Emporium Developmental Mathematics Instruction: Standing at the Threshold

By Zack Beamer

ABSTRACT: In the Emporium Model (EM), students work toward mastery thresholds using commercial instructional software in a computer lab staffed with instructors. This qualitative case study uses classroom observations and interviews to describe instruction and student behavior in EM classrooms for developmental mathematics at one college in the Virginia Community College System. Findings indicate that the effort to reach mastery thresholds may prompt approaches among faculty and students to either overcome limitations of instructional software or misuse aspects of its design. Mastery thresholds can become subject to interpretation, as faculty may give partial credit on certain errors in their efforts to get struggling students towards benchmark scores. Additionally, this study documents how some students may develop clever strategies to exploit features of instructional software programs. This study concludes with recommendations for practitioners teaching or considering EM for developmental mathematics instruction regarding the role of the instructor and the need to anticipate misuse.

Many students enter postsecondary education underprepared for college-level mathematics, and this problem is particularly acute at community colleges. According to the most recent data from the National Center for Education Statistics, 59% of students entering a public two-year college in the United States in 2003-04 enrolled in at least one remedial mathematics course (Chen, 2016), with "remedial" defined as a course offered by a postsecondary institution covering curricular content below college level. Only 45% of those who begin in remedial mathematics go on to earn college-level mathematics credits, and only 62% of students who complete remedial requirements eventually earn credits in college-level mathematics (Chen, 2016). In one study, nearly half of students failed to complete even the first course in their remedial sequence (Bailey, Jeong, & Cho, 2010).

The National Association for Developmental Education (NADE, now National Organization for Student Success) defines developmental education as "a comprehensive process that focuses on the intellectual, social, and emotional growth and development of all students" (NADE, 2019). Although institutions have varying criteria for classifying mathematics curricula as remedial or not, many have implemented major redesigns to the way they prepare their students for college-level mathematics (Bonham & Boylan, 2011). However, the realities of redesign do not always reflect the optimism of administrators seeking structural solutions to persistently poor pass rates and retention outcomes (Cafarella, 2016). This paper discusses the implementation of reforms to developmental mathematics based on the Emporium Model (EM; see Twigg, 2005, 2007, 2011) at one college in the Virginia Community College System (VCCS) and what this implementation reveals about the successes and challenges of EM-based reforms.

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The Emporium Model

The EM began at Virginia Polytechnic and State University in 1999 and expanded in phases, forming a model for 120 large-scale redesigns at two- and four-year colleges across the country by 2010; half of these redesigns were oriented toward reformatting instruction in quantitative coursework (Twigg, 2011). Through the advocacy of the nonprofit National Center for Academic Transformation (NCAT), headed by Dr. Carol Twigg, the most recent figures are that 195 EM-based redesigns are underway across the nation, with 80% already being implemented (NCAT, 2018). The NCAT identifies ten "essential elements" of the EM, noting that the absence of any one element threatens the likelihood for it to succeed:

- Element #1: Redesign the whole course sequence and establish greater course consistency.
- Element #2: Require active learning and ensure that students are "doing" math.
- Element #3: Hold class in a computer lab or computer classroom using commercial instructional software.
- Element #4: Modularize course materials and course structure.
- Element #5: Require mastery learning.
- Element #6: Build in ongoing assessment and prompt (automated) feedback.
- Element #7: Provide students with one-on-one, on-demand assistance from highly trained personnel.
- Element #8: Ensure sufficient time on task.

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- Element #9: Monitor student progress and intervene when necessary.
- Element #10: Measure learning, completion, and cost (NCAT, 2013, p. 1).

According to its advocates, these features together can improve student outcomes while reducing instructional costs (Twigg, 2007). The logic of this model is that the software (Element #3) provides a platform for active, mastery learning (Elements #2, 5, and 6), with instructors checking in to help ensure successful progress (Elements #7, 8, and 9). To achieve mastery, which the NCAT recommends setting between 75% and 90% (NCAT, 2013), students must complete a certain percentage on each quiz and section of homework covering a selection of procedures, concepts, and applications. The hope of this format is that students who might sit passively in a lecture and consequently get left behind would instead have opportunities for remediation though a "do-it-till-you-get-it right approach" (Twigg, 2005, p. 9).

Review of Literature

Studies of the EM have been conducted by the NCAT and independent researchers. Findings regarding student outcomes, however, vary.

