Transitioning a Problem-Based Curriculum from Print to Digital: New Considerations for Task Design

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The purpose of this paper is to report on new considerations for task design of curriculum materials for a digital world. These considerations build upon a print problem-based curriculum that has evolved over 30 years. We offer a new design on problems presented in a digital medium.

Keywords: Task Design, Middle School Curriculum, Digital Technologies.

INTRODUCTION

In this paper, we discuss important task design considerations for problems in a problem-centered curriculum. In our work, we view problems that are embedded within sequences of mathematics problems to promote inquiry-based teaching and learning. Specifically, we report on the design considerations for problems in a print version of a problem-centered curriculum. We then revisit the design considerations for the problem-solving activities based on our work of transitioning from print to digital curriculum. This work is funded by two National Science Foundation projects in the United States. These projects investigate student learning and engagement through use of collaborative and individual spaces on a digital platform.

CHALLENGES OF PROBLEM-BASED CURRICULUM OVER TIME

The Connected Mathematics Project (CMP) at Michigan State University has worked over 30 years to design, develop, field-test, evaluate, and disseminate student and teacher materials for a middle school mathematics problem-centered curriculum, *Connected Mathematics*. The CMP curriculum development has been guided by a single mathematical standard:

> All students should be able to reason and communicate proficiently in mathematics. They should have knowledge of and skill in the use of the vocabulary, forms of representation, materials, tools, techniques, and intellectual methods of the discipline of mathematics, including the ability to define and solve problems with reason, insight, inventiveness, and technical proficiency (Lappan & Phillips, 2009, p. 4).

To accomplish this goal, problems must embody critical mathematical concepts and skills and have the potential to engage students in making sense of mathematics. Thus, each CMP Problem has some or all of the following characteristics:

- Embeds important, useful mathematics
- Promotes conceptual and procedural knowledge
- Builds on and connects to other important mathematical ideas
- Requires higher-level thinking, reasoning, and problem solving

- Provides multiple access points for students
- Engages students and promotes classroom discourse
- Allows for various solution strategies
- Creates an opportunity for teacher to assess student learning

From the onset in 1990, the design and development challenge of the CMP is to create an environment that supports students' mathematical development through the process of exploring, conjecturing, reasoning, communicating, and reflecting. Creating this classroom environment requires thoughtful attention to the strategies students use to solve the problem, to the embedded mathematics, and to connections to prior learnings (Figure 1).

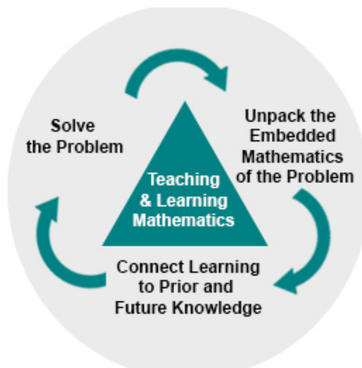


Figure 1: Teaching and learning mathematics in problem-centered classrooms.

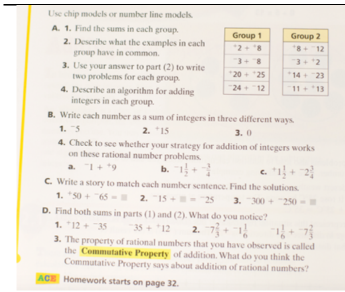
The time required to develop a particular mathematical idea fully, the extent to which students grasp the mathematical subtlety of ideas, and the degree to which students reach useful closure of the idea being developed require careful attention to the mathematical challenge of the problem and the position of the problem within a carefully sequenced set of problems (Lappan & Phillips, 2009).

These design challenges were attented to in the unique design research development process of CMP which spans repetitive years of unit design, field trials, and data feedback cycles. Iterative feedback cycles focused on revisions to the curriculum units based on feedback from teachers and students across the country as well as mathematicians and educational researchers. Approximately 500 teachers in 55 trial sites around the country (and thousands of their students) were a significant part of the team of professionals that informed material development for CMP1, CMP2, and CMP3.

