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Theory to Practice: Reducing Student Attrition in Online Undergraduate Math

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Abstract

Researchers have developed numerous effective theory-based practices for teaching undergraduate general education mathematics (UGEM); however, many universities have struggled for decades to close the gap from theory to practice. This gap contributes to the national lack of skilled STEM workers. Recently, an all-online university closed the gap by shifting their philosophical framework for UGEM from traditionalist methodology to a synthesis of seminal theories and practices. This paper disseminates the implementation of theory-based practices in UGEM toward reducing student attrition (withdraw or fail), including: Rationale for theory identification, construction of a philosophical framework, collection of stakeholder input, implementation, evaluation, post-implementation maintenance and communication, and institutional socialization of the new paradigmatic shift. These efforts yielded an attrition reduction from 17.5% to 4.7% in Quantitative Reasoning 1 (QR1) and from 13.9% to 4.0% in QR2. A key reported outcome is a blueprint for an institution to similarly close the gap.

Introduction

For decades, math attrition has been a challenge in higher education. Many colleges and universities use outdated methods to teach mathematics (Higher Education Today, 2018). A significant gap has been documented between the knowledge shared within the scholarly community and the instructional practices observed in learning environments (Biesta, 2007), especially in STEM (Labov, Singer, George, Schweingruber, & Hilton, 2009; Borrego, Froyd, & Hall, 2010). While new knowledge abounds in mathematics education to guide institutions in better supporting learners of mathematics, many of those theories and practices are not successfully translated to higher education at scalable or sustainable levels (Korthagen, 2007). Many reasons for this translation gap have been identified, including lack of resources (time, talent, funds), lack of expertise, resistance to change, research not being directly applicable to practice, and an overall sense of overwhelm (Kennedy, 1997; Korthagen, 2007; Shadle, Marker, & Earl, 2017).

Often, interventions are implemented at small scales, such as within a classroom, but are unable to be scaled for institutional implementation. Alternatively, specific programs are so dependent on single stakeholders that the gains and progress are lost if those stakeholders leave (Shadle, Marker, & Earl, 2017). Such factors contribute to theory-based practice in UGEM not being widespread. Students remain averse to mathematics (Jameson &

Fusco, 2014), and metrics continue to show that mathematics is a barrier for students to advance to STEM fields and complete college (Dang & Nylund-Gibson, 2017; Watt, Hyde, Petersen, Morris, Rozek, & Harackiewicz, 2017).

Higher education faces an even greater challenge in addressing this theory to practice gap since most teachers of higher education are specialists in specific subject areas, without formal training in education research. There is often little motivation for faculty to seek out education research, which is rarely acknowledged as part of the rigorous process to obtain institutional tenure (Kensington-Miller, Sneddon, Yoon, & Stewart, 2013; Shadle, Marker, & Earl, 2017; Vanderlinde & van Braak, 2010). The purpose of this paper is to disseminate the implementation of theory-based practices in UGEM toward reducing student attrition. A key outcome of this work is a blueprint for reducing the theory to practice gap at an institution.

Theory to Practice

To start implementing a theory, defining a philosophy of learning can be helpful (Elrod & Kezar, 2016). This philosophy outlines what an institution defines as knowledge, learning, and assessment, and how a learning environment should look, sound, and feel for students and instructors. It discusses the role of students and faculty in the learning process. By creating a philosophy for learning, an institution can focus on seminal works in education theory and support institutional stakeholders, including faculty, to adopt a consistent philosophy. It will also help develop consistent strategies for instruction and assessment.

A handful of seminal theoretical works have received general consensus. By focusing on these works, institutions may bring some of their learning environments up to date with, at minimum, the theories that have been agreed upon for multiple decades. Table 1 shows the identified 7 theories used to develop our philosophy of learning, along with associated seminal works. Each of the selected theories are in alignment with the mission and vision of the University.

Table 1. Matrix of Theories Translated into Practice

Theory	Citations
Metacognition and Affect	(Dole & Sinatra, 1998; Mayer, 1998; Moons & Mackie, 2007; Sinatra, 2005)
Conceptual Change	(Strike & Posner, 1992; Carey, 1999; Carey, 2000; Chinn & Brewer, 1993; Chi, 2008)
Social Constructivism	(Vygotsky, 1986)
Academic Self-concept	(Marsh, & Shavelson, 1985; Bong & Skaalvik, 2003)
Holism	(Dewey, 1986; Mahmoudi, Jafari, Nasrabadi, Liaghatdar, 2012)
Systemic Functional Linguistics	(Halliday, 1992; Holliday, Yore, & Alvermann, 1994)
21st Century Knowledge Framework	(Kereluik, Mishra, Fahnoe, & Terry, 2013; Mishra, Anbar, Scragg, & Ragan, 2019)

Theories Used

Each theory in Table 1 applies to learning across all disciplines. To keep focus, each philosophy is summarized in the context of a student learning math.