Positive Findings

Research done by the NCAT (Twigg, 2005, 2007, 2011; 2013) has suggested that implementing the EM may result in improvements to remedial course pass rates. Other research replicated similar results (e.g., Foshee, Elliot, & Atkinson, 2016), with 75% of students of students at a large university meeting their remedial mathematics requirements through an EM-style instructional format. Foshee et al. also found, using a pretest-posttest design, statistically significant increases in academic competence of course material, as well as students' self-assessment of mathematical ability, reading skills, and critical thinking skills.

Mixed Findings

However, others, such as Webel, Krupa, and McManus (2017), have expressed some skepticism towards the broadly positive research findings on pass rates reported by the NCAT (Twigg, 2007). They noted that the NCAT excluded 8 of the 20 institutions from which data were gathered from their reported findings for unspecified reasons. Webel et al. also find that EM-based courses improved students' ability to remember and use formulas but had limited impact on students' ability to solve unfamiliar tasks. Other recent research reported that students in developmental mathematics programs based on similar computer-based mastery learning reforms continued to earn poor pass rates (Ariovich & Walker, 2014; Childers & Lu, 2017). In one such program, only 33% of students passed all their developmental requirements, and, even among those who did so, only 58% went on to pass college-level mathematics courses (Childers & Lu, 2017).

Qualitative research by Ariovich and Walker (2014), using student and faculty focus groups, has provided some insights into the opportunities and challenges posed by the new format. The authors reported that instructors found it challenging to navigate the new instructional role demanded by this format. Those interviewed also suggested that instruction done solely through the computer may not offer sufficient learning opportunities to improve college readiness; faculty saw a need to supplement instructional software with critical thinking activities or groupwork. Some students described a sense of empowerment by virtue of using the self-directed format, but many felt discomforted by the absence of a direct involvement with the instructor. Some students also struggled to see the relevance of the mastery-based format, viewing the course requirements as hurdles to their completion of the course. Even research that reported high course success rates from Foshee et al. (2016) also noted a statistically significant decrease in self-reported study skills and motivation after working in an EM format. Overall, the results of the EM have been mixed, which indicates the need to understand what elements may be unsuccessfully enacted during implementation, or whether there are additional elements beyond those stated by the NCAT that are critical for the success of such reforms.

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The Virginia Community College System and the Emporium Model

The Virginia Community College System (VCCS) instituted a package of reforms, including the EM, across system campuses (see Edgecombe, 2016). Following Elements 1 and 4, previously discussed, the VCCS reorganized developmental mathematics into nine modules, the MTE (Math Essentials) sequence, numbered 1 through 9. A new Virginia Placement Test (VPT) assessed students in two portions, one covering MTEs 1 – 5 (prealgebra and introductory algebra) and a second for MTEs 6 – 9 (intermediate algebra). Students who did not demonstrate proficiency on the first portion were subsequently diagnosed in detail on each of the first five modules. Similarly, students who did not demonstrate proficiency on the second portion were diagnosed on the content from modules 6 – 9. According to a VCCS report (2014), 34% of students satisfied all nine modules (eligible for precalculus), whereas another 11% satisfied modules 1 – 5 (eligible for general education transfer-level mathematics), and an additional 5% satisfied modules 1 – 3 (eligible for certain nontransfer credit-level courses). A detailed description of course prerequisites can be found in the VCCS course catalogue (VCCS, 2018).

Fully 50% of students taking the VPT did not meet at least module 1-3, were deemed "not college ready," and needed to enroll into at least one module before taking credit-level mathematics. For degree programs, at least one credit-level mathematics course is required. This figure may slightly understate the total developmental placement, as some students may be deemed ready for a transfer-level course but require additional developmental coursework before enrolling into a course with higher prerequisite mathematics skills such as precalculus. In early stages of implementation at the observed college, students enrolled in 5-week MTE courses, each course dedicated to the topics in one of the modules. By the final stage of implementation, students enrolled in MTT (Math Technology) courses, the technology-based versions of the MTE courses. Each course section was open to students regardless of the number of modules the students required. Students worked at their own pace, though successful completion of the course for financial aid purposes required students to finish at least one module per 5-week block; it was possible for students to work at a faster place and complete the courses in an accelerated time frame.

To successfully complete each one-credit module, students had to correctly complete a certain percentage on each homework assignment, quiz, and final exam. At the observed college, students first needed to earn 80% on homework sections, which would make them eligible to take a proctored quiz. Students were required to earn 80% on each of three quizzes and at least 75% on the posttest (final exam). For each of these, students were allowed two attempts; the consequences of failing both attempts are discussed in detail in the Findings section.