Even though extensive research on CMP shows that both student and teacher learning increases (e.g., Cai, Moyer, Hwang, Nie, & Garger, 2012; Reys, Reys, Lapan, Holliday, & Wasman, 2003) and CMP students' positive attitudes towards mathematics persisted through high school (Moyer, Robison, & Cai, 2018), the CMP authors continue to seek ways to enhance student and teacher learning. For example, as the CMP authors interacted with the field with the print curriculum, their knowledge of student understandings and teacher needs grew. Many of these new learnings found their way into problem tasks. In some cases, the tasks became longer and more nuanced. As an example, the following is a version of a problem from the *Accentuate the Negative* unit on addition of integers in CMP2 and CMP3 (see Figure 2).

Developing an Algorithm for Addition of Rational Numbers

Problem 2.1 from CMP2



Use chip models or number line models.

A. **1.** Find the sums in each group.
2. Describe what the examples in each group have in common.
3. Use your answer to part (2) to write two problems for each group.
4. Describe an algorithm for adding integers in each group.

Group 1	Group 2
${}^{+}2 + {}^{+}8$	${}^{+}8 + {}^{-}12$
${}^{-}3 + {}^{-}8$	${}^{-}3 + {}^{+}2$
${}^{+}20 + {}^{+}25$	${}^{+}14 + {}^{-}23$
${}^{-}24 + {}^{-}12$	${}^{-}11 + {}^{+}13$

B. Write each number as a sum of integers in three different ways.
1. ${}^{-}5$ **2.** ${}^{+}15$ **3.** 0
4. Check to see whether your strategy for addition of integers works on these rational number problems.
a. ${}^{-}1 + {}^{+}9$ **b.** ${}^{-}1\frac{1}{2} + {}^{-}\frac{3}{4}$ **c.** ${}^{+}1\frac{1}{2} + {}^{-}2\frac{3}{4}$

C. Write a story to match each number sentence. Find the solutions.
1. ${}^{+}50 + {}^{-}65 = \blacksquare$ **2.** ${}^{-}15 + \blacksquare = {}^{-}25$ **3.** ${}^{-}300 + {}^{-}250 = \blacksquare$

D. Find both sums in parts (1) and (2). What do you notice?
1. ${}^{+}12 + {}^{-}35$ ${}^{-}35 + {}^{+}12$ **2.** ${}^{-}7\frac{2}{3} + {}^{-}1\frac{1}{6}$ ${}^{-}1\frac{1}{6} + {}^{-}7\frac{2}{3}$
3. The property of rational numbers that you have observed is called the **Commutative Property** of addition. What do you think the Commutative Property says about addition of rational numbers?

ACE Homework starts on page 32.

Problem 2.1 from CMP3

A. Use chip boards or number line models to solve these problems.

1. Find the sums in each group.

Group 1	Group 2
${}^{+}2 + {}^{+}8$	${}^{+}2 + {}^{-}8$
${}^{-}2 + {}^{-}8$	${}^{-}2 + {}^{+}8$
${}^{+}8 + {}^{+}12$	${}^{+}8 + {}^{-}12$
${}^{-}8 + {}^{-}12$	${}^{-}8 + {}^{+}12$

2. What do the examples in each group have in common?
3. Write two new problems that belong to each group.
4. Describe an algorithm for adding the integers.

B. You know that $-5 + -3 = -8$. Use this information to help you solve the following related problems.
1. $-5\frac{1}{4} + -3$
2. $-5\frac{1}{5} + -3\frac{3}{5}$
3. $-5\frac{1}{3} + -3\frac{2}{3}$

C. You know that $-8 + 5 = -3$. Use this information to help you solve the following related problems.
1. $-8.35 + +5$
2. $-8.55 + +5.3$
3. $-8.65 + +5.25$
4. Does your algorithm for adding integers from Question A work with fractions and decimals? Explain.

D. For parts (1) – (3), decide whether or not the expressions are equal.
1. $-4 + +6$ and $+6 + -4$
2. $+2\frac{2}{3} + -5\frac{7}{8}$ and $-5\frac{7}{8} + +2\frac{2}{3}$
3. $-7\frac{2}{3} + -1\frac{1}{6}$ and $-1\frac{1}{6} + -7\frac{2}{3}$
4. The property of rational numbers that you have observed in these pairs of problems is called the Commutative Property of addition. Explain why addition is commutative. Give examples using number lines or chip boards.