- Metacognition and Affect (MA): Metacognition is how well a student monitors and updates the thinking processes required to conduct mathematical tasks. Affect is a student's psychological or emotional state while engaging in or thinking about mathematical tasks. Affect can impact the cognitive processes students can access and execute. Both metacognition and affect can impact student performance and persistence, in addition to a student's content knowledge.
- Conceptual Change (CC): Theories of conceptual change describe knowledge as conceptions. Some are normative and others are misconceptions. Normative conceptions can support the proper construction of mathematical knowledge, whereas misconceptions can create barriers to learning which may either restrict learning from occurring or promote incorrect knowledge. A student's mathematical knowledge must be elicited and monitored so that, if required, misconceptions can be changed, and normative learning can continue.
- Social Constructivism (SC): Social constructivism posits that a student's understanding is constructed through the integration of cognitive thought processes and shared social language. As a result, conversations and the use of language between social members are what allow students to construct mathematical knowledge, such as intentional classroom discourse as part of the development of mathematical ideas.
- Academic Self-concept (AS): Academic self-concept is a student's belief in her/his ability to engage with content as a participant of mathematical concepts. Students with high academic self-concepts tend to believe they belong in an academic setting that uses math, whereas students with low academic self-concepts tend to believe they do not belong or are imposters in the mathematical setting. A low attrition in math is positively correlated with a student believing they have sufficient math abilities. This includes how the student compares themself to peers, a student's past successes and failures in math, how the student feels they received judgment about math from others (including professors, oneself, and tests), what opportunities the student had to achieve mastery in the past, and the student's perception of the value of the math skills.
- Holism (H): A holistic philosophy suggests that every aspect of a learning environment (not just the actual learning activities) impacts student knowledge and that the environment can be designed to evoke a student's love of learning.
- Systemic Functional Linguistics (SFL): Language is functional, which means its use can differ based on context, audience, and tone. A term may have a colloquial meaning (that a student knows) that differs from a discipline's technical meaning (that a student is learning). A student needs to learn that difference, which is supported by explicitly stating the difference. For example, the term "area" has a specific meaning in math that differs from colloquial uses, such as "a rural area".
- 21st Century Knowledge Framework (21): A framework developed via the review and synthesis of 15 of the most significant 21st-century knowledge frameworks. The synthesis yielded three overarching

categories: foundational knowledge (what a student needs to know), meta-knowledge (how a student acts on that knowledge), and humanistic knowledge (the values a student brings to her/his knowledge and actions). The categories are complementary and inform each other. For example, a student learns to plot linear equations (foundational), then a student is asked to pick a health insurance plan (meta) for her/his family (humanistic).

Practice: Feature Changes

Table 2 details the feature changes before and after the change in the guiding philosophies. We determined whether each feature was guided by best practice according to each theory. To do this, a feature was first selected. Then the following question was posed for each theory: "What would this theory suggest as best practice for this feature?"

If possible, identified suggestions were implemented. For some features, some theories did not offer actionable insight, such as systemic functional linguistics to grade pass back. For some features, implementation was not reasonable given other course constraints, such as social constructivism applied to a high-stakes exam. The suggestions which were implemented for a given feature were noted. Discussion of these decisions and implementation of the guiding philosophies to specific features is below.

Table 2. Feature Differences Informed by Guiding Philosophies

Features	Before (Control)	After (Intervention)
Advisory language		MA, CC, AS, H
Remediation		MA, CC, SC, AS, H, SFL, 21
Discussion questions	CC, SC	MA, CC, SC, AS, H, SFL, 21
Reading assignment	MA	MA, CC, SC, AS, H, SFL, 21
Homework assignment	CC	MA, CC, SC, AS, H, SFL, 21
Grade pass back to student	MA	MA, AS, H
Late work policy		MA, CC, AS, H
Exams	CC	MA, CC, AS, 21
Rigor	CC	MA, CC, AS, H, 21

Advisory Language

Throughout the course, instructions are communicated to students, including documents on course preparation, course navigation, assignment instructions, classroom announcements, and automated messaging. The language for the control group included a lot of resources to prepare via unguided remediation. The tone of this communication was overtly formal and followed the norms of scholarly discourse, which is not accessible to undergraduate, novice math students.

The language in the intervention condition was adapted to be colloquial and accessible. The classroom environment was described and communicated in as a safe place where learning, ideas of all levels, and mistakes were welcome and appropriate. This supported students with being able to safely and openly reflect about their thinking, communicate their ideas in ways that made sense to them, confirm that they fit into the space, and be validated as a whole person.

Remediation

Many students enroll in courses with gaps in their prior knowledge. Remediation is then required to best set students up for success. The control condition included remediation outside of the classroom and the expectation was for students to complete remediation in isolation.

