Engagement Drives Learning Outcomes: Instructional Design Principles for K-12 Math Classrooms

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Introduction: Teaching in the Face of Disengagement

Our methods for teaching K-12 mathematics have changed considerably over the last hundred years, and yet, in some ways, the experience of studying mathematics has not changed much at all. Ideally, every learner would come to class excited about mathematics, ready to dive into rich and fulfilling concepts, but the reality is that some children are disengaged with mathematics and with school in general.

Some of this comes from a child's home experiences, where they may have heard a parent say, "I'm not a math person." A child may not understand why mathematics is important to their future and may not have learned to see the beauty in geometric patterns and algebraic relationships.

There is no single panacea. Disengagement cannot be eliminated through a single brilliant lecture. Educational games, while sometimes more engaging than traditional approaches, walk a fine line between engaging students and appearing to be a form of "chocolate-covered broccoli"—an unappealing but "good for you" lesson wrapped in something fun to cover up the taste. When done poorly, such an approach can actually encourage the idea that mathematics is unimportant and unappealing.

Teaching in the face of disengagement is hard. Fortunately, learning scientists and education researchers have discovered quite a bit about engagement and disengagement, particularly in recent years.

One important lesson is that not all disengagement is created equal. Different forms of disengagement may stem from the same root causes (although even that is not entirely clear!), but there is increasing evidence that the emotions students experience and the disengaged behaviors they display are associated with very different outcomes.

The Causes (and Benefits) of Off-Task Behavior

Off-task behavior is a form of disengagement, but it is not necessarily always bad. It is common for a student to stop working on mathematics and turn to his or her neighbor to discuss some subject of mutual interest (for my 8 year old daughter, that topic would be dinosaurs. Your students may differ). Teachers put a lot of energy into stopping off-task behavior. What's surprising, though, is that off-task behavior doesn't matter as much as many people think. Clearly, it's not good to spend an entire class period off-task, but students also occasionally need short breaks.

There have been hundreds of studies on off-task behavior and learning, and a clear consensus is emerging: In traditional classrooms, where students work alone, off-task behavior is associated with mildly poorer learning outcomes. In classrooms where students work collaboratively, there appears to be no relationship between off-task behavior and learning. The same pattern (no relationship between off-task behavior and learning) is seen in students using computer software to learn in class.

In fact, off-task behavior actually has some benefits. Karel Kreijns has found that it leads to better collaborative work by improving the relationships between students. (Kreijns, Karel 2004). Gregory Moore and his colleagues found that when a student is bored, briefly going off-task could refresh students and improve their emotional state—an improvement that they carry back to their work. (Moore et al. 2011).

This is important, because boredom is one of the more important forms of disengagement. A student who is bored but working does not seem as concerning as a student who is obviously not working. But in fact, boredom tends to prevent high-quality work and learning. Several studies, both in the lab and in real classrooms, have found that boredom is associated with diminished learning outcomes.

The High Price of Boredom and Carelessness

Zachary Pardos and his colleagues found that students who experience more boredom over the course of a year of middle school mathematics are likely to do more poorly on the standardized examination. (Pardos et al. 2014). These effects can persist over time as well. Maria San Pedro and her colleagues found evidence that students who experience more boredom over the course of a year of middle school mathematics are less likely to go to college. (San Pedro et al. 2013).

Boredom can have negative impacts in several ways: First, it is difficult for a student to move from boredom to more positive emotional states that are associated with better learning, such as engaged concentration or even confusion. Boredom tends to follow frustration. A student struggles and then gives up and becomes bored. My research group has found that it is relatively easy to disrupt a student's frustration, but that once students become bored, they tend to stay bored. When a student has given up, it is hard to recapture them. Ironically, the methods that can address boredom are taking a break or switching activities.

Another negative impact of boredom is that students who are bored tend to disengage. For example, my research group has found that many students who become bored using computer software in classrooms tend to then game the system, trying to complete mathematics problems by tricking the software into letting them move on without learning the material (for example, by systematically guessing or by over-using hint features).

This behavior is associated with poorer performance on unit tests (Cocea et al. 2009) and end of year tests (Fancsali, S. E. 2014), poorer performance on standardized examinations (Pardos et al. 2014), and a lower probability of college attendance (San Pedro et al. 2013). The relationship between gaming the system and learner outcomes is surprisingly strong. Several of these papers found it to be of equal strength or stronger than the relationship between cigarette smoking and lifespan!

My research group found that a big reason for this connection is that students game the system selectively. Many students repeatedly game the system to avoid the material with which they are least familiar, preventing them from learning that specific material and causing disproportionate impacts on their learning.

Carelessness is another highly problematic, disengaged behavior in mathematics learning. A student who makes careless errors is missing opportunities to learn. He or she may also appear to be less knowledgeable than they genuinely are. One surprising finding about carelessness (seen both by my research laboratory and by Ken Clements in Australia) is that careless students are generally highly knowledgeable students. However, these students often underperform relative to how much they know.