E. 1. Find the sums in Group 3.
2. What do the examples in Group 3 have in common?
3. Write three new problems that belong to Group 3.

Group 3
${}^{-}5 + {}^{+}5$
${}^{+}9.4 + {}^{-}9.4$
${}^{+}2\frac{1}{4} + {}^{-}2\frac{1}{4}$

F. Write a story to match each number sentence. Find the solutions.
1. $-50 + -50 = \blacksquare$
2. $-15 + \blacksquare = +25$
3. $-300 + +250 = \blacksquare$

G. 1. Use properties of addition to find each value.
a. $+17 + -17 + -43$
b. $+47 + +62 + -47$
2. Luciana claims that if you add numbers with the same sign, the sum is always greater than each of the addends. Is she correct? Explain.

Figure 2: Evolution of a problem from CMP2 to CMP3 (Lappan, Fey, Fitzgerald, Friel, & Phillips, 2006; Lappan, Phillips, Fey, & Friel, 2014).

Transitioning to Digital Curriculum Materials

Building on prior research and development, the current NSF-funded projects explore two broad hypotheses about how a new technology environment can enhance student learning:

- Development and testing of a digital version of CMP will yield important insights into a variety of specific teaching and learning strategies made possible by technology rich educational environments.
- Use of curriculum materials delivered in a digital medium will produce significant improvement of student engagement and learning in diverse settings for middle grades mathematics instruction.

The purpose of one NSF project is to build collaborative and individual spaces on a digital platform to enhance student development, communication, and learning records of mathematics. The purpose of the second NSF project is to enhance student engagement and learning by redesigning problems and embedding them in the same digital platform.

Efforts to (re)design the mathematics problems in the digital curriculum focus on three aspects: (1) the Initial Challenge to contextualize and problematize the situation, (2) What If...? scenarios to surface the embedded mathematics of the problem, and (3) Now What Do You Know? to connect learning to prior and future knowledge. Additionally, the digital medium affords an opportunity for "just-in-time" supports that connect to each component. As shown in Figure 3, these aspects of the mathematics problem relate directly to the identified challenges described earlier.

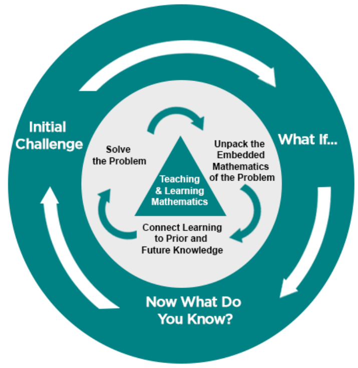


Figure 3: Redesigned problem structure and its connection to the task design challenges.

The new problem design format affords an environment that is visually less daunting with more succinct focus for students and teachers. For example, Table 1 shows the redesign of a problem on developing an algorithm for adding rational numbers that was discussed earlier (see Figure 2). The redesigned problem allows students to develop this algorithm efficiently as it builds on prior knowledge and experiences involving chip models and number lines. Through the problem and its three components, students can choose a model to help solve the problem or another approach such as a numeric strategy. This differs from the print material that directs learners by suggesting particular pathways for developing an algorithm, imposing a particular model, and finding specific sums of two numbers.

The "just-in-time" supports are provided to support students in their problem-solving pathways. Drawing on the affordances of learner-controlled scaffolding for inquiry-oriented mathematics classrooms (Edson, 2017), "just-in-time" supports or prompts are provided by curriculum authors and teachers that can help students solve an immediate difficulty, gain new knowledge, insight, or skill, or recall something that has been learned and forgotten. The premise of the prompt supports in a problem-centered environment is that if the students struggled unproductively in getting started in an open problem, they maintained ownership of the learning by using the supports without teacher intervention (Edson, 2016). In addition, empirical research has shown that students used the prompts as a mechanism to assess their group discussions or solution strategies without confirming their final answers with an external authority (Edson, 2016). Examples of "just-in-time" supports for Problem 1.3 are shown in Table 1.

Initial Challenge	*What If…?*	*Now What Do You Know?*
How can you predict whether the sum of two rational numbers is 0, positive, or negative?	What if you changed the order of the two numbers you are adding. Will this affect your answer? Explain. What if you have more than two addends?	What is an algorithm for adding rational numbers? How does this compare to your algorithm for adding whole numbers?

