cobuilding rich STEM understandings and 21st century skills.

References


Donald G. Prier, Ph.D., is a physicist, test engineer, and a seasoned educator. He received his B.S. degree in Physics from Southern University and A&M College, his masters from Pacific University in STEAM Education, and is currently pursuing his Ph.D. degree in Global STEM Education from Texas Tech University. He can be reached at [Donald.Prier@ttu.edu](mailto:Donald.Prier@ttu.edu).

Monikka M. Mann, PMP, is a second year Ph.D. student in the Systems Engineering and Engineering Management Department at Texas Tech University in Katy, Texas. She can be reached at [m.mann@ttu.edu](mailto:m.mann@ttu.edu).

Hakeem Oluseyi, Ph.D., is an Astrophysicist and the Space Science Education Lead in the Science Engagements & Partnerships group at NASA in Washington, D. C. He can be reached at [holuseyi@fit.edu](mailto:holuseyi@fit.edu).

Rebecca Hite, Ph.D., is an assistant professor of STEM education in the College of Education at Texas Tech University in Lubbock, Texas. She can be reached at [Rebecca.hite@ttu.edu](mailto:Rebecca.hite@ttu.edu).

*This is a refereed article.*