Exploring the Synergy Between the Move Steering Input and Turning a Robot

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Exploring the Synergy Between the Move Steering Input and Turning a Robot

Abstract

The problem-solving task described in this paper helped students understand how the <Move> programming block turns a robot. By exploring how the robot turns according to the <Move> steering input, students gained collaborative problem-solving experiences with diverse mathematical concepts and techniques such as structuring information, finding patterns and using algebraic expressions.

Keywords: Robotics, Programming, Elementary Mathematics, Problem Solving, STEM Classroom Tasks

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Exploring the Synergy Between Programming the Move Steering and Turning a Robot

While programming robots provides many opportunities for learning computational thinking (Noh & Jeongmin, 2019), highlighting the mathematics embedded in these learning tasks may not be as easy. Like Dardis and Wickstrom (2019) noticed, the M is often silent in STEM activities.

This paper describes our experiences working with children as they learned how the <Move> programming block on the Lego Mindstorms Education software worked. This problem-solving task aligns well with the processes described in the NCTM Process Standards (2000), and specifically elaborates the first and the seventh Standard for Mathematical Practice (SMPs; CCSSI, 2010) for problem-solving, structuring information, finding patterns and using algebraic expressions. Exploring the synergy between the <Move> steering input and the resulting robot turn required observing, measuring, and eventually predicting the consequential distance around the circle's edge and the width of the circle.

Overview

We have implemented this task several times in Grades 4 – 7 classrooms and each time found the children highly engaged and amazed at how the robot steering works. There are three parts to this task: (1) determining how the robot's wheels rotate according to the steering setting, (2) determining the pattern of the robot's turns with varying steering setting, and (3) expressing the steering differential with fractions and percentages. Each part delves into important mathematical concepts and takes about 45 minutes (total time: 2 hours and 15 minutes). In the following, we summarize our experiences with classroom implementation for each part and provide analyses of students' mathematical understanding as outlined in the SMPs.

Robotics Tasks

Part 1: Determining How the Wheels Rotate According to the Steering Setting

Robotics Task Considerations

Learning Goal. The learning goal of Part 1 was to discern the relationship between the wheel rotations and the steering setting. The students used the Lego Mindstorms EV3 robot built according to the instructions provided, the Lego Mindstorms Education EV3 classroom software, and a printable recording sheet that is available at http://stem-education.ca/files/SteeringRecordingsheet_2020Part1.pdf for recording observations. Also, a version with the older EV3 Education program is available here: http://stem-education.ca/files/SteeringRecordingsheet-oldEV3_2020.pdf.

Student Mathematical Engagement. Part 1 involved observation and data collection, interpretation of data, as well as the use of negative numbers and fractions. For Grade 4's, integers are not introduced until later. However, Canada's cold weather provided prior experiences of negative numbers for even the youngest children (e.g., -20° Celsius means cold). As well, consistent with Dehaene's (1997) observations, the robot's motion was coherent with an intuitive number line understanding where increasing positive wheel rotations in the <Move> programming block result in forward motion and vice versa for negative numbers. The teachers we worked with provided an initial brief explanation of positive and negative numbers using a number line example, which the children appeared to grasp quickly.

Teaching Reflections. The students were observing and recording the direction and amount of wheel rotations according to variations in the steering setting of the <Move> programming block, i.e., -100, -75, -50, -25, 0, 25, 50, 75, and 100. Note, in this part of the task the robot was held above the ground so the wheels did not touch the floor or surface. Encouraging students to place the arrow-like wheel holder in an upwards position helped facilitate accurate observations (see Figure 1).

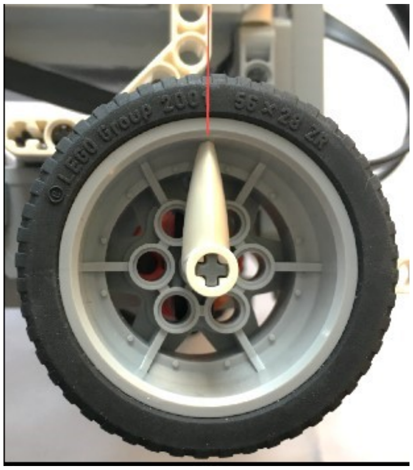


Figure 1. Wheel holder.

Instructions for Part 1

1. Drag and drop a <Move> block onto the programming chain.
2. Enter "right 100" in the <Move> bubble. **Leave the number of wheel rotations as "1".** Leaving the number of wheel rotations at 1 is necessary for consistent results to help students to identify the pattern. 

3. Download the program to the robot.
4. Watch the right wheel. Run the program. Hint: Line up the right white wheel holder with the top support.
5. Which direction does the right wheel travel? Draw an arrow on the worksheet to indicate the direction.
6. How many rotations did the right wheel make? Enter the number of rotations on your worksheet.
7. Repeat Steps 5 and 6 for the left wheel.
8. Draw the direction the wheel travels in the worksheet.
9. Repeat all the steps for 75, 50, 25, 0, -25, -50, -75, and -100.

