Reconsidering two sigma EDM for the complete instructional system

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Carnegie Learning’s History

- Founded @ Carnegie Mellon University 20 years ago
- Pioneers in the personalized and adaptive learning market
  - Intelligent Tutoring System
  - MATHia (was Cognitive Tutor)
- Over 500,000 students/year
- Not just math: CS, World Languages, ELA
Guiding Principle

The more we understand about how students think and learn, the better we can help them think and learn.
Carnegie Learning Implementation
MATHia Approach

Active, Relevant and Adaptive

- Give students complex, real-world problems to solve
- Watch what students do as they solve them
- Provide feedback and opportunities to learn from errors

Mastery Learning

- Ensure students master prerequisites before moving on
MATHia Adaptation

vanLehn, 2006
Blended Learning in Schools
Bloom’s 2 Sigma Problem
the promise of intelligent tutoring systems

Bloom, 1984
Mastery based on knowledge components

The Appalachian Trail is a 2,155-mile hiking trail in the Eastern United States. You plan to hike the section of the trail that is in New Jersey at a rate of 9 miles per day. If the hike will take you 8 days, what is the length of the trail in New Jersey?

Write a proportion to represent the problem.
Use a variable, such as $y$, to represent the unknown quantity.

- $\frac{\text{miles}}{\text{days}} = \frac{9}{8}$
Strong results

7 states
(AL, CT, KY, LA, MI, NJ, TX)

147 schools

18,000+ students

2 years
Data from second year

RAND/US Ed

- CONTROL
- .22

- CARNEGIE LEARNING ALGEBRA I
- .42

- CARNEGIE LEARNING ALGEBRA I HIGHER COMPLETION*
- .54

STANDARD DEVIATIONS
*Students completing more than 27 sections in Carnegie Learning Software
Most students become very similar with regard to learning ability, rate of learning and motivation for learning – when provided with favorable learning conditions.

Bloom, 1976
Unfavorable learning conditions

• Frustration
• Boredom
• Lack of motivation for further learning
• Low confidence
• **Failure to master**
  – Student does not master all skills within some number of problems (25 or so)

Beck and Gong, 2013
Slater and Baker, 2019
Remediate on failure model

- Analytics: Teacher remediates
- Design: Software improves
Implementation Analytics
Design adaptation

Aleven et al, 2017
Strong AI
Data-driven improvements

• 2019 Data
  – 4.4 million hours
  – 7.1 million workspaces
  – 63 million problems
  – 1.1 billion transactions
But there’s another way
Teacher attention is poorly allocated

80% of students never use TDC

1% of students use 42% of TDC time

Fancsali, et al. EDM 2018
Information v. Affirmation

- Information video
- Affirmation video
Information v. Affirmation

- **Tutor** Hi. How can I help you today?
- **Student**: hello I am stuck on a problem I will load it so you can see
- **Student**: I just need to know how to type the expression in the answer box
- **Tutor**: Okay, you need plug 4.2 in 1/2h(6+4)
  - 4.2 is height right?
- **Student** yes i'm going to try it
- **Student** 4.2 goes where
- **Tutor** in h. since 4.2 is height
- **Student**: would it been in ()
- **Tutor** it will be 21
  - 1/2(4.2)(6+4) =21
- **Student**: ok got cha
- **Tutor**: so, that is it.

- **Tutor**: hi! what can I help you with today?
- **Student**: Do you know how to do a factor table?
- **Tutor**: Hmm I am familiar with it. Is there a problem that you wanted to go over, that you could write on the board for us?
- **Student**: This looks like an easy one, but I am not sure so I just want to make sure I understand this correctly
- **Student**: To check this table is all you do multiply the top row by the 7x and see if it matches the bottom row? Is this right?
- **Tutor**: Yeah everything looks good to me. Great job!
- **Student**: I was hoping that I did this right.
Favorable learning conditions

• Acknowledges strengths of different instructional models

• Goals
  – Improve communication between teacher and software
  – Optimize teacher time
Different use cases require different analyses
Design Adaptation Solution

Improve knowledge component model
Learning curve

Cen, Koedinger, Junker, 2006
Splitting knowledge components
Putting the teacher in the loop

Dillenbourg, 2013
vanLehn et al., 2016
Olson, 2017
Holstein, Aleven, McLaren, 2018
LiveLab

- Informs teachers in real time about which students are struggling
- Early identification of students who are unlikely to master
- Teachers take ownership of the software
  - Mark as helped
Piecewise Functions

You purchase your first cell phone. You are very excited because the phone case is covered with sparkly bling. Your parents agreed to pay for the monthly service plan and your data plan. You have to earn the money to pay for texting each month.