The intervention condition included remediation within the reading and homework assignments, encouraging students to embrace the reflection associated with reviewing content they may have seen before. Remediation was actively mediated by course experiences so that students were engaged in constructing holistic and integrated knowledge just-in-time.

Discussion Questions

Each week, students earn course points for both responding to discussion questions and engaging in dialog with class peers. Discussion questions in the control condition asked students to interpret the content and explain their understanding, such as identify and discuss some part of an expression.

Discussion questions in the intervention condition asked students to reflect on their cognitive processes, apply recently learned concepts to everyday experiences, evaluate their level of comfort with the course and content, and consider social applications.

Reading Assignment

Reading assignments are used in the online environment to support students with the development of concepts. The control condition used a traditional textbook for reading assignments. The text used minimal contextualization, written at a level that required transfer and synthesis of content, and often focused more on problem sets than explanations.

The intervention condition used the Quantitative Reasoning zyBook (zyBooks), which was fully integrated with the homework assignment. The material in the zyBook was written using a say-show-ask pedagogy. For example, as shown in Figure 1, the section "Creating equations with x" begins with sub-section "Centering items" using concise text ("say") and an animation ("show"). The animation incrementally reveals the process of solving, using captions to explain along the way. Then, a sequence of short answer questions ("ask") was given, such as shown in Figure 2. Each question covers a different concept, and provides a hint or explanation depending on the student's need, as a way of structured-adaptivity. Note that such questions are not assessments, but rather part of the core learning. A student was given a hint when the student's answer was wrong. A student was given an explanation when the student's answer was correct.

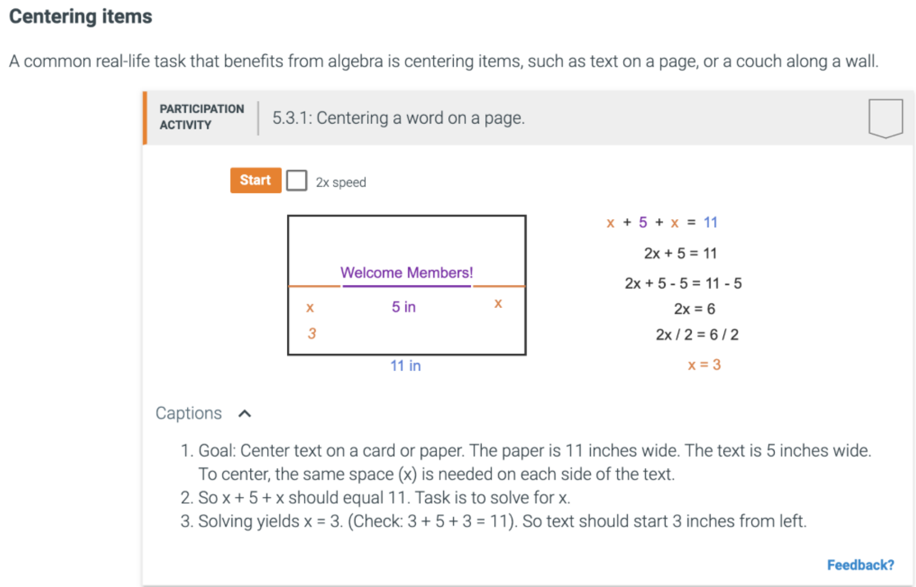

Figure 1. An Example Animation

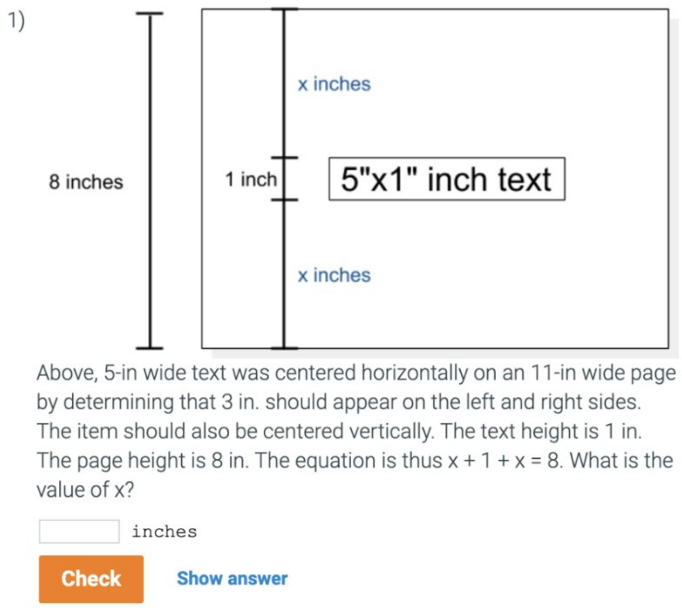

Figure 2. The First of 6 Short Answer Questions

The frequent formative activities within the reading supported students as they worked through metacognitive processes in the development of a conceptual understanding of the content. The tone of the reading was colloquial and accessible for students. Additionally, the contextualization of the content supported students in experiencing themselves as consumers and users of mathematics. The experience strongly contrasts traditional text experiences as it treats learning as a conversation and views the content through a lens of holistic usability.