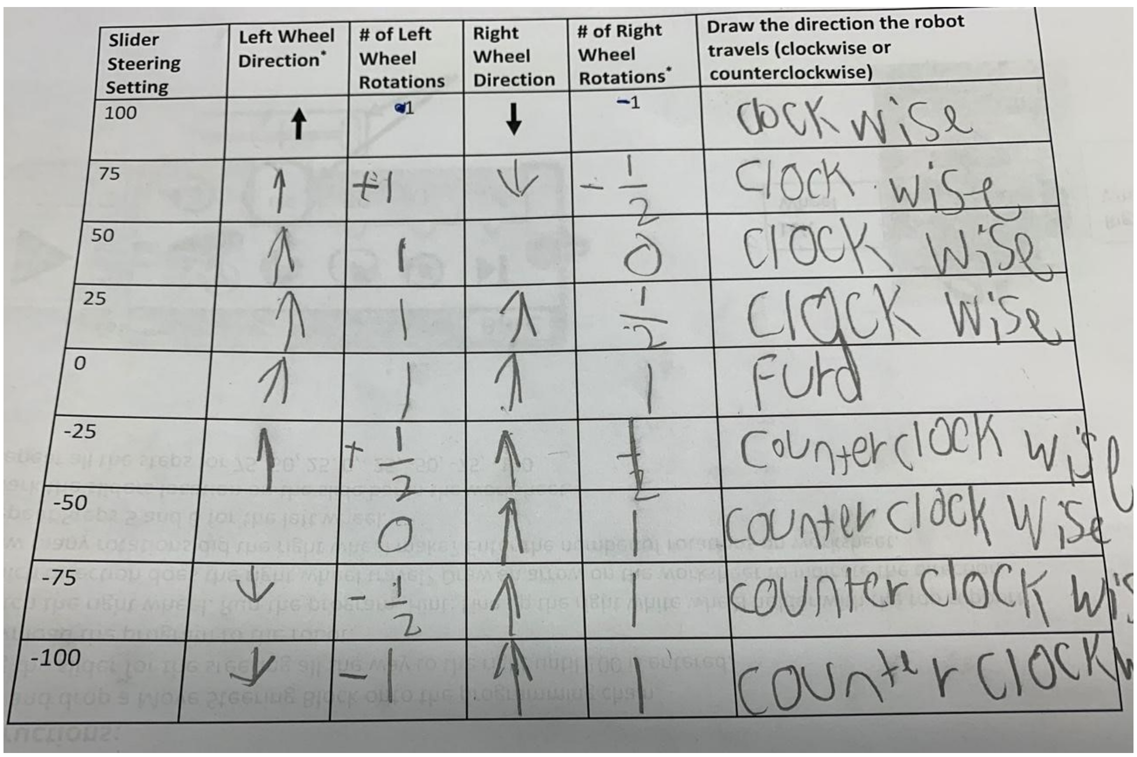
Observations of Student Engagement

Evidence of Student Understanding. Figure 2 below, provides an example of a completed Part 1 recording sheet. Fennell et al. (2013) provide a useful framework for connecting student engagement to the SMPs. Consistent with their framework, one can see from the example of the student's work in Figure 2, students were:

- Analyzing the recorded wheel rotation data to explain how the <Move> steering makes the wheels rotate.

- Utilizing the recording sheet for problem solving by gathering evidence, structuring the evidence in a table, monitoring and evaluating their progress.
- Utilizing the information gathered in the recording sheet to make conjectures, and generalize the pattern between how the wheels rotate and the <Move> steering input.
- Checking their recordings of positive and negative fractions against the movements of the robot's wheels using directional symbols and finding patterns and structures for interpretation.

We noticed that many students found the pattern quite quickly. As shown in Figure 2, the indicated pattern is symmetrical around 0, where the robot turns clockwise with positive steering and counterclockwise with negative steering.



Slider Steering Setting	Left Wheel Direction*	# of Left Wheel Rotations	Right Wheel Direction	# of Right Wheel Rotations*	Draw the direction the robot travels (clockwise or counterclockwise)
100	↑	1	↓	-1	clock wise
75	↑	+1	↓	- 1/2	clock wise
50	↑	1		0	clock wise
25	↑	1	↑	1/2	clock wise
0	↑	1	↑	1	furd
-25	↑	+ 1/2	↑	1	counterclock wise
-50	↑	0	↑	1	counter clock wise
-75	↓	- 1/2	↑	1	counterclock wi
-100	↓	-1	↑	1	counterclock

Figure 2. Example of a Grade 5 student's completed recording sheet for Part 1.

Assessment of Understanding. Students understood Part 1 when they articulated/explained the relationship between negative and positive steering setting and subsequent positive and negative left and right wheel rotations, e.g., a <Move> steering setting of 25 moved the right wheel ½ rotation forward and the left wheel 1 rotation forward. See the second column of Appendix 4 for a summary of steering settings and associated amount and direction of wheel rotations. Also see Appendix 1 for a detailed mapping or Part 1 to the Common Core Standards (CCSSI, 2020).

Part 2: Determining the Pattern of the Robot's Turns with Varying Steering Settings

Unplugged Task Considerations

Learning Goal. The learning goal of the unplugged activity was to discern that larger sized circles have longer circumferences.

Student Engagement. The teachers that we worked with encouraged the students to form groups of 4 or more, link arms, walk around a circle, and get each student count their steps (see Figure 3 below). Watch a video of children being instructed by their teacher to walk around a circle here (https://vimeo.com/392986435). This unplugged task helps students "find a way of relating knowledge to reality" (von Glasersfeld, 1990, p. 22). The bodily, sensori-motor experience of the outer member of the linked circle taking more steps is intended for re-presentation of the abstraction that circles of larger radii will have larger cirumferences (von Glasersfeld, 1995).

In the video, the students were trying to all take the same number of steps at first. The teacher interfered by explaining that it is more important to stay in a straight line. When asked how many steps each student took, they responded 13, 10, 13, and 17. While they each had different numbers of steps, the innermost student had more steps than the second, indicating the group's misunderstanding. This video highlights how it may not be intuitive to learners that the outer part of the circle requires a larger distance around (and thus more steps) than the inner part of the circle.

Figure 3. Students walking around a circle.

Teaching Reflections. To summarize this lesson (after the video), the teacher gathered the groups and each group explained their observations. The teacher selected the group with the best understanding to demonstrate that an increasing number of steps needs to be taken for each student further removed from the center of the circle. With prompting, the students became aware that the outside person needed to travel further than the inside person. This is the same for the robot. To travel along a circle, the outside wheel needs to travel further than the inside wheel. Moreover, larger circles require more wheel rotations for the robot to travel around.

Plugged Robotics Task Considerations

Learning Goal. The learning goal of the plugged robotics task was to discern the relationship between the <Move> steering input and the size and direction of the circle the robot travels around.

Student Engagement. Students were observing and recording the direction and distance the robot travelled according to variations in the steering setting of the <Move> programming block, i.e., -100, -75, -50, -25, 0, 25, 50, 75, and 100. Students also needed to find which blue circle of the steering mat (or circles drawn on the floor) the outer wheel of the robot travels along. One teacher provided an additional task that was not included in the recording sheets. The extension focused on learning about angles by measuring the angle of the arc that the robot travelled with one-wheel rotation for each of the circles of radius 6 cm, 8 cm, 12 cm, and 24 cm.

