Teaching the M in STEM with Robotics: Exploring Understanding by Design for Curriculum Development to Teach Math Concepts Using Robotics

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Abstract
STEM (Science, Technology, Engineering, and Mathematics) education has been at the forefront of national education policies and school reform for the past several decades, and the continual advances in technology and educational research bring new methods of STEM learning. Educational robotics have been introduced to the classroom space as a tool to teach STEM concepts. Research has found that robotics helps students learn STEM concepts and fosters a positive attitude toward STEM subjects. However, there is little research on the curriculum used to teach STEM concepts via robotics, and more specifically, trying to teach mathematical concepts. In this paper, I apply my knowledge and practice of teaching mathematical concepts via robotics—both as a former classroom and collegiate mathematics teacher as well as a current Director of Instructional Technology for VEX Robotics—to evaluate curriculum. Using Understanding by Design as the theoretical framework for curriculum development, I assess how this framework guides robotics curriculum to address math concepts specifically. The elements analyzed were: essential questions, understandings, and assessment evidence. As educational robotics becomes increasingly integrated into classrooms, it is necessary to evaluate the curriculum that is created to apply said robotics, and how pedagogical frameworks serve the goal of integrated STEM learning. This analysis can then be used to help guide further research and development of STEM curriculum, particularly curriculum that focuses on teaching mathematical concepts using robotics.

Keywords: STEM, Robotics, Curriculum

Background

STEM Education and Curriculum

STEM has become a world-wide educational initiative because of its connection to the development of 21st century skills, the need for more emerging technology specialists, and future jobs in emerging technology and workforce development (Herschbach, 2011). Much of STEM education incorporates hands-on, active learning, project-based learning, teaching for understanding, and various other pedagogical frameworks that align with our understanding of how students learn. However, there is currently little to no research about or standardization of STEM curricula, leading to vastly different interpretations of what should be taught and how it should be taught (Herschbach, 2011). Furthermore, STEM includes content areas, like science and mathematics, which have well-established teaching practices and curricula associated with them. While the intention behind the global push for STEM education is sound, its practice is becoming increasingly disjointed, without a clear guiding framework for understanding.

The field of robotics, both industrial and educational, has been growing in popularity. Robotics can be used to not only attract students and hold their interest in the classroom, but they can be used to teach a wide array of topics that students may not have thought could have a technical or engineering component, such as music and art (Barreto & Benitti, 2012). This attracts students with many different fields of interest to the opportunity to learn STEM concepts. Educational robotics have been introduced to the classroom space as a tool to teach STEM concepts. Research has found that robotics helps students learn STEM concepts and fosters a positive attitude toward STEM subjects (Khanlari, 2013). More specifically studied in this paper, is teaching mathematical concepts using robotics.

Not only are the components of STEM important in isolation, but teaching and learning them in an integrated manner allows students to get to experience them in a true contextualized form. For example, learning about the Cartesian Coordinate system by itself is important, but abstract. In the workforce, rarely would an individual work with the coordinate system out of context. Teaching this concept in an integrated manner, alongside other math, science, technology, and engineering concepts allows students to make sense of abstract concepts, as well as answer the question, “when would I ever use this in real life?” (Herschbach, 2011).

Understanding by Design (UbD) Pedagogical Framework

The UbD framework is about planning. More specifically, planning with the concepts in mind that students should walk away knowing at the end of the curriculum (the end goals) (Wiggins et al., 2005). Planning with the end goals in mind focuses curriculum on student understanding and the ability to effectively use concepts learned in context. This method of planning with the end goals in mind, also known as backwards design, occurs in three-stages: identify desired results, determine acceptable evidence, and plan learning experiences and instruction. This can be seen in the UbD Design Template as Figure 1 (Wiggins et al., 2005).