Homework Assignment

The control condition used online courseware for homework assignments. The homework assignments were separate from the reading assignment and completed after all reading assignments had been reviewed. A student must solve a problem to move on to the rest of the assignment. The problems tended to be very similar and required extensive practice of each mathematical concept introduced.

The intervention condition used the Quantitative Reasoning zyBook, wherein the homework assignments were fully integrated with the reading assignment to create a holistic and natural-feeling experience. Homework problems were able to create a progression of incrementally harder levels, as shown in Figure 3. A student first must create the equation with x, then solve for x. At each level, the student was given a randomly generated question. If the student answered incorrectly, the student was provided with a reframing coaching conversation, including how to solve the question, then given a new, randomly generated question of the same difficulty. If the student answered the question correctly, the student was given an affirmative coaching conversation and could move to the next level. All contextualization and features of the readings were also present in the homework assignments, as they were an integrated experience.

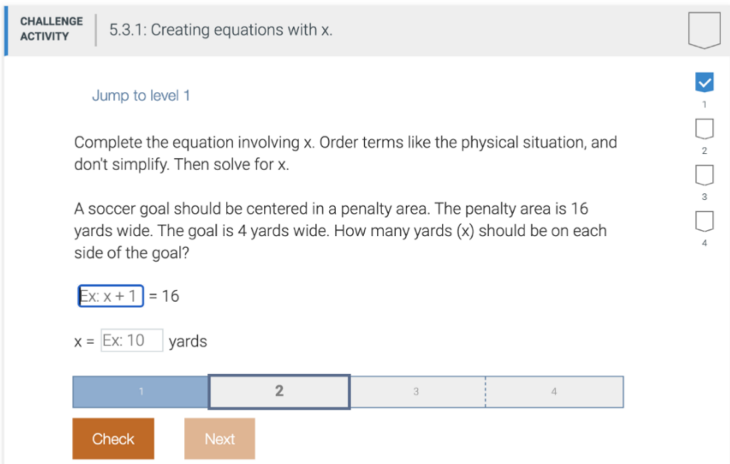

Figure 3. Level 2 of a Randomly Generated Challenge Activity

Grades Passed back to Students

Grades from online learning experiences require being passed back (virtually) from the vendor courseware to the classroom grade book. Some integrations do this quickly and automatically, while others do not. The homework assignment grades in the control condition were returned to students at the end of each week. Faculty were required to complete manual steps for the grades to transfer. As a result, students received information about their performance at delayed intervals.

In the intervention condition, however, grades were returned in real-time, as the student worked on a homework assignment. This validated student progress and challenges so that students could understand how they were situated in the course as a math learner, just in time.

Late Work Policy

The control condition used unwavering deadlines for assignment completion. Exceptions were made at the faculty level. The overarching message to students was that learning is required to be complete by predetermined dates and times.

In the intervention condition, homework assignments and formative learning experiences were due by the end of the course. To provide a learning frame for students, assignments were outlined on a weekly cadence and recommended for completion during that week. The assignments were then accepted through the end of the course to continue learning, building concepts, and reviewing as the student needed. High stakes summative assessments (the midterm and final exams) were only available to complete within a small window within the course.

Exams

The control used exams created by the publisher of the courseware. Alignment between items and Course Student Learning Objectives was unclear. Students were allowed two attempts. Items were multiple choice with one correct answer choice. Exams were weighted at less than 30% of the overall course grade.

The intervention used assessments authored by the college to explicitly align to the Course Student Learning Outcomes. Exam item rigor was determined by adopting the college framework for leveling courses and course outcomes. Exams were housed in the learning management system. Students were allowed one attempt. Items were multiple choice with one correct answer choice. Exams in the intervention condition were weighted at 50% of the overall course grade. Upon comparison of the intervention to control exams, the exams in the intervention condition assessed student knowledge at higher levels of rigor, or cognitive complexity, than the exams in the control condition, according to Bloom's taxonomy (Bloom, 1956).

Rigor

Rigor has varied definitions dependent on context, experience, and philosophical frame. In control conditions, rigor was defined as the ability for students to complete tasks. This resulted in students completing many different math problems that took time and effort but did not particularly demonstrate any sequence of learning.

The intervention condition defined rigor as students' ability to apply concepts at increasing levels of cognitive complexity. This resulted in students engaging in sequenced levels of cognitive challenges to engage in skills aligned to the course student learning outcomes.

Institutional Communication

After fully implementing the features changes, we employed subsequent maintenance and evangelizing tasks. For the positive impact to be maximized for students, various stakeholders needed communication, and some common misconceptions about mathematics education needed to be addressed.

