THE EFFECTS OF VISUAL REPRESENTATIONS AND INTEREST-BASED PERSONALIZATION ON SOLVING PERCENT PROBLEMS

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Visual representations like illustrations and diagrams, as well as story contexts personalized to interests, may be important supports as students confront challenging mathematical topics. We presented 139 seventh grade students with problem sets on percentages that varied both personalization and visuals. Diagrams helped performance, while illustrations were helpful when used without other supports. Personalized contexts were helpful for the students who had mixed attitudes towards mathematics. This research highlights the importance of considering problem and student characteristics together when making instructional recommendations.

Keywords: Curriculum; Middle School Education; Affect, Emotion, Beliefs, and Attitudes

Theoretical Framework and Literature Review

Mathematics story problems are sometimes considered notoriously difficult to solve (Cummins et al., 1988). However recent work has demonstrated that the verbal language of problems, as well as their situated contexts, can enhance students' ability to access and apply mathematical ideas. Koedinger and Nathan (2004) found that the verbal contexts of algebra story problems and word equations facilitated problem-solving accuracy relative to symbolic problems, while Walkington (in press) found that students solve problems personalized to their out-of-school interests quicker and more accurately. Other research suggests personalization may be effective for students with lower achievement levels (Anand & Ross, 1987).

Complementary research has pointed to the importance of visual representations like diagrams and illustrations for supporting students in solving word problems (McNeil et al., 2009). Research on the *multimedia effect* has found that relevant visual representations that accompany text can increase learning (Mayer, 2005). Cognitive processing capacity, the learner's prior knowledge, and problem difficulty are important determinants of this effect (Kalyuga et al., 1998). Authors (date) found that the effect of diagrams interacts with the effect of illustrations, in addition to depending on student background characteristics.

Supports like visuals and personalized contexts may provide a means to *ground* mathematical formalisms in students' prior knowledge (Goldstone & Son, 2005) and elicit *interest* – the psychological state of engaging (Hidi & Renninger, 2006). However, research on cognition also suggests reasons why these supports may not be helpful. Cognitive load theory (Sweller et al., 1998) posits that elements that add *extraneous cognitive load* – mental effort stemming from activities not related to learning – may decrease performance by monopolizing available resources. Mayer's *theory of multimedia learning* also accentuates a limited capacity for processing information and the presence of separate visual and verbal pathways (Mayer, 2005).

We examine the combined effects of visuals and personalization on solving percentage problems. Percentages have applications in everyday life, making them a natural site for personalization, and their part-whole relationships afford diagrams. Our research questions are:

1) What is the impact of personalization and visual representations (diagrams, illustrations) on students' accuracy when solving percentage story problems?

2) How do these trends change when taking into account students' affect for mathematics and their perception of their knowledge of mathematics?

Method

Seventh grade students (N = 139, 60 female) at a suburban Southern middle school participated in the study. The composition of students at the school was 46% Caucasian, 30% Asian, 11% Hispanic, 11% African American, and 2% other racial/ethnic backgrounds, with 12% eligible for free/reduced lunch and 3% classified as Limited English Proficient.

Prior to the study, students rated their interest in 9 topics (sports, music, movies, games, TV, shopping, food, cell phones, and computers). Students also indicated subtopics were interesting to them (e.g., sports subtopics included soccer, swimming and track). We then selected 8 problems on percentages from a worksheet the teachers at the school planned to use (Table 1). Seven personalized versions were developed for each problem, based on the most popular sub-topic. We kept Flesh-Kinkaid readability and order of information consistent, as well as all numbers (Table 2). Of the 8 randomly-ordered problems each student received, 4 were personalized. Problems also had varied visual representations (Table 3). Additionally, a 12-item questionnaire that assessed mathematics attitudes. A factor analysis (Principal Axis Factoring) revealed 3 factors – students' *knowledge* about mathematics (e.g., "I find math confusing"), *value* for mathematics (e.g., "Math is important in everyday life"), and *affect* for mathematics (e.g., "I find many math problems interesting"). Value was not significant in any of the models.