Research Questions

The initial goal of this research was to understand what was going on in these classrooms and whether this format of instruction delivered on the outcomes promised by the EM. That is, the purpose of this study was to unpack how students achieved "mastery." The author's original research interest was to explore interactions between faculty and students in these courses. However, following initial classroom observations it became apparent that much of the meaning making in the classroom was mediated

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through interactions with the instructional software and the course policies around mastery-based learning. This led to the following research questions:

1. How do students interact with the commercial instructional software and what do their interactions reveal about how they achieve mastery thresholds?
2. How do faculty and tutors interact with students in the EM and what role(s) does the instructional software play in this process?

Methodology

The research questions led to a qualitative research design. In order to investigate student and instructor interactions, social actions were studied.

Rationale for Qualitative Research Design and Paradigm Assumptions

Interpretive qualitative research is appropriate "when one needs to [know] more about… [t]he specific structure of occurrences rather than their general character and overall distribution" (Erickson, 1986, p. 121). This research aimed to form an in-depth understanding of human meaning-making processes as discussed in Merriam (2002). Some recent research on the EM (e.g., Taylor, 2008; Twigg, 2011) has largely emphasized impacts on pass rates or cost savings. Webel et al. (2017) noted the need for additional research to explore the character or quality of instruction in these EM-based classrooms. Whereas quantitative research is suited to exploring causal effects of treatment, qualitative case study methodology is appropriate to identify causal mechanisms (Gerring, 2004). In this case, the primary focus was to identify how students achieved mastery, or why they struggled to do so, and what role the faculty had in assisting students to reach mastery.

This research study followed an interpretivist paradigm, as presented in Erickson (1986), in which the central unit of study is social action, which includes behavior as well as a description of its meaning. This research presents the author's understanding of the local constructed realities of students and faculty in these classrooms. These paradigmatic assumptions are reflected in the author's conceptual framework informed by constructivist teaching philosophy and the belief that mathematics is a social endeavor with practices that reflect the values of its members. Following Schoenfeld (1992) and Garofalo (1989), this research acknowledged that student and faculty beliefs regarding the nature of mathematics impact classroom practices and that classroom practices lead to the formation of beliefs about the nature of mathematics. Consequently, the research questions reflected the author's interest in investigating how students interacted with faculty, tutors, and technology in these classrooms, and what the practices of individuals suggested about how they make sense of their activities.

Description of Site and Participants

The site for this present research study was a mid-sized community college in the VCCS. The site was chosen based on convenience and professional connections with practitioners at the college. The author contacted two adjunct faculty members, Arya and Eddard (all names are pseudonyms), to participate in this study via email. Both were willing, even eager, to allow classroom observations. Eddard had worked at the college for multiple years, first as a tutor in the mathematics tutoring center and in his second year as a developmental mathematics adjunct faculty member at the time of the study. Arya was also a developmental mathematics faculty member who was teaching her first semester at the college with several previous years of K-12 teaching experience. The developmental mathematics faculty possessed, at minimum, a bachelor's degree in mathematics.

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The minimum qualifications for embedded tutors was successful completion (a grade of B or better) of Precalculus I and II at the college or the equivalent. In addition to those observed, three full-time faculty participated in interviews: Robb, a developmental mathematics specialist with 5 years at the college; Catelyn, a development mathematics specialist and tutoring center coordinator for the past 4 years; and Sansa, a developmental and credit-level mathematics instructor with over a decade of teaching experience in the VCCS.

According to internal statistics reported by the institutional research department from Fall 2017, 78% of students at the college were part-time and 22% were enrolled full-time, the equivalent of approximately 3000 full-time students. Racial demographics at the college (69% white, 13% African-American, 7% Hispanic, 5% Asian, and 5% multiple race or other) were broadly reflective of the counties serviced by the college, with more female students (58%) than male (42%). The impact of individual student demographics on their classroom experience was not an explicit focus of the present research, so this data is not reported here.

Procedure

Data Collection

This study utilizes three forms of data collection: classroom observations, interviews, and document analysis. As Denzin and Lincoln (2011) discuss, multiple methods add richness and depth to qualitative inquiry.