Zachary Pardos found that this underperformance extends to standardized examinations. Careless students perform considerably more poorly on standardized examinations than equally knowledgeable students who do not become careless. Maria San Pedro similarly found that careless students are less likely to go to college, possibly because their carelessness leads to lower grades on college entrance examinations. Carelessness can also be seen as the opposite of conscientiousness and self-discipline, which have been repeatedly shown to correlate to academic success, from K-12 through to higher education.

Instructional Design Principles for Addressing Disengagement

It is useful to know that emotions such as boredom and behaviors like gaming the system are associated with diminished learning outcomes. But an obvious question emerges as soon as we notice these results: "What can we do about it?"

Research into this question is ongoing. We haven't reached the final answer, in part because the world being studied is changing. Our pedagogical methods are changing, and the children we are teaching are changing. In her landmark book *Computers and Classroom Culture,* Janet Schofield noted that students using computer software for mathematics would come to class early, leave late, and sometimes stay through lunch, just to use the computer software for longer. (Schofield, J. W. 1995).

Today, computer software is not as exciting to students. Over the last fifteen years, I have spent several hundred hours watching children learn (my research lab and network of colleagues is well into the thousands of hours at this point). I have never seen a child stay through lunch to use computer mathematics software. My point is not to cast doubt on Professor Schofield's exemplary work; it is to note that children have changed over the last 25 years. When Professor Schofield was working in classrooms, mathematics learning software was novel and interesting. It isn't anymore.

As mentioned before, games can be fun. But they are not a magic bullet. Case in point: When Mercedes Rodrigo compared an award-winning game, *MathBlaster,* to a workbook-like personalized learning system covering the same mathematical topics, she found that students were more engaged in the workbook-like system and bored by the game. When games fail to engage students, they can fail strongly.

That said, personalized learning systems tend to engage students better than traditional lecture or individual work does. For example, Kevin Mulqueeny and his colleagues found that students using personalized learning for middle-school mathematics were bored almost a third less often than students using traditional curricula. (Mulqueeny et al. 2015). This is because personalized learning is more interactive: Students are continually engaged in activities with a system that responds to them.

Perhaps even more importantly, personalized learning systems change classroom culture. As first noted in Janet Schofield's work (but repeatedly replicated over the years, including by my research group), teachers using learning software must switch from lecturing to working one-on-one with students. This is more engaging to students, and it's better for their learning, too.

Even better results can be obtained when students use learning software that explicitly considers and empowers the teacher. When teachers get analytics reports on student performance and success, they can use this information in what Neal Miller and his colleagues term proactive remediation. In other words, when a teacher determines that a student is struggling, he or she can intervene before the student gives up and becomes bored.

Teachers can also support students who are becoming bored and disengaged in other fashions. The evidence that boredom may be disrupted by off-task behavior presents an opportunity that educators can leverage. While it may not be feasible or even desirable to encourage students to go off-task, it may be possible to re-direct students to other learning activities in order to re-engage them. If many members of a class are becoming bored, a new class activity can be chosen. If only a small number of students are becoming bored, they can be redirected to different activities. This is particularly easy to achieve in classes using personalized learning software, where the remainder of the class can continue to make progress within the software.

Redirection as an intervention not only addresses boredom, it is directly linked to improved learning. Shimin Kai and Mia Almeda researched the differences between middle school students who persist productively in learning mathematics versus students who persist but do not learn successfully. They found that one of the biggest factors separating these two groups of students was whether their teacher assigned them to work on multiple topics or on a single topic until they mastered it. Switching between topics made it much more likely that the student's persistence would lead to success.

Addressing students who are gaming the system can be done in many ways. Perhaps the best approach was conceived by Ivon Arroyo and her colleagues who found that explaining to students why gaming the system leads to poorer learning outcomes reduces how often they game the system and improves their learning. Another approach, which I'm embarrassed to say that I studied as a graduate student a dozen years ago, is to give students more mathematics problems to complete if they gamed. You would then explain that they would have to keep completing problems until they stopped gaming. This reduced gaming and improved learning… but students hated it. In general, solutions that substitute one form of negative emotion for another type of negative emotion are probably not desirable. Hopefully, I have learned a few things since then.

Addressing carelessness has been less thoroughly studied in itself. However, as mentioned earlier, carelessness is associated with the broader concepts of conscientiousness and self-discipline. Although conscientiousness has often been treated as a stable, long-term personality trait, other work argues that people (including young children) can learn self-discipline and how to behave in a more conscientious fashion.

Adele Diamond and her colleagues find evidence that curricula that teach students self-disciplined behaviors can lead to better outcomes for students, even as early as in preschool. (Diamond et al. 2007). Darshanand Ramdass and Barry Zimmerman find that teachers can help students learn self-discipline in the context of homework activities by having students log their homework activities and then reviewing students' homework habits with them. (Ramdass, D., & Zimmerman, B. J. 2011).

A fuller review of some of the approaches for teaching self-discipline and self-control strategies to children can be found in Angela Duckworth and Stephanie Carlson's article *"Self-regulation and School Success."* (Duckworth, A. L., & Carlson, S. M. 2013). One common finding across this research is that relatively simple interventions, such as telling students to check their work, are less effective than more comprehensive approaches where the student is guided by the teacher through more complex practices of understanding and learning to regulate their behaviors.