Teaching Reflections. For this Part 2, the students used vinyl printouts of a steering mat available at http://stem-education.ca/files/SteeringMat.pdf. These mats cost about $30US each to print. To avoid this cost, teachers could draw four concentric circles with diameters 48 cm, 24 cm, 16 cm, and 12 cm. Using an anchored string of the appropriate length (i.e., 24 cm, 12 cm, 8 cm, and 6 cm) attached to pen or washable marker (or chalk), the circles could be drawn on the floor or on poster boards. Also, selected mathematical terms should be explained. Using Figure 4 as an example within the context of this Part 2, the teachers introduced *circumference* of a circle, *diameter* and *radius*.

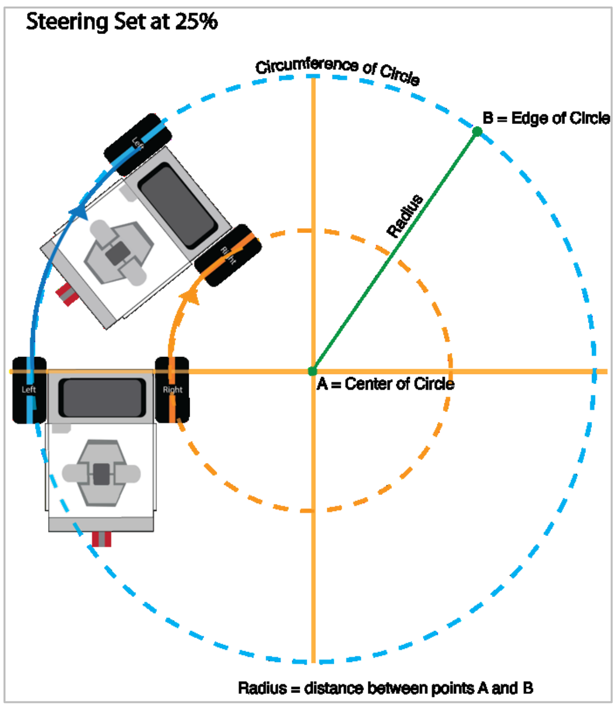


Figure 4. Diagram illustrating terminology for steering of <Move> programming block set to 25.

Instructions for Part 2

1. Drag and drop a <Move> block onto the programming chain.
2. Drag the arrow for the steering until 25 is entered.
3. Which blue circle on the steering mat does the outer robot wheel follow?
4. Measure the radius of the blue circle. Record the radius in the table.
5. How many wheel rotations does it take for the robot to make one full circumference of the blue outer circle? Record the number of wheel rotations in the table.

6. Record which robot wheel follows the outer circle.
7. Repeat all the steps for 100, 75, 50, 0, -25, -50, -75, and -100.

Observations of Student Engagement

Evidence of Student Understanding. Below, Figure 5 shows a student finding the radius and Figure 6 shows two students with their teacher finding the circumference of the circle on the steering mat associated with the steering on the <Move> programming block set to 75.

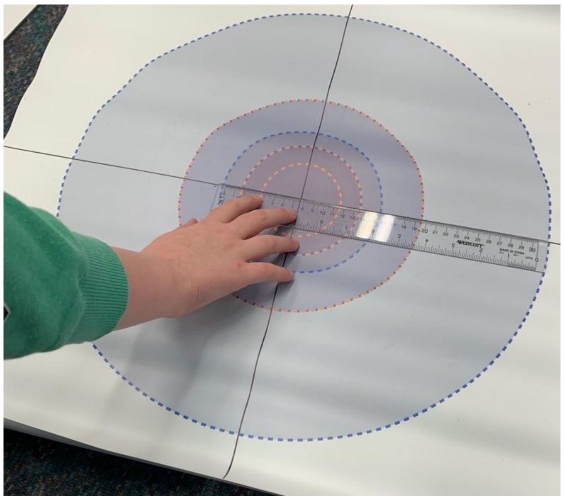


Figure 5. Student measuring the radius.

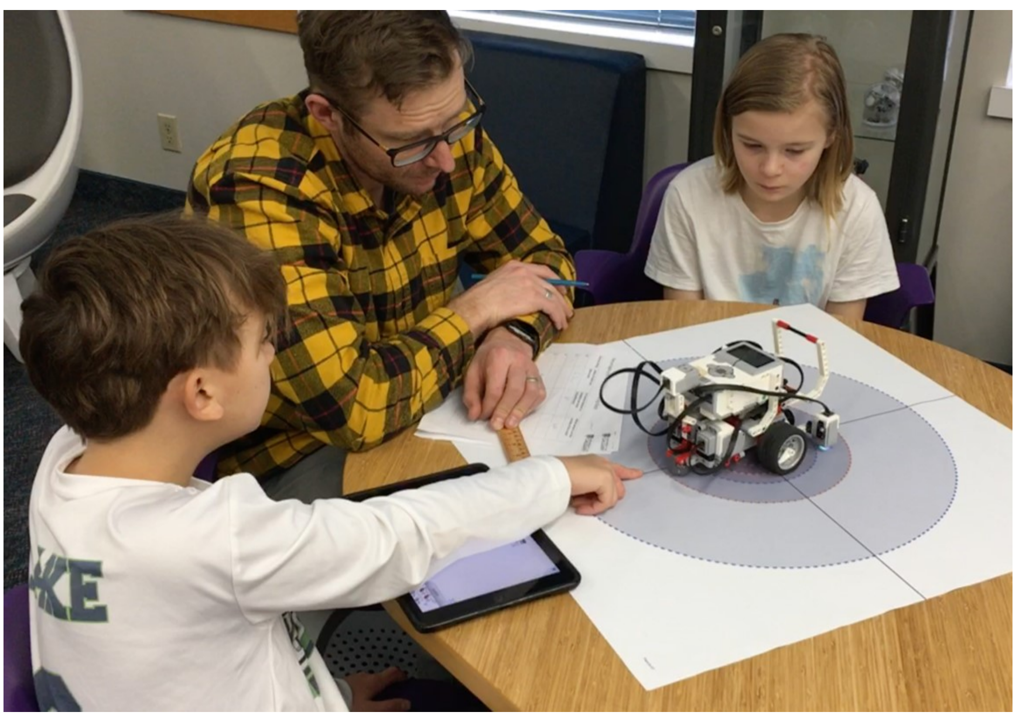


Figure 6. Teacher with students finding the circumference of the circle with wheel rotations. Steering set

to 75.

The following dialog from the video (*https://vimeo.com/430192409*) beginning at 00:24 illustrates how students were engaging with decimal numbers on the <Move> programming block to find the precise distance the robot travels around the circle with a radius of 8 cm. The robot had previously made it half-way around the circle. The students were learning how to precisely measure the circumference with wheel rotations using decimals to hundredths.