Observations. The principle method of data collection in this study was 15 hours of classroom observations. The observed classes, which included students working on everything from fraction operations to quadratic equations, were taught in a computer lab for two, consecutive 75-minute class periods over six total class periods. The computer lab accommodates two course sections, each with about 15 students. Both faculty members and their students were observed. The author employed purposeful sampling to identify various ways that faculty and students interacted and ways that students utilized instructional software, which included observation of student's screens as they worked through computer-based assignments. During the first 10 hours of observation, the author maintained a detached role from students but engaged in informal conversion with faculty and tutors. These informal conversations clarified instructor understanding of course policy or their reflections on interactions with students. The final 5 hours of observations included direct interaction between the author and students, following Schoenfeld's (1992) notion of a "roving consultant," posing questions to students to get insights into the meaning of their actions.

Interviews. After gathering observational data, the author conducted five semistructured interviews, one with each of the five faculty members. These interviews each lasted between 30 minutes and 1 hour. These interviews focused on themes observed during data collection in the field, such as how faculty used the software, how they perceived students using the software, and what formal and informal policies they followed.

Documents. The final method of data collection included documentation, such as the departmental course syllabus and pacing guides. The documents were examined to identify how policies were communicated to students. Additionally, the instructor view of the commercial software made it possible to view sample problems that students would encounter; this allowed the researcher to better understand the features of the software.

Data Analysis

The author employed Erickson's (1986) method of analytic induction to generate and analyze data. During observations, the author conducted reflexive analysis of themes in the data to better inform the data collection process for observations and interviews, a process discussed in detail in Yin (2017). Throughout the process of data analysis, the author sought disconfirming evidence to align assertions to the data and present a coherent description of themes. Interviews were analyzed with an emphasis on *in vivo* codes, which preserve the voice of research participants (Corbin & Strauss, 2008; Miles, Huberman, & Saldaña, 2014). Initial findings were presented to observed faculty during interviews as a form of member checking, and these assertions were revised to incorporate the responses of those interviewed (Erickson, 1986; Yin, 2017). The following findings are presented in the form of assertions; each assertion begins with an analytic to vignette (Erickson, 1986). These vignettes were created as a composite of multiple field-note observations and data from interviews, synthesized into a narrative form intended to capture the character of recurrent practices in these courses.

Findings

The findings are organized here into three assertions. The first assertion addressed both research questions by describing how faculty interacted with students who struggled to meet mastery thresholds using the software. The second assertion explored the second research question more broadly, describing the role of the faculty member in this format of instruction in detail. The third assertion responded to the first research question by describing instances in which students correctly answered questions, but they did so by utilizing strategies that that appeared to constitute a misuse of the instructional software help features.

Mastery Threshold Interpretation and Manipulation

Assertion 1: Though mastery thresholds are fixed by policy, in practice they may become subject to faculty interpretation and manipulation.

Vignette 1: A student leaves the quiz area of the mathematics tutoring center with a disappointed look on her face. Arya, the instructor, immediately surmises that she did not earn the threshold score and invites her to come to go over the quiz together. The student, an African-American woman in her late 30s, places a sheet of paper with her work from the quiz on Arya's desk. "How did you do?", asks Arya. The student responds, meekly, "I got a 73%." Arya responds encouragingly, "Oh, that's so close, and it is quite an improvement over your first attempt. Can we go over your work together?"

Arya opens her computer to a view of the student's quiz attempt. Looking over the sheet of paper, she mutters to herself, "Let's see what you did here." She navigates to the first incorrect answer and pauses, comparing the correct answer in the software to the student's work in front of her. Gesturing to the computer, she asks the student, "Do you see what happened here? You wrote 3/6 for the slope. Do you know why it didn't give you credit?" The student responds, "Oh, is that supposed to be ½?" Arya, pleased, replies, "Exactly. I'll go ahead and give you half credit on that one, because you knew what you were doing. Just be sure you simplify your expressions before entering your answers, just like you did back in the first module."

Arya compares the next answers on the screen to the writing on the paper, and tells the student, "It looks like you're still making the same errors on the problems with the intercepts, but let's see if there is anything else you did correctly that the system didn't catch." She stops, with a perplexed look on her face, at the next question. "Oh, that's odd," she says to herself. "It looks like you wrote 4..8, with two decimal points. I'll give you full credit on this one, that's clearly just an input error." Arya overrides the score in the system, which updates the newly reflected grade. She reports, "It looks like that gets you up to an 81%, so you're ready to move on. Do you know what you need to do next?" The student replies, a relieved look on her face, "Yes, I just need to finish the next homework and quiz 3 and then I can take the posttest." Arya smiles at the student, who walks back to her computer terminal and brings up the instructional video for the next section.