Stage 1—Desired Results	
Established Goals: (G) • What relevant goals (e.g., content standards, course or program objectives, learning outcomes) will this design address?	
Understandings: (U) *Students will understand that . . .* • What are the big ideas? • What specific understandings about them are desired? • What misunderstandings are predictable?	**Essential Questions:** (Q) • What provocative questions will foster inquiry, understanding, and transfer of learning?
Students will know . . . (K) • What key knowledge and skills will students acquire as a result of this unit? • What should they eventually be able to do as a result of such knowledge and skills?	*Students will be able to . . .* (S)
Stage 2—Assessment Evidence	
Performance Tasks: (T) • Through what authentic performance tasks will students demonstrate the desired understandings? • By what criteria will performances of understanding be judged?	**Other Evidence:** (OE) • Through what other evidence (e.g., quizzes, tests, academic prompts, observations, homework, journals) will students demonstrate achievement of the desired results? • How will students reflect upon and self-assess their learning?
Stage 3—Learning Plan	
Learning Activities: (L) What learning experiences and instruction will enable students to achieve the desired results? How will the design W = Help the students know **W**here the unit is going and **W**hat is expected? Help the teacher know **W**here the students are coming from (prior knowledge, interests)? H = **H**ook all students and **H**old their interest? E = **E**quip students, help them **E**xperience the key ideas and **E**xplore the issues? R = Provide opportunities to **R**ethink and **R**evise their understandings and work? E = Allow students to **E**valuate their work and its implications? T = Be **T**ailored (personalized) to the different needs, interests, and abilities of learners? O = Be **O**rganized to maximize initial and sustained engagement as well as effective learning?	

Figure 1: UbD Design Template

Within the desired results stage (also known as stage 1), there are certain elements that are involved in the planning. These elements include first establishing the goals. Are these goals related to content standards, certain learning outcomes, or objectives of a particular course? These are prompts that help facilitate the designing and writing of the goals. It’s important to have goals, to ensure both the educator and the student have a shared understanding of what is expected. Once the goals are established, the understandings and essential questions are to be written. The understandings are focused on big ideas. Not only are discrete understandings of the big ideas to be outlined here, but also possible or common misunderstandings. This helps to ensure a clear distinction between what students will understand, and some potential concepts that may also lead to misunderstandings or confusion.

Next are the essential questions. Essential questions are written in order to foster inquiry, understanding, and the transfer of learning concepts. These should be questions that require students to think critically, that can be answered by the end of the design plan, and should not be simple yes or no questions. After essential questions comes identifying what students should know and be able to do. This is important to be explicit about to ensure what key skills students should have at the end of the design plan, and truly put all the learning and understanding into practice. This piece of the planning is making the application explicit.

After stage 1 (desired results) is stage 2: assessment evidence. Stage 2 is about planning and documenting what tasks students will engage with in order to show their understanding. Included in this planning is identifying certain criteria for the tasks, so both the educator and student have a clear picture of what is expected. Other aspects of this planning include evidence such as quizzes, tests, observations, homework, exit slips, or other means of capturing student knowledge. Students should also be presented with prompts or activities that allow them to reflect and assess their learning. More specifically, can they answer the essential questions and does the student meet the certain identified understandings?

After stage 2 is stage 3: learning plan. The learning plan is outlining what the actual instruction is that the students will experience. This includes elements such as relating to students' prior knowledge and interests, providing them with opportunities to explore and experience key ideas, as well as the opportunity for students to evaluate their work and what it truly means in context. This is the essence of the UbD framework that is focused not just on teaching certain concepts, but ensuring that students develop a deep understanding of those concepts, and can demonstrate that understanding.

Understanding Authenticity

"Authentic" learning is a term that is used quite a lot in educational curriculum, but what exactly does it mean? Shaffer and Resnick (1999) suggest that there are four kinds of authentic learning: learning that is personally meaningful for the student, learning that is authentic in relation to the real-world (outside of the school space), learning that allows for thinking in the authentic space of a specific discipline, and learning where the means of assessment are an authentic reflection of the learning itself. Curriculum development, and more specifically robotics curriculum written to teach mathematical concepts, should be authentic in one or more of the suggested kinds of authentic learning to promote deeper understanding.

Purpose of the Study and Methods

There is little research on the curriculum used to teach STEM concepts via robotics, and more specifically, trying to teach mathematical concepts. In this study, I apply my knowledge and practice of teaching mathematical concepts via robotics—both as a former classroom and collegiate mathematics teacher as well as a current Director of Instructional Technology for VEX Robotics—to evaluate curriculum.

Using Understanding by Design as the theoretical framework for curriculum development, I assess how this framework guides robotics curriculum to address math concepts specifically using a qualitative journal approach from my own experience as a curriculum developer in the robotics field. The robotics curriculum analyzed and written was the VEX GO Parade Float STEM Lab Unit. More specifically, Lab 4: Calculating Distance and Lab 5: Turning, as these focused on math skills.