Communication of Changes

The communication of programmatic changes was differentiated based on the role of various stakeholders. Different stakeholders support students in different ways. As a result, the information that was most meaningful to each group was fundamentally different. Different messaging was compiled for institutional leaders, student-facing support services, college partners, faculty, and vendor partners.

High-level summaries that synthesized theoretical rationale, methodological choices, data, results, and forecasting were prepared for institutional leadership. Student-facing support services were offered descriptions of what was to change with respect to the student experience in the classroom. Implementation dates, talking points to respond to anticipated student frequently asked questions, walkthroughs of the student experience in the new setting, and high-level data were shared with these teams to be able to best support having informed discussions with students.

College partners were informed of fundamental shifts in philosophy that would impact course design principles and assessment practice. Faculty were provided descriptions of changes, detailed accounts of faculty feedback and commentary from the pilot study, theoretical rationale for changes, pedagogical strategies for navigating the curricular paradigm shift, and a schedule for when additional feedback would be collected. Faculty were also encouraged to share thoughts with college leadership as frequently as they would like.

Vendor partners were provided detailed timelines, task lists, and implementation data, which were shared in weekly meetings to ensure implementation remained on track. To ensure appropriate communication was being provided to each set of stakeholders, frequent calls for feedback were conducted. When additional needs were identified, communication plans were enhanced and further developed.

Institutional Misconceptions About Math Education

As communication plans were deployed, communication frequency and specificity increased between the College and institutional stakeholders. As the authenticity of these conversations increased, it became apparent some common perspectives about the field of mathematics needed to be adjusted within the student-facing service teams. The held misconceptions included that

(1) academic rigor is equal to the amount of time spent,

(2) remediation before the course helps student success,

(3) independent remediation contributes to student success, and

(4) math is not important in real life.

These perspectives were adjusted to match the theories being implemented. In response to uncovering these misconceptions, the College deployed a Misconceptions About Math series to help resolve some of those misconceptions within the student-facing support teams so that they would be better equipped to help coach students through those same misconceptions as well. The intervention included a video series, town hall discussions with College leadership, and the development of an asynchronous resource.

The video series included four short (1-3minute) video clips of four common misconceptions that students may have about mathematics, which could impact their ability to be set up for success upon entering math courses. The videos included a description of the misconception, how it might be a barrier for learning, and talking points for how to coach towards resolving the misconception. Townhall discussions involved the College leadership presenting high-level philosophical reasons for updating courses, data from the impacts of implementation, the previously discussed misconceptions about math, talking points for students, and open-ended dialogue to address any topics that student-facing service teams found meaningful.

Following the town hall discussions, themes were synthesized and used to create an asynchronous interactive resource that student-facing service teams could access as needed. The resource was created in the same interface that students used in mathematics courses so that the teams could also experience the same environment that students would. To further support student-facing service teams, example sections from the revised courses were included in the resource.

Feedback from the Misconceptions About Math series was positive. Student-facing service teams frequently reflected that they had the same misconceptions that were being discussed and it was impeding appropriate coaching of their students. The institutional culture of how mathematics was discussed began to shift from one of aversion to one of interest and appreciation.

Method

Study of Course Implementations

All QR1 and QR2 sections used the course implementations from the intervention. This section describes the study to assess student attrition rates and faculty perspectives. Further, we implemented and assessed 6 other UGEM courses that had varying degrees of theory to practice.

Pilot Study

A pilot study was conducted as a proof of concept (see supplemental materials I). The pilot study was run on 2 courses. The control group had 520 students across 11 sections. The intervention group had 152 students across 3 sections. The pilot data showed that student attitudes and outcomes improved with the feature changes and supported moving forward with the full-scale implementation.

Data Collection and Analysis

The analysis compares student attrition rates (W+F) in course offerings before the feature changes and after the feature changes. The analysis includes QR1 and QR2 because QR1 and QR2 had notably higher degrees of translation than the other UGEM courses. This analysis includes course offerings from the same terms of the year:

- QR1 (course number <redacted>): January 2019 – October 2019 compared with December 2019 - October 2020. QR1 did not have a December 2018 offering.
- QR2 (course number <redacted>): February 2019 – October 2019 compared with February 2020 - October 2020.

Note that subsequent course attrition rate is hard to measure because subsequent courses diverge substantially.

Results

Attrition Rates

Student attrition rates were defined as the percentage of students earning an F grade in the course or withdrawing from the course. As given in Table 3, QR1's attrition rates reduced from 17.5% before the course's features changes to 4.7% after the changes. Similarly, QR2's attrition rates reduced from 13.9% to 4.0%.

Table 3. Attrition Rate before and after Feature Changes

	Before changes	After changes
QR1	17.5% (N=5851)	4.7% (N=7716)
QR2	13.9% (N=6619)	4.0% (N=8083)

Figure 4 shows each offerings' attrition rate. Attrition during the control period is shown on the left, and after the intervention is shown on the right. Attrition rates before changes were around 15-20%, whereas attrition rates after changes were around 4-5%. A change in the university's learning management system may have contributed to the particularly high attrition rate around April'19 and May'19.