> *Faculty jointly adopted the practice that students could earn partial credit, but only if they provided their quiz work on paper.*

Vignette 1 illustrates the structural mechanism of the mastery thresholds as enforced by the software and occasionally circumvented by the instructor. Students could not take a quiz until they earned at least 80% correct on each section of homework prior to that quiz. In addition, any student earning below 80% on two attempts on the same quiz was blocked from taking a third until receiving a faculty override. As Catelyn explained, the goal of including these benchmarks was to enforce a universal standard of proficiency:

> All of these policies are ideally for students to be successful…[the] policy for homework is you must get 80% of the homework. That's something that we all do and just kind of follow, and no one questions that one and you can't touch it because the system is built that way. (Interview, 11/20/17)

Inevitably, not all students followed this "ideal" path. It was common enough that, if students failed two quiz attempts, the mathematics faculty devised departmental policies in response. The syllabus stated: "If you fail to achieve an 80% after two attempts, a teacher conference is required." The policy did not specify what needed to happen in a teacher conference, though all faculty in this study described procedures like the "quiz review" portrayed in the vignette.

During quiz reviews, faculty would diagnose why a student failed to reach the threshold score and determine the appropriate course of action. Faculty would sometimes reset certain sections of the homework, thus requiring students to revisit them before qualifying to take the quiz again. Other times, faculty might simply allow a third attempt if they believed that a student was capable of meeting the threshold without further practice after having reviewed their errors. Though the software recorded student answers and indicated the correct answer, faculty found this to be insufficient to make an informed judgment about a student's understanding. To incentivize having students write down their work, faculty jointly adopted the practice that students could earn partial credit, but only if they provided their quiz work on paper. Faculty had the ability to override a student's score in the software on individual items. Each of the five faculty members in this study had some informal process of assessing partial credit for certain incorrect answers. Despite the lack of official policy on what merited partial credit, most faculty considered giving partial or complete credit when the software marked the following as incorrect:

- answer format errors (e.g., improper use of parentheses and decimal points),
- unsimplified expressions (e.g., fractions such as 3/6), and
- arithmetic mistakes judged to be minor in the context of the problem.

Many faculty described other contextual factors that weighed into their judgment to award partial credit. Four of the five said they only offered it to students who were close to reaching the threshold and only if the students demonstrated understanding of the material. Arya emphasized the pragmatic balance between having students rework material at the potential cost of preventing them from completing the course in the allotted time.

> Do they have enough of this material to move on to the next section? Are we doing them a disservice to give them partial credit? Or is this really going to help them achieve their goal of passing in two weeks? (Interview, 11/29/17)

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Although offering partial credit was a common practice toward getting students through the course benchmarks, at no point during observations did faculty override the software to take away points on problems the software counted as correct. Though faculty would occasionally reset entire sections to require students to rework previous material, none of them reported taking away credit on a per-item basis.

Assertion 2: Faculty served a role as classroom facilitator, offering individualized remediation as well as providing oversight and encouragement.

> Vignette 2: The first student arrives to class at 8:45, as he always does, 15 minutes before class begins. Drinking his coffee, Eddard clicks through his online roster, checking what homework each student has completed since the previous day of class and assessing when each student might be prepared for the next quiz. A young Caucasian woman with a streak of bright blue in her dark hair sits down at a computer. Eddard checks her progress relative to the module pacing guide at his workstation as she logs in. Seeing that she is a week behind where she needs to be to finish the module in another two weeks, he walks over to her.
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> "Did you catch any of the Capitals game last night?" he asks her. "Yeah", she responds, "It was a great game to watch but they fell behind in the third." After another bit of small talk, he gives a gentle reminder. "You know you still need to finish sections 4.7 and 4.8 before you can take the next quiz? You should probably focus on those before you do any more work on the 4.9 homework." He watches as she navigates from section 4.9 to section 4.7 on her computer, and he tells her, "Remember that we only have a week left before the end of the module. If you put some extra time in between now and Wednesday, you can be on track to finish. But I really want you to get the second quiz done before the end of next Monday. Otherwise I need to reset all of your work, and I really don't want to do that."
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> "Yeah, I know", she responds, exhaling. "I work all day tomorrow and I have to pick up my kids today at 3pm." Eddard shrugs and replies, "That's ok, I have office hours today right after my next class. We can go over the section on problem-solving if you still have questions after today. I'm going to check back in on your progress in a bit." Students continue to trickle in and Eddard heads back to his workstation, scanning the class as he records attendance. After sending a quick message out to nonattending students, he gets up and starts circulating around the room.

