Using Problem-Based Learning Analytics to Investigate Individual and Collaborative Mathematics Learning in a Digital Environment Over Time

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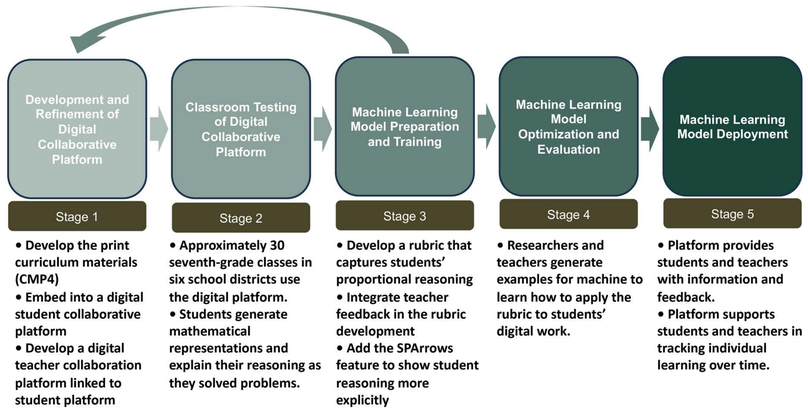
Research Overview

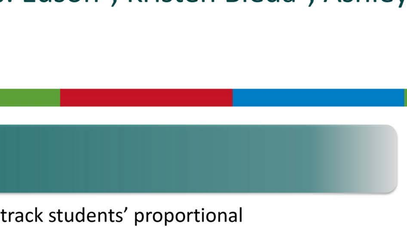
The research goal is to identify, support, and track students' proportional reasoning within and across mathematics problems, investigations, and units.

What is a supervised machine learning rubric that can be used to train computers to diagnose and track evidence of students' proportional reasoning from a digital collaborative platform with an embedded problem-based curriculum?



Methods

- **Platform:** The digital collaborative platform is designed for classroom use that includes curriculum materials, digital tools (e.g., text, graph, table, drawing), and collaborative features (e.g., real-time sharing and retrieving, teacher comments).



- **Curriculum:** The *Connected Mathematics4* curriculum materials (Phillips, Lappan, Fey, Friel, Slanger-Grant, & Edson, 2025), a problem-based curriculum for middle school mathematics, are embedded in the digital collaborative platform.
- **Participants:** Teachers and students used the digital platform during the 2023-24 school year and 2024-25 school year (data collection ongoing). Implementation spans ~100 problems across 8 curricular units, producing ~57,000 student documents.
- **Data sources:** Student work from 2023-24: java-script object notation programming text, screenshot images of student and teacher documents, platform documents containing mathematical structures

School		A	B	C	D	E	F	G	H
Number of Students		661	726	463	387	408	405	381	718
Racial Identification (%)	African American	10.29	6.89	12.96	0	0.98	15.31	2.36	1.11
	Hispanic/Latino	8.18	4.13	3.46	0	3.68	2.47	9.71	96.80
	White	41	55.1	77.97	99.22	92.65	59.75	63.25	0.97
	Asian	29.65	23.97	2.16	0.78	0	12.35	19.95	0.14
	Native American	0	0.14	0.22	0	0	1.48	0.26	0.56
	Two or more	10.89	9.87	3.24	0	2.70	8.64	4.46	0.42
English Learners (%)		8.93	7.85	0.86	Private	0	Private	0.5	47.00
Free/Reduced Lunch (%)		17.55	19.83	20.30	Private	32.35	Private	0	85.00
Disability (%)		10.59	12.26	9.94	Private	9.31	Private	15.8	15.00

Rubric for Proportional Reasoning

Our approach to students' machine learning is supervised, meaning that we ground the data in desired outcomes that relate to students' proportional reasoning.

- While proportional reasoning is critically important across different mathematics strands, grades, and STEM disciplines (Cai & Sun, 2002, Cramer & Post, 1993; Hoyles et al., 2021; Lamon, 1993, 2007), research on students' proportional reasoning tend to show students reliance on rote algorithms to get correct answers without explaining the reasoning behind these strategies (Ayan-Civak et al., 2023).

Machine Learning Rubric for Proportional Reasoning

Criterion 1: Student Approach	The student approaches the contextual problem using reasoning about (1) Part-to-Part Relationship and (2) Part-to-Whole (or Whole-to-Part) Relationship
Criterion 2: Student Representation	Student representations based on their inscriptional resource used in the digital collaborative platform: Text, Table, Shapes Graph, Graph, Drawing, Expression, Number Line, Image
Criterion 3: Student Strategy	Strategies include (1) Building Up or Down; (2) Scaling Up or Down without Unit Rates; (3) Scaling Up or Down with Unit Rates; (4) Other Proportional Reasoning; and (5) Non-Proportional Reasoning

Adapted from Ben-Chaim et al. (1998)