Just-in-Time Supports	Just-in-Time Supports	Just-in-Time Supports
• How could you model the example you have? Would a chip model be helpful? How would you use a number line to model your example? • Have you tried adding two positive numbers? Two negative numbers? One positive and one negative? Do you have a record of the examples you have tried? • [Teacher generated option]	• Study the patterns in the examples you recorded. • What patterns will help you add two numbers with the same sign? • What patterns help you add two numbers with different signs?" • [Teacher generated option]	• What is an algorithm for adding two numbers with the same sign? • What is an algorithm for adding two numbers with different signs? • [Teacher generated option]

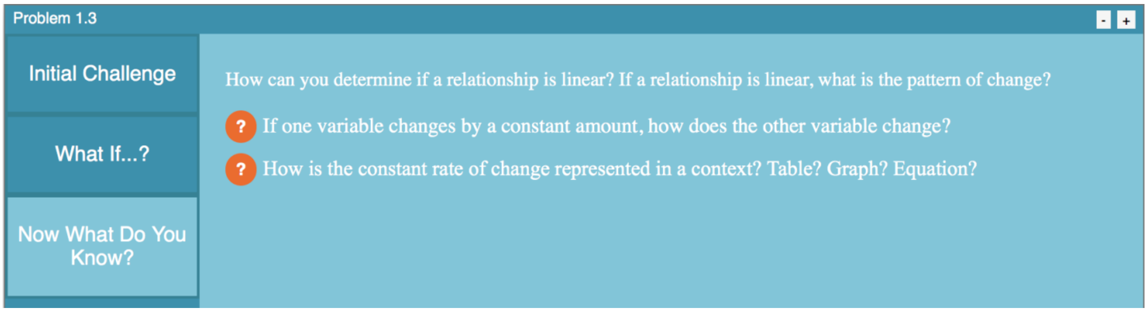
Table 1: Redesign of Problem 2.1 of Accentuate the Negative.

In the digital medium, the problem appears differently than on print. Figure 4 shows the Initial Challenge for Problem 1.3 of the *Moving Straight Ahead* unit as seen on the digital platform. Here, students navigate through each component of the new design.

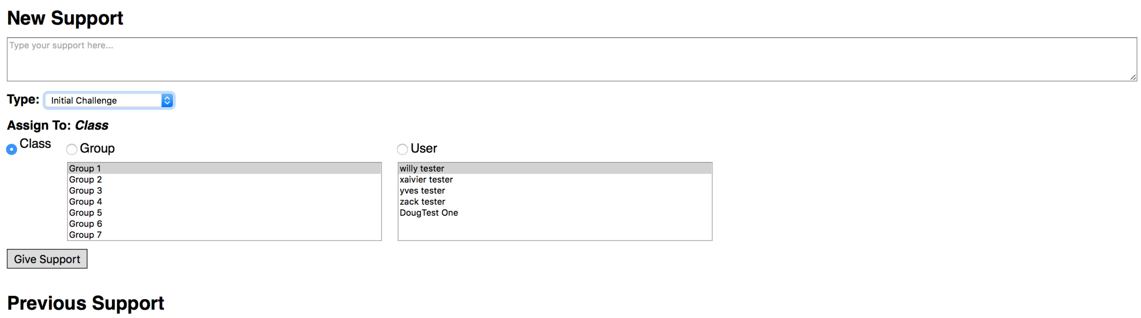
Figure 4: The Initial Challenge of a problem from the *Moving Straight Ahead* unit.

Student selected supports would be immediately available to each and every student and their groups as they explore problems. Students could select supports by clicking on buttons to reveal the prompts. The teachers could modify or create new supports. Another option is that teachers can generate and/or release prompts. While planning or enacting problems, teachers can assess the needs of their students, and release prompts to the entire class, select groups of students, or individuals. Not all students would access these supports unless the teacher released them.