Vignette 2 offers a narrative depiction in response to the second research question about how instructors interact with students within this instantiation of the EM. The support role of the faculty largely appeared to align with the vision laid out in the NCAT elements in which instructors monitor student progress and provide individual assistance. Per observations shared in the vignette, monitoring included using the instructional software, circulating around the room, asking questions, ensuring that students were on-task, and providing reminders about due dates. Faculty also connected with students outside of class time, sending notifications to non-attending students or those who were behind schedule.

Faculty used departmentally-developed pacing guides to remind students where they ought to be in the course. Some faculty characterized this aspect of their instructional role of providing encouragement and keeping them on task. Robb drew an analogy to sports:

> I think of myself as a facilitator, like a coach. Just like a coach in basketball, you're running plays.... You're motivating, you're joking with them, you know? You're telling them that you believe in them, you can do it, but you've got to believe in yourself at the same time. (Interview, 11/20/17)

Building rapport was critical to keeping students on a path towards success.

Robb and Eddard both discussed the emotional dimension of providing motivation. This part of the instructional role could be emotionally challenging, according to Robb. As he characterized it, for some students the lack of motivation was a significant hurdle in a self-paced course. As a result, it was common for students to end up behind schedule. Eddard noted that the challenges some students faced were compounded by their lack of planning to complete the module in the allotted 5 weeks: "Not only do [some of them] not do their work, but they also don't plan on how they're going to complete the rest of the class" (Interview, 11/20/17).

Though developing rapport with students is not an explicitly mentioned element mentioned by NCAT, a common view among faculty in the study was that building rapport was critical to keeping students on a path towards success. Catelyn remarked, "I can build motivation with someone that I'm able to connect to." (Interview, 11/30/17). Faculty perceived the opportunity to form personal connections through one-on-one communication as a strength of their implementation of the EM. As Robb put it, "I know whether one is a Yankee fan." (Interview, 11/28/17). Catelyn expressed similarly positive sentiments about the ability to form relationships with students in this instructional format and leverage relationships to get students to where they need to be.

> That's the beauty of it, you get to be personal with all of the students. So, the first thing I do every class, I make sure to get to every student before doing any math and I ask: how are you doing? How's your pacing? What can we do to get you on pace? (Interview, 11/20/17)

However, because of the self-paced nature of the course, faculty reported that they rarely had more than one student working on the same subject matter at any time, and consequently could only do remediation on a one-on-one basis. This remediation occurred as faculty and tutors circulated around the room or during the quiz reviews discussed in the first assertion. There was also an encouragement aspect to remediation as well, what Arya described as

> … recognizing what [the students are] doing right that isn't being recognized by the software…. Because the student and I are mostly discussing what they get wrong, it can be very demoralizing. So, I feel like it is an important role as a teacher to recognize what they're doing right." (Interview, 11/29/17)

In the vision of the EM described by NCAT, both faculty and tutors provide the same high quality of remediation. Indeed, tutors did circulate around the room and answer questions, sometimes working with an individual student for 20 or 30 minutes in one sitting. However, faculty described tutor quality as highly variable, and consequently the amount of instruction that faculty could expect tutors to deliver depended on the strength of each tutor's mathematical foundations. Given the time limitations on instructors, Robb emphasized the importance of getting students to "self-remediate" by using the help features in the software. However, the way that some students used these features called into question whether the help features provided insights into the procedures or a counterproductive shortcut to the correct answer.

Assertion 3: Some instructional software help features may be vulnerable to exploitation, which may undermine mastery thresholds as evidence of procedural fluency.

> Vignette 3: A blonde student in an athletic jacket opens section 4.5 to a multiple-choice question. She immediately clicks "A.". A red "X" appears on the screen, along with a message. Within a half-second, she has clicked and made this message disappear, then attempts "B." The red "X" reappears, informing her that she has run out of attempts on this question. It gives her

the option to move on to the next question or attempt a similar question. Within an instant she has elected to complete a similar question and starts this time with "C." A green check mark appears, praising her, "Excellent!"

On the next problem, which is also multiple choice, she immediately employs the same strategy, idly clicking and reattempting until she stumbles into the right answer. She skips over a word problem and is next presented with an algebra exercise:

Solve the equation

A = P + Prt for t.   t = __________

Though the equation corresponds to an application that an instructor might recognize as the simple interest formula, the problem is presented without context. After getting this question wrong, the student gets a similar exercise and sees a new version.