Graham: So, it's kind of like a 75 [percent of a full turn], so maybe add a little bit more. Okay, give that a shot… Let's line it up properly (repositions robot on mat).

Brennan: (Points finger to back wheel, downloads program to the robot and observes the turn.)

Graham: That was pretty close… okay, let's say 2 point…

Brennan: …631 (enters the numbers into the <Move> programming block).

Graham: Mmhh… we could have said 2.7.

Brennan: (Downloads program to the robot and observes the turn) …oh, 2.68.

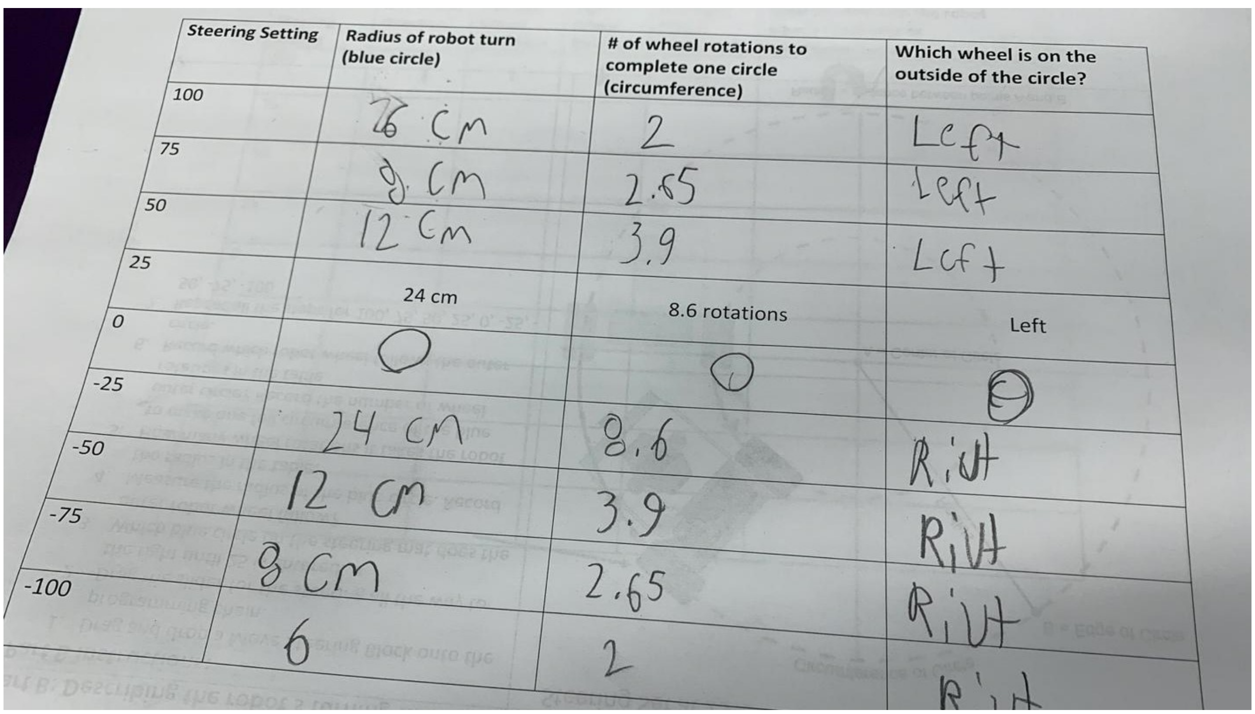
Graham: Yeah, or maybe 2.65. You are quite precise. Give that a shot.

The example of the student's work in Figure 7 below can be interpreted according to Fennell et al.'s (2013) framework. The students were:

- Analyzing the recorded wheel rotation data to explain the pattern between the <Move> steering input and the mathematical characteristics of the robot's travel.
- Utilizing the recording sheet for problem solving by measuring the radii of the circles in cm, the circumference of the circles in wheel rotations (geometric measurement of circles), and which wheel of the robot is on the outer circle.
- Utilizing the information gathered in the recording sheet to make conjectures, and generalize about the symmetrical pattern between negative and positive steering settings, corresponding to the direction the robot travels around the circle.

- Utilizing the information gathered the recording sheet to make conjectures, and generalize about the pattern between larger input values corresponding to the circles with smaller radii, and the circumferences.
- Checking their recordings to find how the radius and circumference of the negative steering is a reflection of the positive steering (exact numbers).

Figure 7 shows that the student could discern the relationship between <Move> steering input and the size and direction of the circle the robot travels around.



Steering Setting	Radius of robot turn (blue circle)	# of wheel rotations to complete one circle (circumference)	Which wheel is on the outside of the circle?
100	26 cm	2	Left
75	8 cm	2.65	Left
50	12 cm	3.9	Left
25	24 cm	8.6 rotations	Left
0	O	O	O
-25	24 cm	8.6	Right
-50	12 cm	3.9	Right
-75	8 cm	2.65	Right
-100	6	2	Right

Figure 7. Example of a student's completed recording sheet for Part 2.

The exchange with the teacher continued as the students filled in the recording sheet. The dialog below (starting at 2:34 in the video, available at https://vimeo.com/430192409) is an extract of their conversations where the students were beginning to consolidate their observations. Recall that the goal of Part 2 was to understand how larger steering settings correspond to tighter robot turns or turns with smaller radii. Notice how the student articulated his emerging understanding of how the steering input changes the circle the robot travels around.

Graham: Last time, because it was at 100, our radius was tighter, we started from about there… (points with pen).

And it just spun in place (makes a circular motion above the robot).

Brennan: So every time we go on with one [steering input] we just come out a circle more?

Graham: That's a very good observation…

So, every time you are changing your percentage of steering (points to student's program on iPad), you are probably moving to a different spot (points away from the center of the circle).

And it'll be either a larger radius or a smaller radius depending on the number (points to student's program on iPad).

Assessment of Understanding. After completing Part 2, students were able to interpret and explain (i) the relationship between positive and negative steering inputs to the direction of the robot turn, (ii) the relationship between steering input to radius and size of the circle the robot travels around, and (iii) the relationship between the number of wheel rotations and the distance the robot travels around the circle. See the third column of Appendix 4 for a summary of steering settings and associated circle that the robot travels around. Also see Appendix 2 for a detailed mapping or Part 2 to the Common Core Standards (CCSSI, 2020).