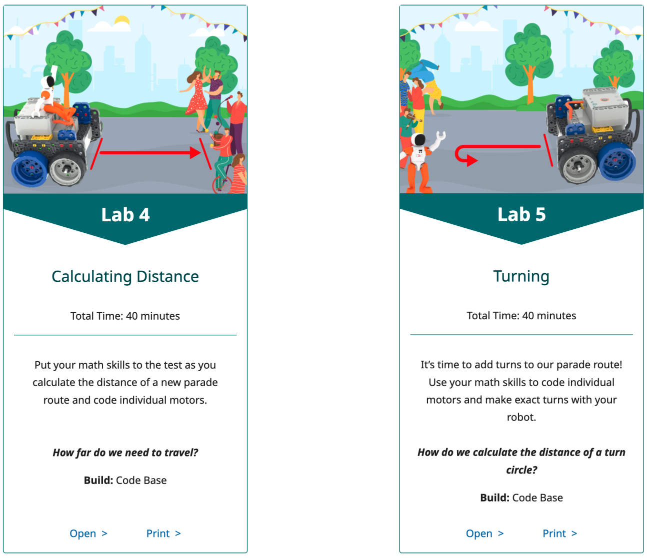

Figure 2: Labs 4 and 5 of the VEX GO Parade Float Unit

The elements of the Understanding by Design pedagogical framework analyzed in this Unit were essential questions, understandings, and assessment evidence.

In the entire Parade Float Unit, students learn to sequence behaviors in order to solve the authentic task of having to autonomously drive their robot to travel a parade route of a certain set distance. Students will design a parade float for their robot, and then use mathematical formulas such as circumference in order to code the individual motors of the robot to drive and turn on the parade route. In Lab 4: Calculating Distance, students first calculate how far one VEX GO wheel turn is. Then, using this knowledge, they calculate how many wheel turns are needed in order to travel the length of the entire parade route (48 inches). Students then will showcase and apply their learning in context by coding the robot to travel the parade route by using the number of wheel turns they calculated as the parameter in their code in order for the robot to travel the parade route.

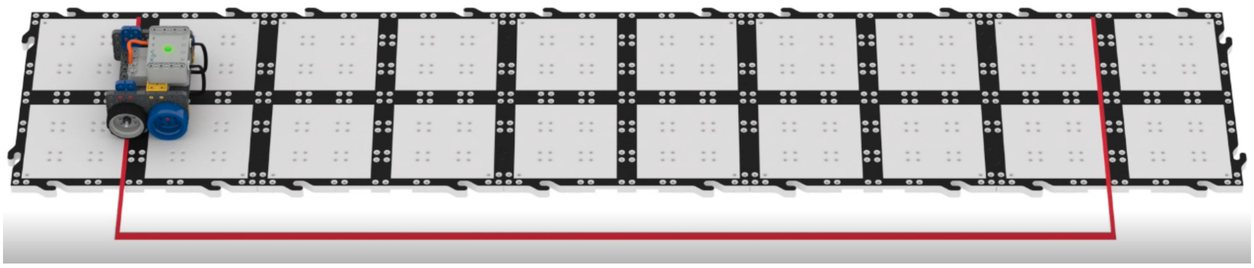
Figure 3: Lab 4: Calculating Distance Parade Route

In Lab 5: Turning, students first calculate how many wheel turns are needed in order to turn the robot 360 degrees. Students will then showcase and apply their learning in context by calculating how many wheel turns are needed to turn 180 degrees. Students will then code the robot to travel along the parade route, turn around 180 degrees, and then drive back to the start of the parade route.