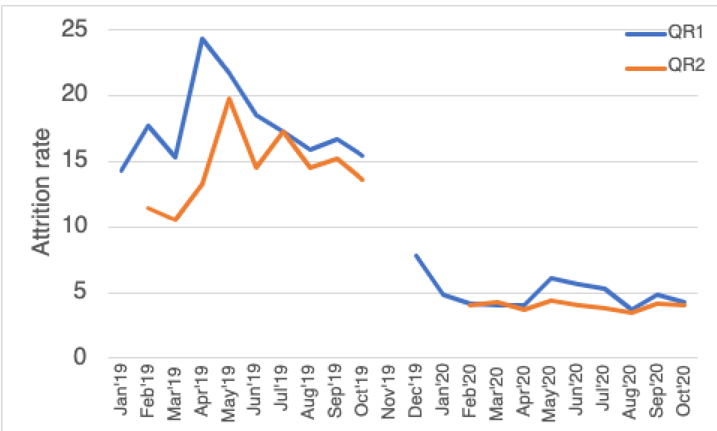

Figure 4. Attrition Rate of Each QR1 and QR2 Offering

Although attrition rates are a key outcome, we wanted insights from faculty to help narrate the impact of the observed changes.

Student Persistence through QR Sequence

A preferred progression is for a student to take QR1 then take QR2 as the next course, then take a non-QR course. Sometimes, a student will take QR1, then get frustrated with math, and take a non-QR course, then return to take the subsequent QR course; such a scenario would not be considered a preferred progression. We focused on degree seeking students actively enrolled in an eligible program to obtain a bachelor's degree.

Table 4 shows persistence data for students that started QR1 in a particular date range. Between April and September 2019, 2427 degree seeking students started QR1 before feature changes, which we call the control group. Between April and September 2020, 3725 students started QR1 after feature changes, which we call the intervention group. We tracked how many students completed QR2 by February of the respective years.

Students in the intervention group progressed to QR2 at a higher rate (84.0%) than students in the control group (69.6%). We also tracked students as they progressed into the third course of the preferred progression (which was dependent on student program) by February of the respective years. Students in the intervention group progressed to the third course at a higher rate (85.1%) than students in the control group (70.8%); in other words, 14.3% (= 85.1% - 70.8%) of 3725 students, or 533 additional students, were kept on track after feature changes.

Last, we tracked how many students retook QR1 as a second course (if they did not successfully complete it the first time). Students in the intervention group retook QR1 at a lower rate (2.0%) than students in the control group (7.6%). This is likely due to the decreased attrition in the intervention group as described in the previous section.

Table 4. Degree Seeking Students Entering Subsequent Courses within 5-10 Months

	Students Started QR1	Students started QR2 as second course by Feb	Students started third after QR1 course by Feb	Students retook QR1 for their second course by Feb
Control	2427	69.6%	70.8%	7.6%
Intervention	3725	84.0%	85.1%	2.0%

In addition to attrition rates and student persistence, we sought insights from faculty to help narrate the impact of the observed changes.

Faculty Perception

A survey was administered to faculty after the first course implementation. The survey asked:

- How many times the instructor taught the course
- Three Likert-like agreeability questions from Strongly Agree (5) to Strongly Disagree (1):
  - o The new materials are an improvement from the previous materials.
  - o The new materials support students with developing mathematical content knowledge.
  - o The new materials support positive student attitudes and self-efficacy.

The survey included 19 faculty members in QR1 and 23 faculty in QR2.

Table 5 shows the number of times each responding instructor had taught either QR1 or QR2. Note that one survey was sent to QR1 faculty and another survey to QR2 faculty. QR1 appears to have a bimodal distribution with some faculty being new to teaching the QR1 course and some being highly experienced.

Table 5. Number of Times Faculty Members taught the Course

Times taught	QR1	QR2
0	8	4
1-2	3	6
3-4	0	2
5 or more	8	11

Table 6 shows the mean and standard deviation of faculty perspectives on the new course materials on the scale Strongly Disagree (1) to Strongly Agree (5). Faculty tended to have a positive perspective on the new course materials, having responses slightly greater than half-way between "Neither Agree nor Disagree" and "Agree". A 3.0 would be considered neutral. However, the relatively high standard deviation indicates that faculty perspectives were quite diverse.