Solve the equation

Q = R + Rst for t   t = _________

In format, the equation is identical to the previous exercise, though it is even less apparently connected to a meaningful application. The algorithm generating this problem may have simply replaced the letters, which does not change the meaning but further detaches it from an actual applied context. The student inputs (Q – R)/Rs, getting the second version correct on the first try. She moves on to another question.

Solve the equation

P = t + s + r for t.   t = _________

Looking at the box, she inputs (P – s)/r, and the red 'X' reappears. Though the answer is wrong, she re-inputs the exact same answer for her second and third attempts. Once she completes this third attempt, the software offers the correct answer, t = P – s – r. She pauses to write this answer in her notebook and attempts a similar exercise.

Solve the equation

P = b + c + a for b   b = ________

Her gaze shifts rapidly between the screen and her paper. Into the box, she inputs P – b – c. The resulting equation, b = P – b – c, is incorrect, and the red 'X' appear. After looking back down at her paper and pausing briefly, she writes P – c – a into the blank for her second attempt. The green check mark congratulates her on another job well done.

Vignette 3 documents two of the most egregious approaches to producing the correct answer documented in fieldnotes. Though they are extreme examples, there were multiple instances of different students employing such approaches, which were made possible by the particular help features of the instructional software. The software has two features, "Help Me Solve This" and "View an Example" which present scaffolded explanations of problems. Second, students can always earn full credit on a problem by reattempting another algorithmically generated version. Third, the software gives students the correct answer after they have exhausted their allotted number of attempts for a given version.

Some strategies to exploit the system were simple, like those for dealing with multiple-choice questions. Since students only needed to guess the correct choice of three or four choices and can regenerate the problem as many times as desired, students could arrive at the correct answer simply by inputting an answer a sufficient number of times. Even students who did not intend to abuse the system might "stumble into the right answer" by guessing, as Arya put it. While using the instructional software, at one point the author encountered an instance where the next "similar exercise" was the exact same as the previous.

At a higher level of sophistication, another strategy was for students to use the "View an Example" feature and follow the steps, copying down on a sheet of paper using their own numbers.

Even students who did not intend to abuse the system might "stumble into the right answer" by guessing.

In at least two instances the author found students following some variation of this strategy, clicking through the steps of "View an Example," taking notes, and replacing the numbers in the problem on their paper with their actual numbers. Since the "View an Example" problem is similar in form to the actual exercise, all that students needed to do was figure out the appropriate arithmetic computations when replacing the numbers and variables. Once this yielded a correct answer, students could simply move on to the next exercise.

Catelyn, a full-time faculty member who preferred a rival commercial instructional product, pointed the blame specifically at the design features in the current software.

> I feel [it] is a cheat, because it tells you. If you don't know, you can hit [the button], and I see students doing that, and you can just put the wrong answer in so many times. It will tell you the answer and you can look up and you can see where it comes from. So, it's more of a pattern. And then the problem they give you is so similar that you're replicating the pattern and not learning the concepts. I hate it, I actually really hate it. (Interview, 11/20/17)

Eddard echoed these comments, noting that "just because they have 100% doesn't mean they understand 100%" (Interview, 11/20/17). The author noted the use of these strategies during an observation with Arya. During an interview which took place later, she commented that she had since taken a more aggressive approach with students when she saw them immediately jumping to the help features on every problem. Sansa reported that seeing students employ these strategies informed her decisions of assessing partial credit during quiz reviews, but ultimately, she could not take away points when students follow alternative strategies.

> You obviously don't understand what you are doing, so you don't earn partial credit on that kind of thing. If [you] can pass it without actually doing any of that, I don't have control to say you don't pass because you don't understand. (Interview, 11/15/17)

Discussion

The goals of this research were to identify how students were using instructional technology for the EM and what strategies students and faculty used to reach mastery thresholds. The findings presented in the third assertion address the second research question. The documented instances of some of these strategies undermine the significance of the mastery thresholds as documentation of student learning. Some students achieved benchmark scores in some part through an awareness of how to manipulate this particular instructional software system. It may be that the broad range of success outcomes in the literature on the EM can be partially explained by differences in instructional software and classroom policies and practices surrounding this software.

Ostensibly, the goal of developmental mathematics should be to help students develop transferable skills and conceptual understanding that prepares them for credit-level mathematics. Indeed, the findings in the first and second assertions provide some indication that faculty recognize the imperfections of the instructional software and the need for personalized intervention. To some extent the EM format gave faculty the opportunity to intervene and prevent software misuse. However, although the structure of the EM can allow for individualized attention, the push to achieve mastery thresholds may set up incentives for faculty and students to take shortcuts to achieving benchmark scores. The existence of these shortcuts and workarounds when using software can help account for how a 75% success rate for EM-based courses in studies such as Foshee et al. (2016) was accompanied by reductions self-reported study skills and motivation. Perhaps the issues with motivation perceived by faculty in the present study were a consequence of the method of instruction, rather than any reflection of the character of students placed into these courses.