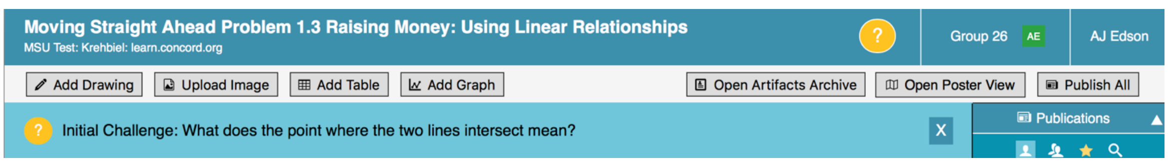
For example, Figure 5 shows the student-selected supports (in orange) and the teacher-released supports (in yellow) when they have been activated by students in the digital medium. Also shown in Figure 5 is how the teacher can write the prompts and release the prompts to students. Note that teachers are notified when students activate the teacher-released supports.



a. Activated student-selected supports on the student digital platform.



b. Teacher space for generating teacher-released supports on the teacher digital platform.



c. Activated teacher-released support on the student digital platform.

Figure 5: Example of student-selected supports and teacher-released supports for Problem 1.3 of the *Moving Straight Ahead* unit.

Figure 6 shows a screenshot of the platform for a student with individual and collaborative spaces: Figure 4 is embedded in the upper left-hand corner, collaborative drawing, table, and graph tools are in the middle and the column to the right allows students to share their work with other students and the teacher.

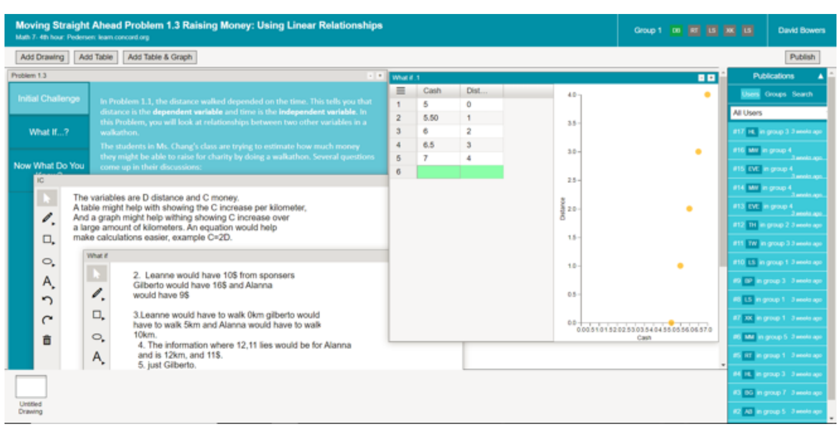


Figure 6: Sample student screenshot for Pb 1.3 of the *Moving Straight Ahead* unit.

CONCLUSION: NEW DESIGN CONSIDERATIONS

The design considerations that exist for print curriculum are still relevant for digital curriculum. These include: (a) identifying the important ideas and their related concepts and procedures; (b) designing a sequence of tasks to develop understanding of the idea; (c) organizing the sequences into coherent, connected curriculum; (d) balancing open and closed tasks; making effective transitions among representations and generalizations; (e) addressing student difficulties and ill-formed conceptions; (f) deciding when to go for closure of an idea or algorithm; (g) staying with an idea long enough for long-term retention; (h) balancing skill and concept development; (i) determining the kinds of practice and reflection needed to ensure a desired degree of automaticity with algorithms and reasoning; (j) writing for both students and teachers; and (k) meeting the needs of diverse learners (Lappan & Phillips, 2009).

The move to a digital platform that incorporates collaborative and individual learning spaces is not without risk, especially when problems are redesigned. New questions on task design considerations arise for developing digital curriculum:

- Will the nuances of the understandings emerge so that students form solid conceptual and procedural foundations?
- Does the redesign depend on the location of the problem in the learning progression? How effective is it?
- How do the "just-in-time" supports vary within and across a sequence of problems? When are they needed? Who is using them? How often?
- How much and what kind of new teacher support is needed? How does the teacher customize the environment?
- Does the new digital environment promote learning? When? Under what settings?

Since we are working with a well-researched and widely implemented print curriculum, we are building on learning progressions and teacher supports that are effective across the middle school curriculum. This provides a basis for the research project to study how use of the redesigned problems and "just-in-time" supports in a digital platform can promote an inquiry-based classroom environment where students are engaged in making sense of mathematics.

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