Extension: An extension for Grades 7 had students calculate the circumference (c) of the circle based on the radius (r) using the formula: $c = 2\pi r$. In the example and the dialog associated with Figure 7, the recorded circumference of 2.65 wheel rotations is pretty close to the actual circumference, as the following calculations illustrate: $c = 2\pi r = 2\pi \cdot 8\ cm = 50.27\ cm$. There are 17.6 cm per wheel rotation. So, $50.27\ cm \div 17.6\ \frac{cm}{wheel\ rotation} = 2.86\ wheel\ rotations$. The students converted their measured circumference of wheel rotations into cm and compared their answers to explain similarities and differences. While they noticed their answers were close, they brainstormed that slight variations occurred due to rounding or measurement errors, as well as mechanical friction when the robot moved.

Part 3: Expressing the Steering Differential with Fractions and Percentages

Robotics Task Considerations

Learning Goal. The learning goal of Part 3 was to discern that the <Move> steering input is a differential of wheel rotations expressed as a percentage.

Student Engagement. The students were discerning how the steering differential is the difference in power that is delivered to each wheel. When the differential is at its maximum, each wheel is going in different directions for the same amount of rotations. For example, as found in Part 1 above, when the <Move> steering was set to 100 the left wheel moved forward and the right wheel moved equally backward and from Part 2 above, the robot turned around a circle of radius 6 cm. This was the tightest turn the robot made, and it essentially pivoted on the spot.

Teaching Reflections. One of the teachers we worked with demonstrated the concept of a steering differential using the YouTube video *Around the Corner – How Steering Differential Works*. A student noted that excavators with chain tracks use the same differential when moving.

Instructions for Part 3

1. Draw bars to represent how much each wheel rotates (when the steering block is set to 1-wheel rotation) for 75, 50, 25, and 0.
2. Color in the bars to indicate the amount of power going to the wheel.
3. Describe the robot's turn.

Observations of Student Engagement

Evidence of Student Understanding. Figure 8 below, shows a) how the steering was programmed at 100%, b) the direction the wheels rotated, and c) the movement of the robot. The right wheel travelled one-wheel rotation backward and the left wheel travelled one-wheel rotation forward. This was represented as equal sized bars or rectangles (see Figures 8a and 8b below).

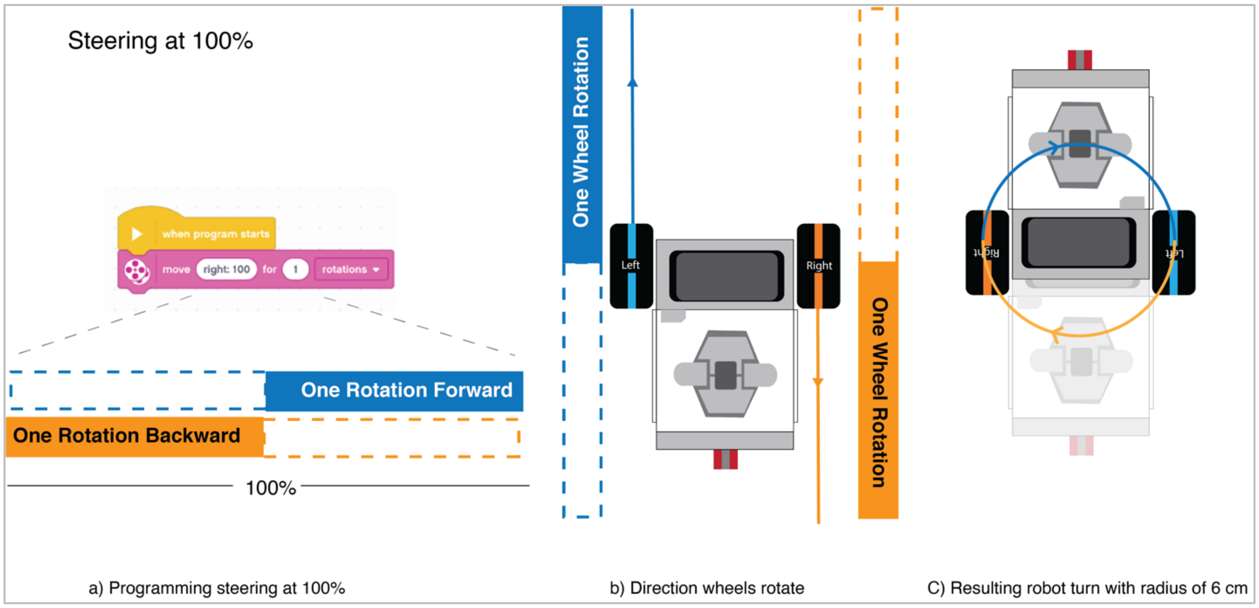


Figure 8. Steering Differential at 100%.

Fennell et al.'s (2013) framework is useful for describing how a student's work/engagement in Figure 9 connects to the SMPs. Figure 9 below illustrates that students were:

- Analyzing the recorded data to interpret and explain the relationship between negative and positive steering input to direction and amount of left and right wheel rotations.
- Utilizing the information gathered to make conjectures about the independent variable (steering input) and dependent variable (wheel rotation).
- Checking their recordings to find the pattern between the independent variable (steering input) and dependent variable (wheel rotation).
- Utilizing the information gathered in the recording sheet to make conjectures and generalize about the steering differential expressed as fractions and percentages.