- The first 50 texts each month are free.
- Any texts over 50 cost $0.02 each.

Let \( t \) represent the number of texts sent per month.
Let \( c(t) \) represent the monthly cost for texts.

Define each piece of the function. Then, graph the function.

\[ c(t) = \begin{cases} \text{ } & \text{if } \text{ } \\
\text{ } & \text{if } \text{ } \end{cases} \]

Use the piecewise function to answer each question.

1. How much will it cost to send 42 texts in a month?
   Select the statement that best describes the solution.

2. If you paid $1.7 in one month for your texts, how many texts did you send?
   Select the statement that best describes the solution.

Monthly Cost dollars

0 10 20 30 40 50 60 70 80

Graph

Problem: pfff2-073  Client Version: 3.3.40  Server Version: 3.3.40 © 2018 Carnegie Learning
Piecewise Functions

- 2892 students
- 82.3% master
- Problem variety
  - 2 or 3 pieces
  - Function can be
    - $f(x) = c$
    - $f(x) = ax$
    - $f(x) = a(x-b)$
Criticality

• The extent to the knowledge component is the determining factor in mastery
  – For students who master: percent of students who master the KC in the last problem
  – For students who do not master: percent of students who do not master the KC
Most Critical KC

You purchase your first cell phone. You are very excited because the phone case is covered with sparkly bling. Your parents agreed to pay for the monthly service plan and your data plan. You have to earn the money to pay for texting each month.

- The first 50 texts each month are free.
- Any texts over 50 cost $0.02 each.

Let \( c(t) \) represent the number of texts per month.

1. Define piece using more complex variable expression.

Use the piecewise function to answer each question.

1. How much will it cost to send 42 texts in a month?

Select the statement that best describes the solution.

- The solution is a single value.

Select the piece of the piecewise function that is used to determine the solution.

\[ c(t) = \begin{cases} 0 & \text{if } 0 \leq t \leq 50 \\ 0.02(t - 50) & \text{if } t > 50 \end{cases} \]

Enter the cost to send 42 texts in a month.

- $0.94

2. If you paid $1.77 in one month for your texts, how many texts did you send?

Select the statement that best describes the solution.

- The solution is a single value.

Select the piece of the piecewise function that is used to determine the solution.

\[ c = 0.02(t - 50) \text{ if } t > 50 \]
Learning curve – critical KC
Segmented Learning Curve – critical KC

Murray et al., 2013
Indicator

• Indicator knowledge component: KC that provides the earliest reliable warning that a student might fail to master

• Best indicators
  – Strongly discriminate between mastering and non-mastering students
  – Discriminate early
Critical and indicator KCs

- Critical for 67.2% of students
- 12.7% of students who fail to master workspace master this KC

- Critical for 18.1% of students
- 91% of students who fail to master workspace master this KC
Indicator KC

You purchase a phone case for the monthly money to pay.

- The first text.
- Any text.
- Let $t$ represent.
- Let $c(t)$ represent the monthly cost for texts.

**Graph**

Monthly Cost

Number of Texts per Month

- $c = 0$ if $0 \leq t \leq 50$
- $c = 0.02(t - 50)$ if $t > 50$

**Questions**

1. How much will it cost to send 42 texts in a month?

Select the statement that best describes the solution.

- The solution is a single value.

Select the piece of the piecewise function that is used to determine the solution.

Select the statement that best describes the solution.
Completing the system
Different models for different students
EDM supporting favorable learning conditions

**Design Adaptations**
- Focus: Improvements that affect the largest number of students
- Timeframe: long

**Learning Analytics**
- Focus: Optimizing planning time, institutional decisions
- Timeframe: Medium

**Teacher-in-the-loop orchestration**
- Focus: Optimizing in-class teacher time
- Timeframe: short
Conclusion

• What makes a good teacher-in-the-loop intervention?
  – Applies to a subset of students
  – Represents a fundamental misconception or knowledge gap that teacher can address
  – Can be easily understood by teacher
    • And informs software
  – Can apply infrequently
    • Don’t overload the teacher