Table 1: Normal versions of percent problems

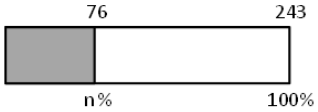
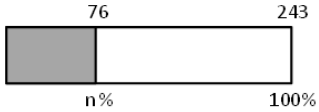
Structure	Set 1	Set 2
A	A Southwest Airlines passenger plane can seat 98 passengers. On the Monday flight there were 63 passengers. What percent of seats on the plane have passengers in them?	Kris worked a total of 243 days last year. His work required that he travel out of town on 76 of those days. What percent of the time did Kris's job require him to travel and be out of his office?
B	The Pelican's Club printed color fliers for an upcoming event. They prepared 1468 fliers to distribute. 1282 fliers were passed out. What percent of the fliers are left over?	Mr. Carney is a handyman. He had a total of 130 jobs last month where he either replaced a door handle or installed a sink. Last month, he installed 77 sinks. What percent of his jobs last month involved replacing door handles?
C	Shawn has been shopping for a new office chair. The retail price for the office chair that Shawn likes is $254. On Friday the chair will go on sale for 20% off of the price. How much will Shawn pay for the office chair if he purchases it on Friday with the sale (excluding tax)?	Joey works for an accounting and tax company. The company usually charges their customers $618 per job. However, the company is having a special where all jobs are 30% off currently. What is their discounted charge for a customer who hires them (without tax)?
D	Rene is going to volunteer her time at the local library. She will spend 15% of her volunteer time shelving books. If she has committed to work at the library for 48 hours, how many hours will she spend shelving books?	Last week, Holly worked 68 hours at her office. 70% of that time was spent writing a software instruction manual. How many hours did she spend writing the manual?

Table 2: Examples of personalized versions of a problem

Original	Southwest Airlines passenger plane has a capacity of 98 passengers. On the Monday flight there were 63 passengers. What percent of seats on the plane have passengers in them?
Adventure Games	In your favorite strategy game on the PlayStation, you need to gather 98 gold coins to gain a level. You have currently gathered 63 coins. What percent of the coins have you gathered?
Texting	You have sent 98 text messages on your phone so far today. You notice that 63 of the messages have been to your best friend. What percent of the messages were sent to your

	best friend?

Table 3: Variations in visual representations

	No Illustration	Illustration
No Diagram	Kris worked 243 days last year. His work required that he travel 76 of those days. What percent of the time was Kris out of his office?	Kris worked 243 days last year. His work required that he travel 76 of those days. What percent of the time was Kris out of his office? 
Diagram	Kris worked 243 days last year. His work required that he travel 76 of those days. What percent of the time was Kris out of his office? 	Kris worked 243 days last year. His work required that he travel 76 of those days. What percent of the time was Kris out of his office?  

Students solved the problem set during their normal math class; responses were coded for accuracy. Data were analyzed using mixed-effect logistic regression models (Snijders & Bosker, 1999). The dependent measure was whether the student got the problem correct or incorrect, and predictors included presence of personalization, diagram, and illustration. Random intercepts controlled for problem structure. Students were categorized as high or low on each construct from the attitudes questionnaire.

Results

Did personalization and visual representations influence accuracy?

While the main effects of diagram and illustration were not significant (*ps* > .1), the interaction of diagram by illustration was significant, $\chi^2(2) = 6.82$, $p = .033$. Diagrams were superior to text alone ($p = .007$), illustrations were marginally better than text alone ($p = .06$), and the diagram by illustration interaction ($p = .034$) indicated that the combined presence of diagrams and illustrations was equivalent to text alone. For the sample as a whole, the effect of personalization was not significant and did not interact with either visual condition (*p*s > .1).

Did these trends change when taking into account affect and knowledge for mathematics?

Students were classified into 4 groups based on their ratings of knowledge of and affect towards mathematics on their questionnaire: High Affect and High Knowledge (HAHK), High Affect and Low Knowledge (HALK), Low Affect and High Knowledge (LAHK), and Low Affect and Low Knowledge (LALK). Overall accuracy was highest for HAHK students (M = 85%, SE = 5.4%) and lowest for LALK students (M = 74%, SE = 6.6%). For all students diagram presence significantly improved performance when there was no illustration, but had no effect when an illustration was present. The effects of illustration and personalization were more complex as there was a three-way interaction among personalization, illustration, and students' reported level of knowledge in mathematics, $\chi^2(4) = 10.28$, $p = .036$, as well as among personalization, illustration, and students' reported level of affect, $\chi^2(2) = 6.55$, $p = .038$.