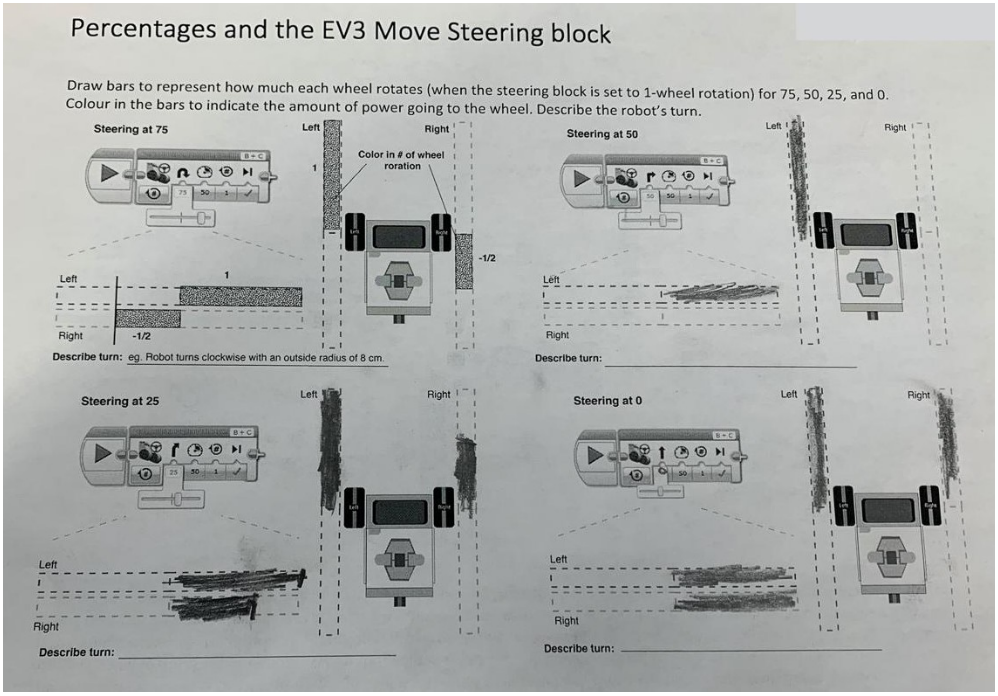


Figure 9. Example of student's work on Part 3 with an older version of *EV3 Education*.

Assessment of Understanding. Students understood Part 3 when they articulated/explained the relationship of steering differential percentage to the amount and direction of left and right wheel rotations. See the fourth column of Appendix 4 for a summary of steering settings and the steering differential represented as fractions. Also see Appendix 3 for a detailed mapping of Part 3 to the Common Core Standards (CCSSI, 2020).

Summary

Learning how the <Move> Steering programs the robot to turn was a fun, rigorously structured inquiry that incorporated the NCTM Process Standards (2000), and specifically elaborated the first and the seventh Standard for Mathematical Practice (SMPs; CCSSI, 2010) for problem-solving, structuring information, finding patterns and using algebraic expressions. The robot became a valuable tool for engaging mathematical ideas. The constant interplay of the students actively experiencing the task, the robot performing actions, the programming interface that determined robot movements, and the accompanying/complementary graphic and symbolic representations on the recording sheets supported students' conceptual understanding of the embedded mathematics. The task also simultaneously facilitated students' self-paced problem-solving, collaboration, and mathematical reasoning skills. After completing the tasks, students had a greater understanding of how the steering of the robot works, enabling them to have greater precision with any future robotics tasks.