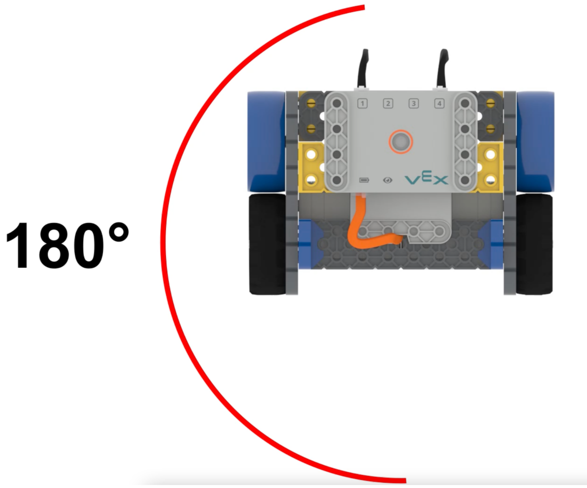

Figure 4: 180 degree turn of the Code Base

Analysis

Understandings

The purpose of the understandings are to target the big ideas for a particular concept or concepts. This is also a place to highlight possible misunderstandings. The understandings for the Parade Float Unit are: how to design a solution to an authentic problem, and how to sequence behaviors into the correct order to create a solution to a problem. The big ideas or concepts for these understandings are designing solutions to an authentic problem and how to sequence behaviors in order to solve that problem. When writing these Unit understandings, I wanted to adhere to the UbD framework for Unit understandings, that focuses on big ideas. Since the big ideas for this Unit are coding the Code Base in order to travel a predetermined parade route, I wrote the first understanding to be focused on solving an authentic problem. Referring to Resnick and Shaffer's (1999) types of authenticity, the authenticity of the problem for this particular Unit is adhering to specific constraints, which could be viewed the same as a car driving on the right side of the road, in the correct lane (learning that relates to the real-world outside of the school environment), as well as coding certain vehicles or even drones to complete a certain predetermined path (learning that provides an opportunity to think in a particular industry standard or discipline).

The second understanding is how to sequence behaviors into the correct order to create a solution to a problem. In this case, the authenticity of this understanding is sequencing in any sense, sequencing could be anything from the steps one takes to put shoes on in the morning, an outline of turn-by-turn directions, or the logical sequence of a coding program. Any of these aspects deal with learning that is meaningful to the student, learning that relates to the outside world, and learning that provides the experience of thinking as if one were in industry.

Based on this explanation, the understandings for this Unit are not only authentic in more than one way for each understanding, but they also adhere to the UbD outline for what Unit understandings should consist of. However, there is room for improvement as far as identifying what misunderstandings could arise, as noted in the UbD Design Template.

Essential Questions

The purpose of the essential questions are to foster inquiry, understanding, and transfer of learning. The essential questions for the Parade Float Unit are: how can anything be engineered to solve an authentic problem? And how can the iterative process be used to create a sequence of movements for the float to accomplish the parade route? These essential questions were written in a way to support the Unit understandings. These essential questions also promote understanding about how to sequence behaviors in order to solve a particular problem. In the context of the parade route, the problem is, what is the correct sequence of behaviors in order to code the robot to complete the route? I wrote these essential questions in order to foster inquiry and transfer the learning from the skill of sequencing, to the applied context of sequencing code blocks to drive and turn the Code Base to travel a specific parade route.

Based on this explanation, the essential questions for this Unit adhere to the UbD outline for what Unit essential questions should consist of.

Assessment Evidence

The purpose of the assessment evidence is to identify what authentic performance tasks will students use to demonstrate the desired understandings, as well as identify what criteria the performances of understanding will be judged on. The assessment evidence for Lab 4 is: students will discuss how they used their measurements to calculate the number of wheel turns necessary for their robot to complete the parade route. They will also explain how they used their measurements to calculate the number of wheel turns necessary to drive the exact length of the parade route. Then, they will utilize their solutions in the parameters of their project to have their robot drive the length of the parade route. After, students will be able to explain why they calculated distances in wheel turns and how they applied their solution in their VEXcode GO projects.

For these performance tasks, students not only have to discuss and reflect on their work, but they also have to demonstrate that they understood how to solve an authentic problem and could sequence behaviors in order to code the Code Base to travel a specific predetermined distance. This demonstration is done by actively coding the robot and viewing if the robot traveled the route correctly or not.

Based on this explanation, the assessment evidence for this Unit adheres to the UbD outline for what Unit assessment evidence should consist of. One element of the assessment evidence that could be more explicit is the criteria that the performances of understanding will be evaluated. For example, what the expectations are while discussing verbally could be better outlined.

Conclusions

This robotics curriculum was designed in order to solve an authentic problem and teach mathematical concepts via robotics. The math concepts covered in these activities were not only understanding place value, rounding decimals, calculating circumference and diameter, but also skills that relate to solving authentic problems. These include breaking down a task into smaller parts, sequencing behaviors, and being able to explain the reasoning behind problem solving methods. Using robotics allows students to round and measure using the number line authentically to obtain parameters, as well as solve for the circumference of each wheel of the robot, and the robot's footprint while turning. This is teaching and applying these mathematical concepts in an authentic and scaffolded way using the UbD framework.

As educational robotics becomes increasingly integrated into classrooms, it is necessary to evaluate the curriculum that is created to apply said robotics, and how pedagogical frameworks serve the goal of integrated STEM learning. This analysis can then be used to help guide further research and development of STEM curriculum, particularly curriculum that focuses on teaching mathematical concepts using robotics.

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