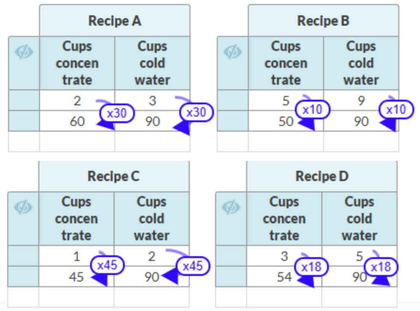
Application of the Rubric

Student Work Example 1

Recipe A: 2/5 or 0.4 cups of concentrate per one cup of orange juice
Recipe B: 5/14 or 0.35 cups of concentrate per one cup of orange juice
Recipe C: 1/3 or 0.33 cups of concentrate per one cup of orange juice
Recipe D: 3/8 or 0.375 cups of concentrate per one cup of orange juice
So, recipe A is the most orangey, while recipe D is the least orangey

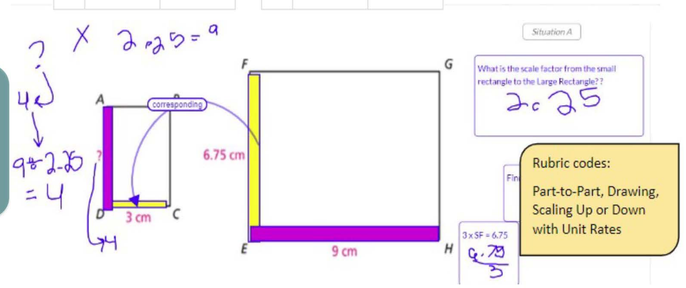
Rubric codes:
Part-to-Whole, Text, Scaling Up or Down with Unit Rates

Student Work Example 2



Rubric codes:
Part-to-Part, Table, Scaling Up or Down without Unit Rates

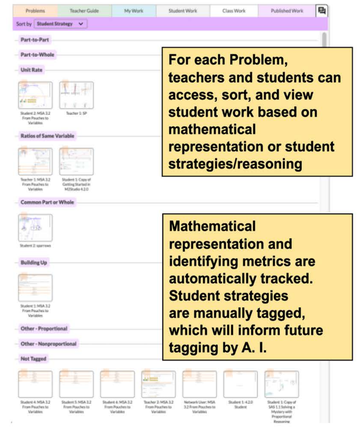
Student Work Example 3



Rubric codes:
Part-to-Part, Drawing, Scaling Up or Down with Unit Rates

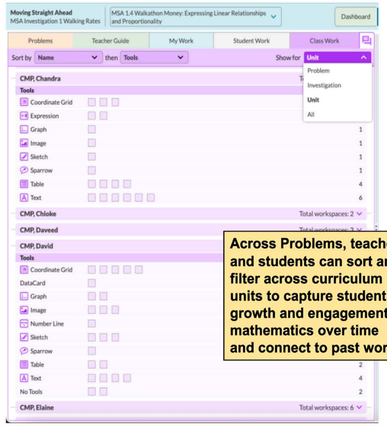
AI Features in the CMP Digital Platform

Sorting Student Work by Rubric Criteria



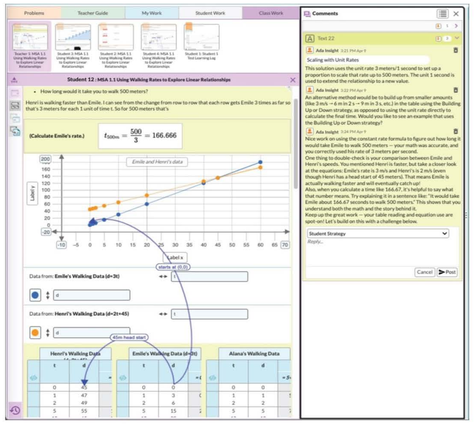
For each Problem, teachers and students can access, sort, and view student work based on mathematical representation or student strategies/reasoning

Mathematical representation and identifying metrics are automatically tracked. Student strategies are manually tagged, which will inform future tagging by A. I.



Across Problems, teachers and students can sort and filter across curriculum units to capture student growth and engagement in mathematics over time and connect to past work.

Teacher View with Tagging and AI Feedback



Teachers and researchers review student documents and manually "tag" student work by placing comments on documents/tiles where students show proportional reasoning or strategies.

These tags inform the machine learning algorithm we are developing, so in future the platform can automatically tag student documents with appropriate proportional reasoning or strategies and directly deliver feedback to teachers and students as "Ada Insight".

Discussion

AI-Enhanced Support for Students' Proportional Reasoning

- Students and teachers can easily scan class work within and across problems to identify common/different strategies and representations. Teachers can use this information to plan class discussions and future problems to foster students' proportional reasoning.
- To improve the accuracy of AI performance, it is critical to provide the machine with good tagging examples. Manual tagging can also be beneficial for teachers (or together with students) to reflect on students' proportional reasoning.

Next Steps

- Teachers and researchers will continue tagging (coding) student work to train the model (Stage 3). Data from 2023-24 is ~22% coded, with additional coding ongoing.
- Get an A.I. model running in the platform and allow teachers and researchers to provide feedback to evaluate and optimize the model (Stage 4).
- Future research projects aim to develop a "generative" artificial intelligence model to provide personalized feedback on students' proportional reasoning.

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