University of Michigan
Center for Research on Learning and Teaching in Engineering
CRLT ENGIN

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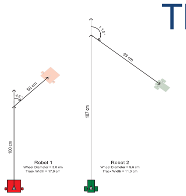
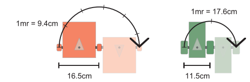
More than Just Playing with Numbers

The power of middle school students using math to think about how robots work



Eli M. Silk
esilk@me.com

Christian D. Schunn
schunn@pitt.edu



Background

Research Question

When students use math to guide basic robot movements, what is the effect of **framing** the task in terms of mechanistic thinking versus calculational thinking?

Frame – *"set of expectations an individual has about the situation in which she finds herself that affect what she notices and how she thinks to act" (Hammer et al., 2005)*

Activity Context

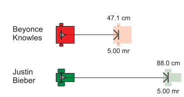
Robot Synchronized Dancing –

A *Model Eliciting Activity* (design task with series of express-test-revise cycles) in which student teams invent strategies for synchronizing different-size robots (same underlying proportional relationships, but different constants)

Dance Routine					Beyonce Base Program Parameters	
	Movement Type	Target Distance	Target Turn	Target Time	Motor Rotations	Motor Speed
1	Straight Forward	47.1 cm		5.00 sec	5.00 rot	1.00 rot/sec
2	Straight Backward	75.4 cm		5.00 sec	8.00 rot	1.60 rot/sec
3	Point Turn Right		196 °	3.33 sec	3.00 rot	0.90 rot/sec
4	Point Turn Left		131 °	3.33 sec	2.00 rot	0.60 rot/sec
5	Straight Backward	22.6 cm		3.75 sec	2.40 rot	0.64 rot/sec
6	Straight Forward	30.2 cm		3.76 sec	3.20 rot	0.85 rot/sec
7	Swing Turn Left Forward		66 °	3.33 sec	2.00 rot	0.60 rot/sec
8	Swing Turn Right Forward		98 °	3.33 sec	3.00 rot	0.90 rot/sec
9	Swing Turn Left Backward		131 °	3.33 sec	4.00 rot	1.20 rot/sec
10	Swing Turn Right Backward		164 °	3.33 sec	5.00 rot	1.50 rot/sec

Create a "how to" toolkit that the Bots-N-Sync *captain can use to modify submitted dance routine programs so that all of the dancers do the routines in sync with each other.*

Focus here on how to get robots to have ***synchronized straight distances*** *– two robots going the same distance forward or backward.*



Experimental Manipulation

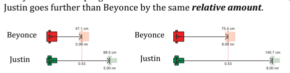
- Two groups (5^{th}-7^{th} grade) each in 1-week instructional activity
- Students worked in teams (dyads/triads), 4 teams per group
- Contrasting framings support different student approaches

Calculational **Group**	***Mechanistic*** **Group**
Design Task Setup	
Input-Output Focus	Modeling Intuitions Focus
Instructor: "Many people are starting to see patterns in how what you put into the program (motor rotations) relates to what you get out (distance). For example, more motor rotations make the robot move a greater distance. Create a method to determine how many motor rotations are needed to go a given distance."	*Instructor: "Many people think that the size of the wheels seems to matter. For example, robots with bigger wheels need less motor rotations to go a given distance. Create a method that uses wheel size to determine how many motor rotations needed to go a given distance."*

Example Cases

Identify Empirical Patterns

Every time that we program the same motor rotations on both robots, Justin goes further than Beyonce by the same ***relative amount***.



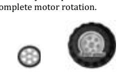
Move 1 → $DIST_B ÷ DIST_J$ = 47.1cm ÷ 88.0cm = 0.53

Move 2 → $DIST_B ÷ DIST_J$ = 75.4cm ÷ 140.7cm = 0.53

It's always the same scale! Scale Factor = 0.53

Identify Key Physical Features

The circumference of Beyonce's wheels are smaller than Justin's, so Justin should only do a part of a motor rotation every time Beyonce does a complete motor rotation.



Move 1 → $Wheel_B ÷ Wheel_J$ = 9.42cm ÷ 17.58cm = 0.53

It's the ratio of the *wheel circumferences*! Scale Factor = 0.53

Instructional Support

Calculational Group	Mechanistic Group
Focused on Identifying Numerical Patterns and on Correctness of Calculations	Focused on Connecting Quantities and Operations to the Physical Situation
Instructor: "What are the steps you took to get this value?"	*Instructor: "What does this value/operation correspond to on the robot?"*

Advantages of *Mechanistic* Teams

Manipulation Check: Do Groups Think about Task Differently?

Yes – *Mechanistic* teams...