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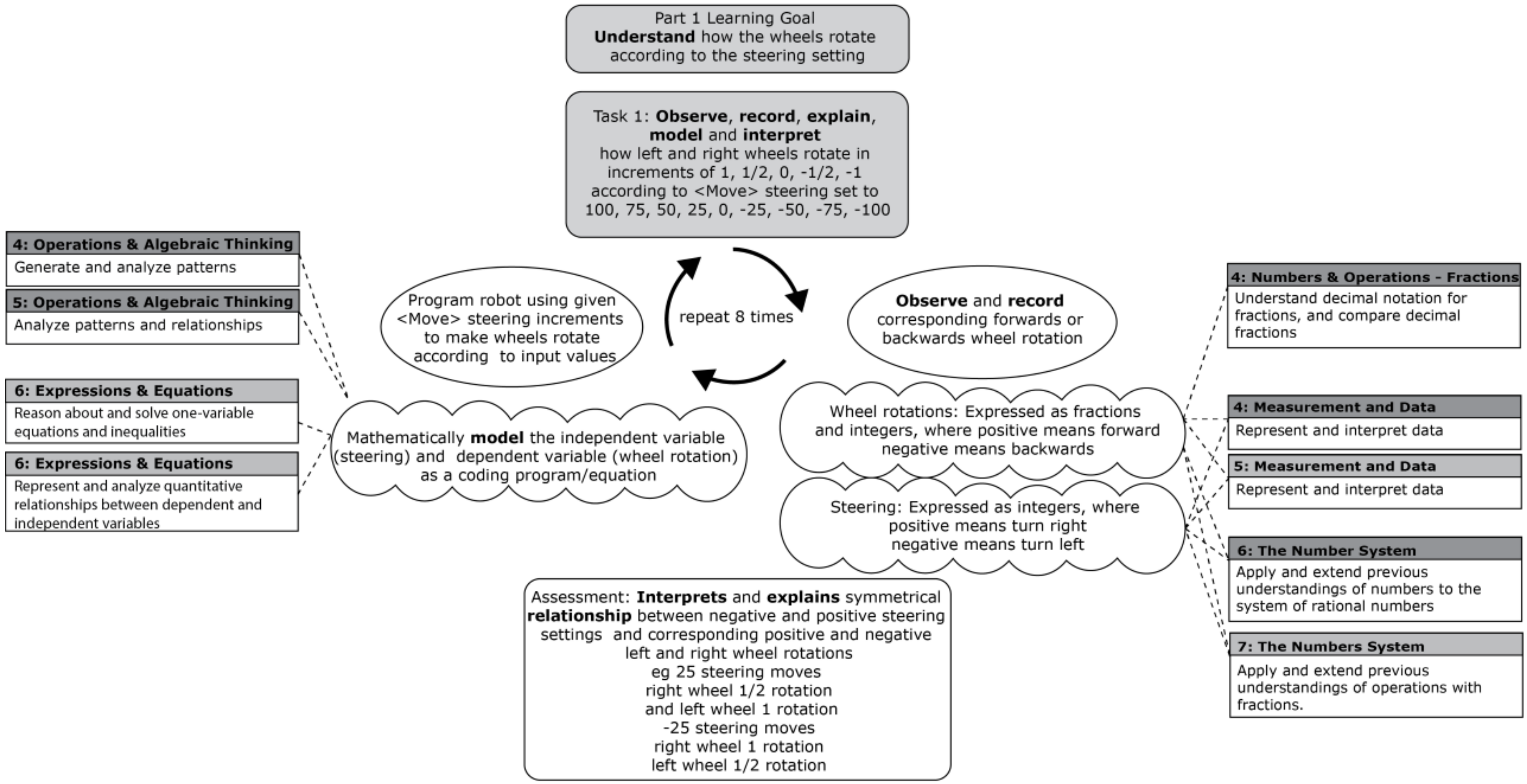
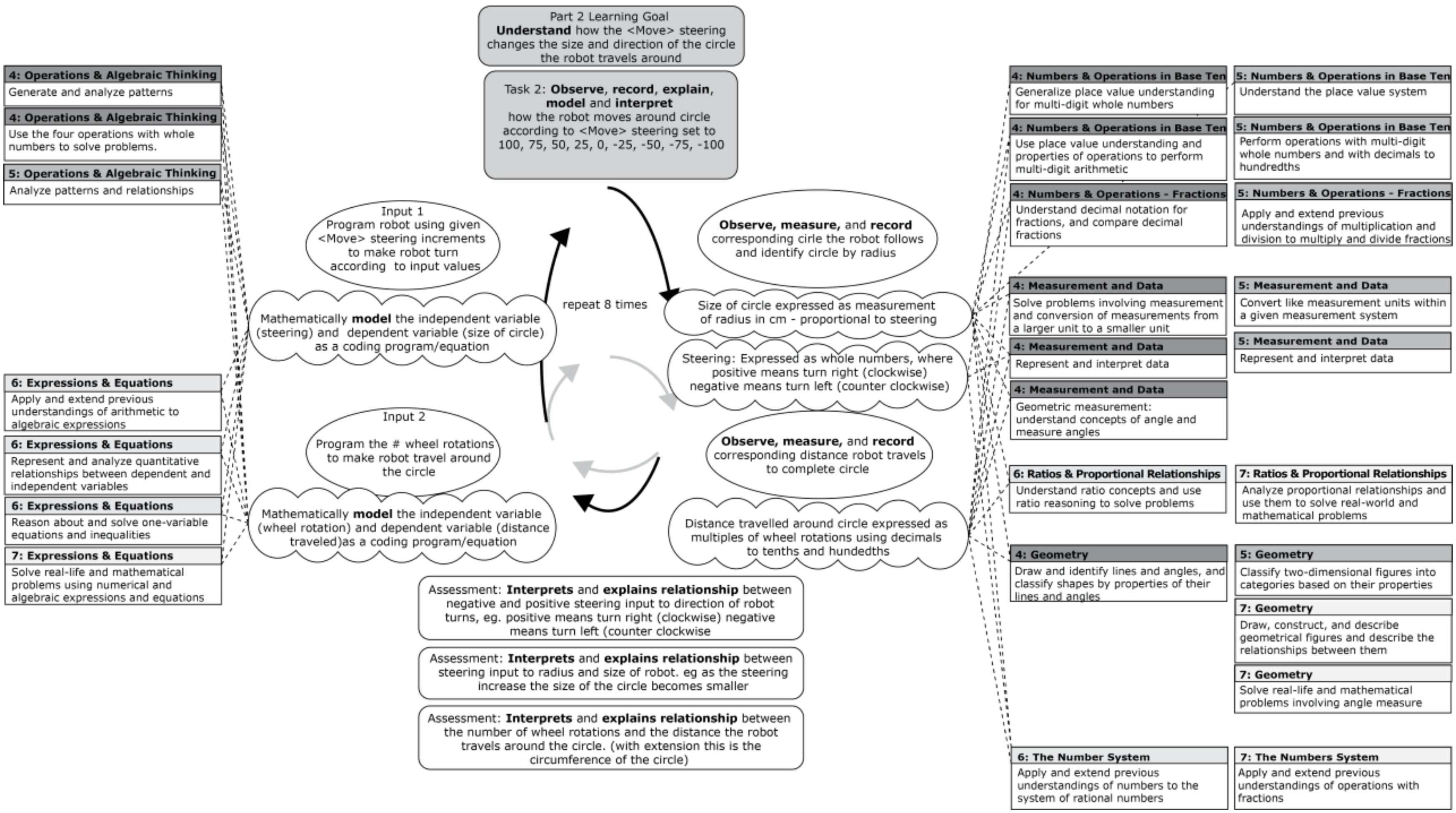
von Glasersfeld, E. (1995). *Radical constructivism: a way of knowing and learning*. Taylor and Francis.