For HAHK students, illustrations improved performance when there was no diagram and no personalization; performance was not otherwise affected by personalization. The performance of

LALK students was not affected by illustrations or personalization. For HALK and LAHK students, the general trend was for illustrations to be helpful when there was no personalization and no diagram. However, for HALK students, personalization combined with an illustration increased performance compared to personalization alone or an illustration alone. For LAHK students, personalization increased performance when there was no illustration (p = .008) but the combined effects of personalization and illustration reduced performance (p = .007).

Discussion and Significance

For seventh graders solving percent story problems, diagrams provided an important support. Decorative illustrations and personalization were supportive in more limited circumstances – their effects depended on other supports present and student background. The salience of decorative illustrations and personalized may overwhelm limited cognitive processing capacity when combined with another support. A key limitation of the analyses is that the data set was relatively small for the complexity of these patterns, and limited to only 7th grade students solving one problem type. Ultimately either a larger data set, or a data set with more varied performance, would be needed to establish specific trends. However, some of the broader patterns from the data suggest important implications. First, when students are struggling, relatively superficial modifications like personalization or illustrations may not help them engage with the mathematics - only diagrams assisted LALK students. Second, purely decorative illustrations can help performance, challenging research suggesting that seductive details of illustrations increase cognitive load. Our data cautions against adding other potentially-distracting supports when illustrations are present, however. We conclude that the scaffolding effects of different supports are not necessarily additive, and may interact in complex ways.

Students need a variety of supports to access mathematical ideas in the middle grades curriculum. Scaffolds like illustrations and personalized contexts have the potential to ground ideas and elicit interest; but we also need to be aware of some caveats when using these scaffolds. This study broadens current perspectives on mathematical learning by investigating some factors that mediate the effectiveness of these supports. Being aware of students' backgrounds and current mathematical understanding, as well as the trade-offs of different supports, is important for both curriculum design and in-the-moment instructional decisions.

References

Anand, P., & Ross, S. (1987). Using computer-assisted instruction to personalize arithmetic materials for elementary school children. *Journal of Educational Psychology*, *79*(1), 72-78.

Cooper et al (ADD)

Cummins, D. D., Kintsch,W., Reusser, K., & Weimer, R. (1988). The role of understanding in solving word problems. *Cognitive Psychology*, *20*, 405–438.

Goldstone, R. L., & Son, J. Y. (2005). The transfer of scientific principles using concrete and idealized simulations. *Journal of the Learning Sciences, 14*, 69-114.

Hidi, S., & Renninger, K. (2006). The four-phase model of interest development. *Educational Psychologist, 41*(2), 111-127.

Kalyuga, S., Chandler, P., & Sweller, J. (1998). Levels of expertise and instructional design. *Human Factors,40*(1), 1 – 17.

Koedinger, K., & Nathan, M. (2004). The real story behind story problems: Effects of representations on quantitative reasoning. *Journal of the Learning Sciences*, *13*(2), 129-164.

Mayer, R.E. (2005). Cognitive theory of multimedia learning. In R. E. Mayer (Ed.), *The Cambridge Handbook of Multimedia Learning*. New York, NY: Cambridge University Press, 31 – 48.

McNeil, N. M., Uttal, D. H., Jarvin, L., & Sternberg, R. J. (2009). Should you show me the money? Concrete objects both hurt and help performance on mathematics problems. *Learning and Instruction, 19*, 171-184.

Snijders, T. & Bosker, R. (1999). *Multilevel Analysis: An Introduction to Basic and Advanced Multilevel Modeling*.

Sage Publications.
Sweller, J., Merrienboer, J., & Paas, F. (1998). Cognitive architecture and instructional design. *Educational Psychology Review*, *10*(3), 251-296.
Walkington (in press). ADD