Table 6. Average Faculty Perspectives on the New Course Materials

	QR1	QR2
The new materials are an improvement from the previous materials.	3.4 (1.4)	3.5 (1.3)
The new materials support students with developing mathematical content knowledge.	3.5 (1.4)	3.4 (1.4)
The new materials support positive student attitude and self-efficacy.	3.6 (1.4)	3.6 (1.4)

Differing Degrees of Translation: Other UGEM Courses

QR1 and QR2 had a high degree of translation, meaning that nearly all to all of the features were implemented in these courses. The other 6 UGEM courses had lower degrees of translation than QR1 and QR2, meaning that fewer of the features were implemented in these courses. This section shares the impact of attrition rates when a lower degree of translation is used.

This analysis includes course offerings from the same terms of the year for the other 6 UGEM courses:

- Introduction to College Algebra (course number <redacted>): February 2019 – October 2019 compared with February 2020 - October 2020.
- College Algebra (course number <redacted>): March 2019 – October 2019 compared with March 2020 – October 2020.
- Calculus 1 (course number <redacted>): March 2019 – September 2019 compared with March 2020 – September 2020.
- Calculus 2 (course number <redacted>): July 2019 compared with June 2020. Calculus 2 does not run each term. At the time of this writing, June 2020 was the only term to have completed, and the nearest comparison 1 year prior was July 2019.
- Statistics 1 (course number <redacted>): September 2019 – October 2019 compared with September 2020 – October 2020.
- Statistics 2 (course number <redacted>): September 2019 – October 2019 compared with September 2020 – October 2020.

Table 7 shows attrition rate and student count before and after feature changes for the other 6 UGEM courses. Each UGEM course had a lower attrition rate after the feature changes were implemented in the respective course.

Table 7. Attrition Rate before and after Feature Changes

	Before changes	After changes
Intro College Algebra	21.7% (1652)	10.7% (1594)
College Algebra	17.2% (1538)	9.9% (1472)
Calculus 1	36.2% (116)	10.5% (114)
Calculus 2	23.1% (26)	10.5% (19)
Statistics 1	16.9% (195)	10.6% (151)
Statistics 2	23% (61)	15.3% (72)

Need Scalability and Sustainability: Differing Degrees of Translation

Translation of theory into practice took substantial effort and intentionality in the quantitative reasoning courses. The process for quantitative reasoning revisions would not easily be sustainable or scalable in the remainder of the UGEM courses. As an attempt to continue to improve, but at a scalable rate, different degrees of translation were explored. Differing degrees were determined by implementing partial components of the philosophical framework. These partial translations were implemented to determine if improvements in student outcomes were acceptable, or if full framework implementation would be required to achieve results. Data from initial implementation of partial translation showed improvements in student outcomes, though not as great as full framework implementation.

Introductory courses had the highest amount of translation, because of their foundational nature. Additionally, these courses are where misperceptions and misconceptions about mathematics arise, and we wanted to resolve those early. Higher-level courses tended to have fewer attrition issues, so received fewer translations. This does not mean that we did not implement our philosophical framework in these revisions. However, we did implement less of it.

Table 8 shows the degrees of translation for each theory. The “Low” degree tends to contain older, more foundational research, and the “High” degree contains all theories, including the latest theories.

Table 8. Degrees of Translation for Each Theory

	Degree of Translation		
Theory	High	Medium	Low
Metacognition and Affect	x	x	x
Conceptual Change	x	x	x
Social Constructivism	x	x	x
Academic Self-concept	x	x	
Holism	x	x	
Systemic Functional Linguistics	x		
21st Century Knowledge Framework	x		

Table 9 shows the degrees of translation for each course feature. Some course features are easily updated, such as discussion questions and advisory language, so we included more theories in such course features.

Table 9. Degrees of Translation for Each Course Feature

	Degree of Translation		
Features	High	Medium	Low
Advisory language	MA, CC, AS, H	MA, CC, AS, H	MA, CC, AS, H
Remediation	MA, CC, SC, AS, H, SFL, 21	MA, CC, SC, AS	MA, CC, SC
Discussion questions	MA, CC, SC, AS, H, SFL, 21	CC, SC, AS, H, SFL	CC, SC, H
Reading assignment	MA, CC, SC, AS, H, SFL, 21	MA, CC, SC, AS	MA, CC, SC
Homework assignment	MA, CC, SC, AS, H, SFL, 21	MA, CC, SC, AS	MA, CC, SC
Grade pass back to student	MA, AS, H	MA, AS, H	MA, AS, H
Late work policy	MA, CC, AS, H	MA, CC, AS, H	MA, CC, AS, H
Exams	MA, CC, AS, 21	MA, CC, AS	MA, CC
Rigor	MA, CC, AS, H, 21	MA, CC, AS, 21	MC, CC, AS

The above tables are key outcomes of this theory to practice work that will be used at our university, effectively enabling a blueprint for future implementations. This blueprint may be valuable to many other universities looking to reduce attrition rate, via assessing the potential impact of course revisions when facing challenges in resources and/or prioritization.

Blueprint for Translating Theory into Institutional Practice

After the intuitional paradigm-shifting was complete, a blueprint for future changes of this magnitude was created (see Figure 5). This blueprint will be used for translating theory to practice in other disciplines such as science at the institution.