- Used (mental) images/animations
  - not just numbers/operations
- Based solutions on physical features

But mechanistic thinking is **not easy**

- Not ALL Mechanistic teams adopted it
- However, NO Calculational teams did

# Posters with the feature (out of 15)	Calc	Mech
Situation Pictures	1	7
Physical Features	0	6
Label Interm. Values	8	12
Explanation	4	8

Mechanistic Teams Invent More Sophisticated Solutions

No differences in some ways

- Both invent working strategies (valid)
- Both articulate them well (clear steps)

And **important differences** in other ways

- Less reliance on adjusting/guessing
- More generalizing beyond given context

# Posters with the feature (out of 15)	Calc	Mech
Valid	13	13
Clear Steps	15	15
Fully Specified	6	15
Generalized	8	11

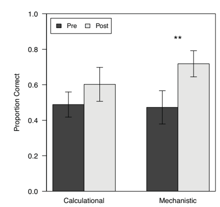
Mechanistic Teams Improve use of Mathematics

10-item individual pre-post assessment

A robot moved forward 6 centimeters when it was programmed to do 4 motor rotations. The programmer needed to make her robot move forward 24 centimeters. How many motor rotations does she need to enter in her program to do her move correctly?

Repeated Measures ANOVA with follow-up tests suggest that only the *Mechanistic* Group reliably improves Pre-Post

- Mechanistic Group: Gain = .23, 95% CI [.09, .37]
- Calculational Group: Gain = .10, 95% CI [-0.06, .26]



Mechanistic Teams Transfer their Solutions

Mechanistic teams more likely to use robot dancing solutions in a later competition task – recognizing similar underlying structure

<u>1</u> out of 4 *Calculational* Teams vs. <u>4</u> out of 4 *Mechanistic* Teams

Calculational Team

S: Not really. No. Cause there isn't any, like, it isn't like we are comparing two different robots to do the same thing. All robots are the same in this. We're not using two different robots to do the same thing. So there really is no need for any strategies like that.

Mechanistic Team

S1: We used the, the strategies that we learned all throughout the week. Um, we, like, for the straights, we, um, used the circumference of the wheel as the rotations and measured it, measured the area.

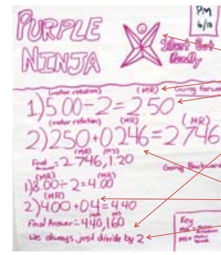
I: What do you mean by measured the area?

S2: Like how far it was from here to here. And then we like said, I think the wheel was 26 cm, so we said one rotation would be 26 cm, two would be whatever that is times two.

Framing Changes Reasoning Focus

Contrasting Solutions Illustrate Difference in Math Use

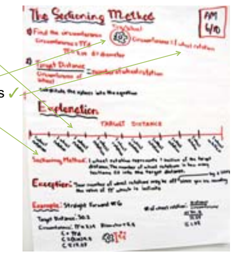
Calculational Team



MECHANISTIC SCORE
✗ Situation Pictures ✓
✗ Physical Features ✓
✗ Label Intermediate Values ✓
✗ Explanation ✓

QUALITY SCORE
✓ Valid ✓
✓ Clear Steps ✓
✗ Fully Specified ✓
✗ Generalized ✓

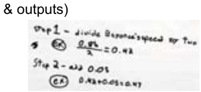
Mechanistic Team



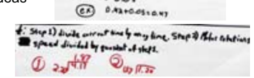
Calculational ≠ Low-Level Math Reasoning

Calculational teams make sensible and meaningful math-to-robot connections

- They do connect their math to the situation (in terms of inputs & outputs)
  - *"Since Beyonce's always half as slow as Justin, we decrease Justin's speed by half"*



- They do make connections to and build off each other's ideas
  - *"It's showing the, um, like how, sort of like how the Green team had divided by two, but we wanted it more exact number ... the more exact number of how much the time, of how much the speed is. It's a bit less than half the time."*



- But the connections they do make are **limited**, because they don't take advantage of physical features or mental images/animations to focus or evaluate their mathematical choices

Conclusions

- Setting up learning environments that encourage students to use math in a robot context can be beneficial for learning about both math and robots
- But the power of math as a representational tool may not be fully realized unless tasks are framed so that students consider math as more than just a calculational tool
- Framing tasks so students use math to think about robots' physical mechanisms may be ideal for deep learning

More Information

Silk, E. M. (2011). *Resources for learning robots: Environments and framings connecting math in robotics* (Doctoral dissertation, University of Pittsburgh). Available from ProQuest Dissertations and Theses database (Publication No. AAT 3485771).

Silk, E. M., Higashi, R., & Schunn, C. D. (2011). Resources for robot competition success: Assessing math use in grade-school-level engineering design. *Paper presented at the annual meeting of the American Society for Engineering Education*, Vancouver, BC, Canada.

Silk, E. M., & Schunn, C. D. (2011). Resources for learning robots: Facilitating the incorporation of mathematical models in students' engineering design strategies. *Paper presented at the annual meeting of the American Educational Research Association*, New Orleans, LA, USA.

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