Appendix 1: Mapping of Part 1 to Common Core Standards



Appendix 2: Mapping of Part 2 to Common Core Standards



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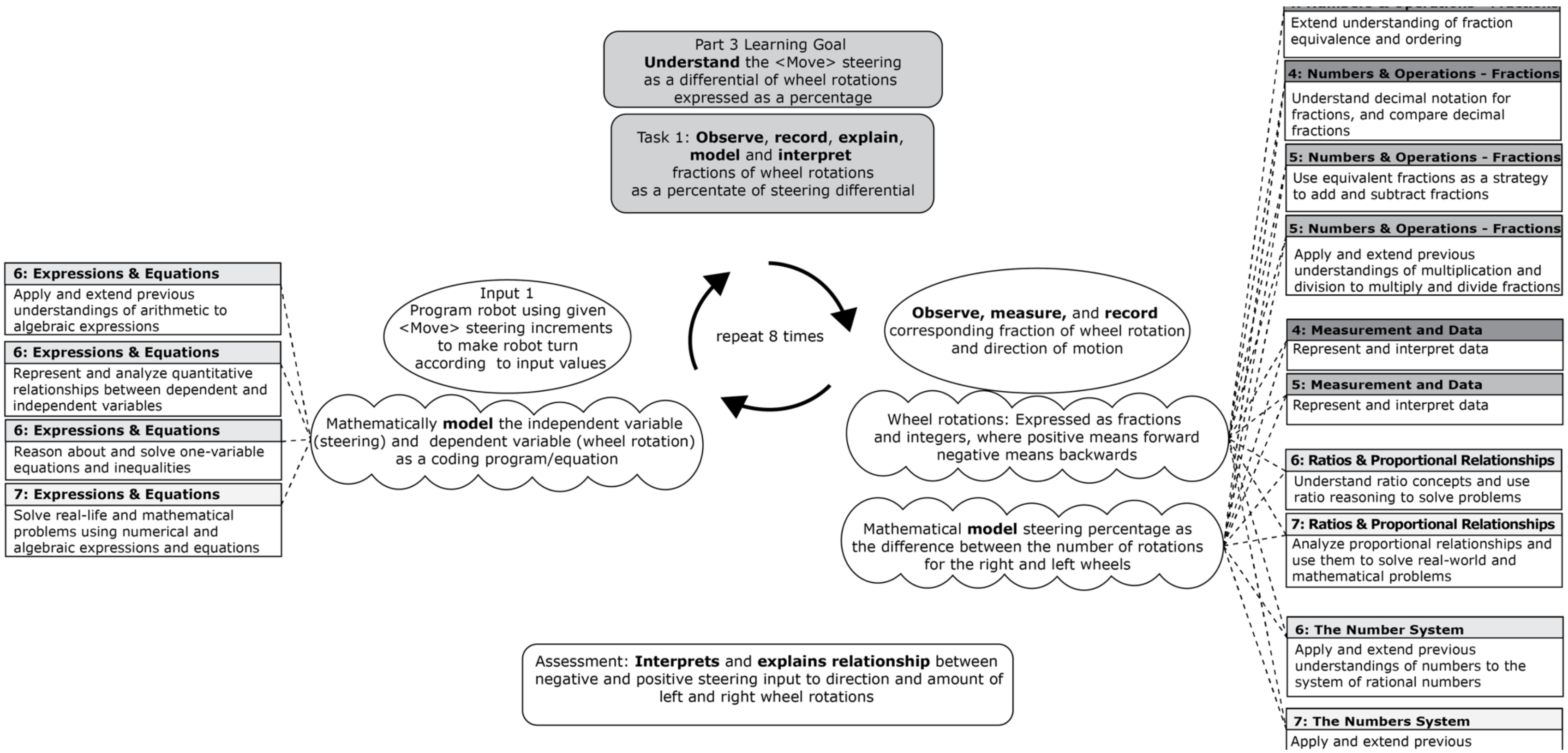
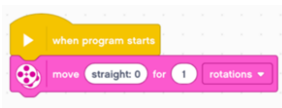
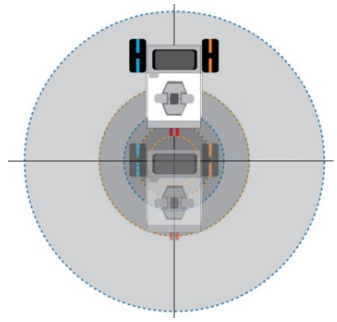
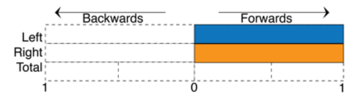
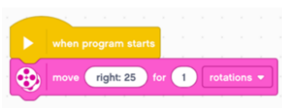
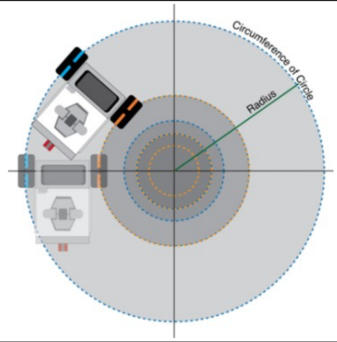
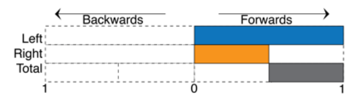
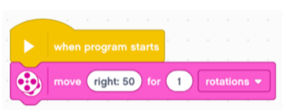
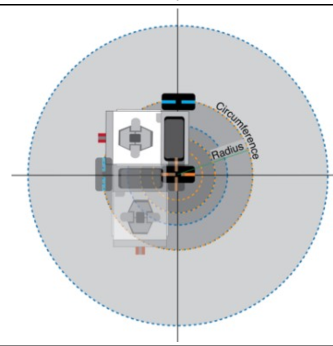
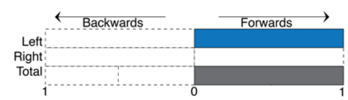
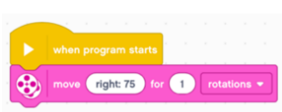
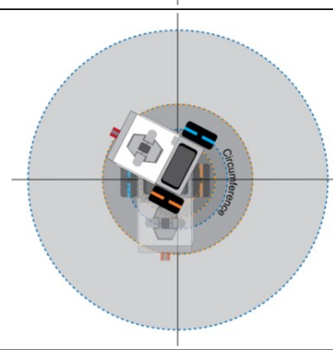
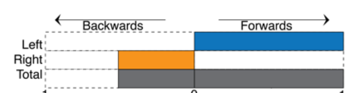
Appendix 3: Mapping of Part 3 to Common Core Standards



Appendix 4: Summary Table of Steering Settings, Associated Robot Turns and Steering Differential

	Steering is set to 0. The wheel rotation is set to 1. Both wheels rotate forward 1-wheel rotation. The robot moves straight. Differential is 0%.		
	Steering is set to 25. The left wheel rotates forward 1 rotation. The right wheel rotates forward $\frac{1}{2}$ rotations. Differential is $\frac{1}{4}$ or 25%.		
	Steering is set to 50. The left wheel rotates forward 1 rotation. The right wheel does not rotate. The robot pivots on the right wheel. Differential is $\frac{1}{2}$ or 50%.		
	Steering is set to 75. The left wheel rotates forward 1 rotation. The right wheel rotates backwards $\frac{1}{2}$ rotation. The robot turns tightly to the right. Differential is $\frac{3}{4}$ or 75%.		

Francis, K., Rothschuh, S., Hamilton, S., & Diehl, G. (2021, May). Exploring the synergy between the move steering input and turning a robot. *Elementary STEM Journal 25*(4), 26-32.

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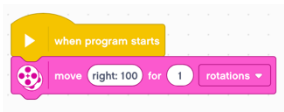
<td>
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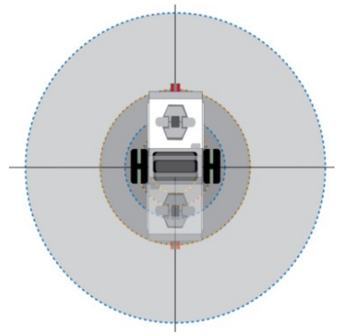
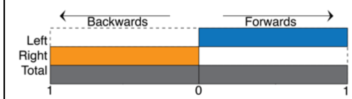
<td>Steering set to 100. Left wheel rotates forward 1-wheel rotation. Right wheel rotates backwards 1-wheel rotation. The robot pirouettes right. Differential is $\frac{2}{2}$ or 100%.</td>
<td></td>
<td>
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