Figure 5. Blueprint for Institutions to Translate Theory into Practice

Step 1: Create Philosophical Framework

A philosophical framework is a set of educational theories used to guide implementation decisions. When adding a theory to your framework, validate compatibility with other theories, and seek evidence for that theory's efficacy. Such evidence is invaluable for later discussions with institution stakeholders and developing ideas for implementation. Table 1 lists the 7 theories used in this paper.

Step 2: Identify Course Features

Make a list of course features for a given course. Some course features may overlap. Sometimes a course feature will be spread across multiple other course features, such as "rigor" being a qualitative measure of the difficulty of homework and exam questions. We identified 9 course features as shown in Table 2.

Step 3: Apply Framework to Features

Pick a theory from your philosophical framework and then apply that theory to each course feature, drafting how that theory could be implemented. We found it much easier to think about how to apply 1 theory to many features than apply all theories to 1 feature. After drafting implementations for 1 feature, the subsequent features tend to be much quicker.

Step 4: Pilot for Proof of Concept

A pilot is useful to both gather evidence as a proof of concept, and quickly identify and resolve pain points in the pilot course. The pilot may be multi-phased and undergo frequent scrutiny. A pilot course is going to have numerous minor issues that would be naturally ironed out over a few course offerings. Such minor issues can collectively distract students from learning and instructors from teaching. Attention should thus be given to quickly resolve issues, so the pilot has a chance to show proof of concept. In any case, the results of the pilot inform a decision on next steps.

Step 5: Future Implementation Plans

Future implementations include improvements to the pilot course and performing step 3 ("Apply Framework to Features") on other courses. During and after the pilot course, numerous ideas for improvement will arise and need to be addressed. Separately, the experience of translating theory to practice for the first course will make such translations faster for subsequent courses in the same discipline. The pilot will have likely reduced institutional barriers to implementing the philosophical framework (developed in step 1) in new courses.

Step 6: Induce Institutional Paradigm Shift

The institutional paradigm shift requires unique training for each group of stakeholders, so each group can articulate the translations using appropriate language. In many cases, the way stakeholders viewed and defined math education required change to accurately represent new courses. When opening these rather philosophical conversations, we found it helpful to begin the conversation with information specific to various stakeholder roles.

Institutional leadership appreciated first understanding the outcomes of the pilot, namely reduced attrition rates and improvement in student experiences that aligned with university goals. Cross-college leadership (such as Associate Deans) wanted to know if students were prepared for their programs, such as one Associate Dean being interested in student preparation to later engage in field-specific research and methodology courses. Faculty appreciated explanations on the math-specific research theories and evidence therein.

Assessment teams and instructional designers were interested in the research theories in a broad sense. Student support services appreciated support with engaging in empathetic and validating communication about mathematics with students. This group is very important and large because they directly and regularly communicate with students. A key for maintaining the shift seems to be providing resources for them to sustain their knowledge by providing an inventory of misconceptions about math education and student experience in math. Further, a set of continuous feedback loops help maintain the paradigm shift by deliberately creating a system of oversight. Namely, periodically gathering feedback from faculty and students, as well as using an assessment process and plan.

Conclusion

A key challenge to resolving the shortage of skilled STEM workers is to learn how to support students with developing mathematical knowledge and skills required to move forward in those fields. Undergraduate math education has frequently failed to prepare students because of the large gap between educational theory and classroom practice. We closed the theory to practice gap by translating 7 modern education theories across 9-course features. After implementation, attrition reduced from 17.5% (5,851 students) to 4.7% (7,716 students) in QR1 and from 13.9% (6,619 students) to 4.0% (8,083 students) in QR2 at the university. Degree seeking students increased persistence through the QR1 and QR2 sequence from 70.8% to 85.1%, meaning 533 additional students were kept on track after implementation.

Moreover, attrition notably reduced in 6 other UGEM courses that had lesser degrees of theory to practice translation, indicating that strategically implementing theories for a subset of course features can still have a substantial impact. The attrition reductions validated the implementations. A key contribution of this work is a blueprint for an institution to similarly close the theory to practice gap in courses, including objectives for communicating with each stakeholder group.

If the theory to practice gap is going to be closed, more than just an awareness and understanding of education research and best practice is required. Institutional barriers for closing the gap must be addressed. Otherwise, translations from theory to practice are neither scaled nor sustained at institutional levels. The blueprint for translation addresses some of those challenges such as gathering varied and appropriate support from institutional stakeholders and the potential requirement of inducing an institutional paradigm shift about a particular phenomenon or topic. For this gap to be closed, leadership from various groups need to work together, including leaders in education research, administrators, instructors, student support services, instructional designers, operations/logistics, and more. Such efforts, although substantial, have enormous potentials, such as undoing generational cycles of less than effective math education.

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