Summary

In this article, I have reviewed some of the recent scientific findings on engagement and learning in the classroom. I discuss how both emotional engagement and behavioral engagement are associated with diminished learning and poorer student outcomes. However, not all disengagement is equal in its impact. Gaming the system, carelessness, and boredom have substantially stronger relationships with student outcomes than off-task behavior, for example. Fortunately, disengagement can be addressed. Although considerable research is still needed on how to best support all students in surpassing disengagement in mathematics, several approaches have been successful at re-engaging students and helping them learn the self-discipline necessary to avoid disengagement and succeed at learning.

References

Arroyo, I., Ferguson, K., Johns, J., Dragon, T., Meheranian, H., Fisher, D., & Woolf, B. P. (2007). Repairing disengagement with non-invasive interventions. *Proceedings of the International Conference on Artificial Intelligence and Education,* 195-202.

Baker, R.S., Corbett, A.T., Koedinger, K.R., Wagner, A.Z. (2004) Off-Task Behavior in the Cognitive Tutor Classroom: When Students "Game The System". *Proceedings of ACM CHI 2004: Computer-Human Interaction,* 383-390.

Baker, R.S.J.d., D'Mello, S.K., Rodrigo, M.M.T., Graesser, A.C. (2010) Better to Be Frustrated Than Bored: The Incidence, Persistence, and Impact of Learners' Cognitive-Affective States During Interactions with Three Different Computer-Based Learning Environments. *International Journal of Human-Computer Studies,* 68 (4), 223-241.

Baker, R.S.J.d., Moore, G., Wagner, A., Kalka, J., Karabinos, M., Ashe, C., Yaron, D. (2011) The Dynamics Between Student Affect and Behavior Occuring Outside of Educational Software. *Proceedings of the 4th bi-annual International Conference on Affective Computing and Intelligent Interaction.*

Baker, R.S.J.d., Corbett, A.T., Roll, I., Koedinger, K.R. (2008) Developing a Generalizable Detector of When Students Game the System. *User Modeling and User-Adapted Interaction,* 18, 3, 287-314.

References (continued)

Bruckman, A. Can Educational Be Fun? Keynote, Game Developer's Conference, (1999).

Clements, M. A. (1982). Careless errors made by sixth-grade children on written mathematical tasks. *Journal for Research in Mathematics Education,* 136-144.

Cocea, M., Hershkovitz, A., Baker, R.S.J.d. (2009) The Impact of Off-task and Gaming Behaviors on Learning: Immediate or Aggregate? *Proceedings of the 14th International Conference on Artificial Intelligence in Education,* 507-514.

Diamond, A., Barnett, W. S., Thomas, J., & Munro, S. (2007). Preschool program improves cognitive control. *Science,* 318(5855), 1387.

Duckworth, A. L., & Carlson, S. M. (2013). Self-regulation and school success. *Self-regulation and autonomy: Social and developmental dimensions of human conduct, 40*, 208.

Fancsali, S. E. (2014) Causal Discovery with Models: Behavior, Affect, and Learning in Cognitive Tutor Algebra. *Proceedings of the International Conference on Educational Data Mining.*

Kai, S., Almeda, M.V., Baker, R.S., Shechtman, N., Heffernan, C., Heffernan, N. (under review) Modeling wheel-spinning and productive persistence in Skill Builders. Manuscript under review.

Kreijns, K. (2004). Sociable CSCL environments. Social affordances, sociability, and social presence. Unpublished Masters Thesis, Open University of the Netherlands.

Miller, W.L., Baker, R., Labrum, M., Petsche, K., Liu, Y-H., Wagner, A. (2015) Automated Detection of Proactive Remediation by Teachers in Reasoning Mind Classrooms. *Proceedings of the 5th International Learning Analytics and Knowledge Conference,* 290-294.

Mulqueeny, K., Kostyuk, V., Baker, R.S., Ocumpaugh, J. (2015) Incorporating Effective e-Learning Principles to Improve Student Engagement in Middle-School Mathematics. *International Journal of STEM Education,* 2 (15).

Pardos, Z.A., Baker, R.S., San Pedro, M.O.C.Z., Gowda, S.M., Gowda, S.M. (2014) Affective states and state tests: Investigating how affect and engagement during the school year predict end of year learning outcomes. *Journal of Learning Analytics,* 1 (1), 107-128.

Ramdass, D., & Zimmerman, B. J. (2011). Developing self-regulation skills: The important role of homework. *Journal of advanced academics,* 22(2), 194-218.

Rodrigo, M.M.T., Baker, R.S.J.d. (2011) Comparing Learners' Affect While Using an Intelligent Tutor and an Educational Game. *Research and Practice in Technology Enhanced Learning,* 6 (1), 43-66.

San Pedro, M.O.Z., Baker, R.S.J.d., Bowers, A.J., Heffernan, N.T. (2013) Predicting College Enrollment from Student Interaction with an Intelligent Tutoring System in Middle School. *Proceedings of the 6th International Conference on Educational Data Mining,* 177-184.

Schofield, J. W. (1995). *Computers and classroom culture*. Cambridge University Press.