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The NCAT acknowledges the potential that "misuse of the computer software" can lead to problems in their discussion of Element #7 on the importance of highly trained personnel (2013, p. 6). Advocates for the Emporium Model might argue that the findings in the present study would indicate that the model was not properly implemented. However, the instructional software was from a major publisher, which would indicate that similar issues may be found within other instantiations of the EM. The transferability and limitations of the current research are turned to next.

Limitations

Several particulars may limit the transferability of these findings to other EM-based programs. The assertions developed were based on a limited observational sample of two adjunct faculty supplemented by interviews with three additional instructors. It is also possible that faculty or student demographic factors may impact classroom interactions, but this was not explored during data collection or analysis. There is also the potential that the observer effect introduced bias into the findings. Another limitation is that data collection did not include interviews or survey data from students or tutors. Finally, the strategies students employed likely depended on the specific design features of the instructional software. This limitation points to important recommendations for practitioners and future directions of research.

Recommendations for Practitioners Using the Emporium Model

Because some software systems may incorporate design principles that allow students to produce correct answers without a deep understanding, faculty need to be keenly aware of the potential for misuse. The findings from this case study support the following best practices:

- Encourage students to complete exercises using pencil and paper to increase the likelihood they may transfer procedural skills to future coursework.
- Observe how often students utilize instructional help features; discourage students from immediately using the help features when starting an exercise.
- Answer student questions with a holistic focus on the entire question, not just a single step in a longer process.
- Meet with each student on a regular basis to assess their progress; identify ways to help struggling students overcome barriers to success.
- Monitor student progress with multiple methods, through instructional software as well as by regularly interacting with students, both in-person and virtually.
- Build rapport with students to ensure that students are comfortable bringing their questions and difficulties to the instructor.
- Incorporate assessment methods outside of the instructional software system to ensure that students can transfer skills outside of the context of a particular instructional system.
- Consider multiple instructional software alternatives (e.g., ALEKS, Knewton, MyMathLab, Hawkes); explore the student view as well as the instructor view, and avoid software with features that may be vulnerable to exploitation.
- Avoid assessment questions that are easily exploited, such as multiple-choice questions for which students can reattempt the question with no penalty.

The strategies that got them through [EM courses] might not prepare them for success in credit-level mathematics.

- Train faculty and tutors working in EM-based courses to recognize potential misuse of instructional software.

Directions for Future Research

As mentioned previously, student strategies are likely to be responsive to the design features of the software system. One major direction for future research would be to compare student approaches when utilizing various software alternatives. A mixed-methods study at multiple sites could measure the effectiveness of various software programs on student performance; supplemental direction observation could provide insights into what factors may account for any differences. Using screen captures to document the prevalence of various student strategies could also document exactly how students interacted with instructional software. Furthermore, future research would benefit from capturing the perspectives of students in developmental mathematics courses, such as in Acee et al. (2017). Lastly, a longitudinal study that followed students who took developmental coursework under the EM model could identify the future performance and challenges experienced by these students as they transition into credit-level coursework.

Conclusion

Though the NCAT found that many colleges implementing the EM for developmental mathematics instruction saw improvements, these reforms are perhaps not a "silver bullet" (Twigg, 2011) for improving student outcomes in developmental mathematics. Students beginning in remedial coursework may struggle with the independent format of the EM. The instructors, facing time pressures, may not be able to provide sufficient assistance for individual students struggling on a broad range of topics. Even when students do pass EM courses, the strategies that got them through might not prepare them for success in credit-level mathematics. Indeed, the VCCS is now in a process of phasing out EM-based courses, moving away from a modularized curriculum and computer-based instruction, and towards direct placement and corequisite initiatives. A detailed discussion of the reasons behind this shift away from EM courses can be found in Beamer (2019). The findings presented in this article suggest that colleges using the EM ought to look carefully not only at course pass rates, but also at the strategies students and instructors are using to reach the thresholds. If these strategies do not appear to be preparing students for college-level mathematics, colleges ought to consider how they are implementing the EM. Ultimately, it may be that other instructional formats of developmental education may be a better way to help underprepared students succeed in their college-level mathematics coursework.

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