

WHITE PAPER

Theory to Practice: Closing the Gap in Undergraduate Math to Reduce Student Attrition

Jacquelyn Kelly, PhD, University of Phoenix

Jim Bruno, University of Phoenix

Alex Edgcomb, PhD, zyBooks



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Jacquelyn Kelly, PhD, University of Phoenix, jacquelyn.kelly@phoenix.edu

Jim Bruno, University of Phoenix, jim.bruno@phoenix.edu

Alex Edgcomb, PhD, zyBooks, alex.edgcomb@zybooks.com

Abstract

Researchers have developed numerous effective methods and theoretical models for teaching undergraduate general education mathematics (UGEM); however, many universities have struggled for decades to bridge the translational gap in courses. This gap has contributed to the national lack of a skilled STEM workforce. Recently, University of Phoenix has decided to close the gap in translating theory into practice by shifting the institution's philosophical framework about math education from traditionalist methodology to a synthesis of seminal theories and best practices.

The purpose of this paper is to disseminate the implementation of theory-based practices in UGEM toward reducing student attrition, including: Rationale for theory identification, the construction of a philosophical framework for course implementation, collection of stakeholder input, implementation, evaluation of the impact on attrition, post-implementation maintenance and communication, and institutional socialization of the new paradigmatic shift.

These efforts yielded an attrition rate reduction from 17.5% to 4.7% of students withdrawing or failing in Quantitative Reasoning 1 and from 13.9% to 4.0% in Quantitative Reasoning 2. A key outcome of this work is a blueprint for an institution to similarly close the theory to practice gap in courses.

Introduction

For decades, math attrition has been a challenge in higher education. While new knowledge has been discovered in the field of mathematics education to guide institutions in better supporting learners of mathematics, many of those theories and practices are not successfully translated into the institutions of higher education at scalable or sustainable levels [Korthagen2007]. In 2012, the National Council for

Teachers of Mathematics released their position statement regarding the link between research and practice:

“Linking research and practice in mathematics education is necessary for addressing critical issues of mathematics teaching and learning. Researchers and school personnel must work together to address and examine issues pertinent to the teaching and learning of mathematics. Together they need to consider ways to implement strategies across contexts that build on findings from research. Collaboration between researchers and school personnel provides integrated perspectives for addressing critical issues in mathematics teaching and learning” (National Council for Teachers of Mathematics, 2012).

Many varied 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 overwhelming [Kennedy1997][Korthagen2007][Shadle2017].

Often, interventions are implemented at small scales, for example, within a classroom, but are unable to be scaled for institutional implementation; or, specific programs are found to be supportive, but so dependent on single stakeholders, that when those stakeholders leave, the gains and progress leaves with them [Shadle2017]. Such factors contribute to theory-based practice in UGEM not being widespread. Students remain averse to mathematics [Jameson2014], and metrics continue to show that mathematics is a barrier for students to advance to STEM fields and in their general rates of college completion [Dang2017][Watt2017].

The purpose of this paper is to disseminate the implementation of theory-based practices in UGEM toward reducing student attrition, including: Rationale for theory identification, the construction of a philosophical framework for course implementation, collection of stakeholder input, implementation, evaluation of the impact on attrition, post-implementation maintenance and communication, and institutional socialization of the new paradigmatic shift. A key outcome of this work is a model for reducing the theory to practice gap at an institution.

Background and Related Theory

For many years, there has been a documented gap in the knowledge shared within the scholarly community and the instructional practices observed in learning environments [Biesta2007]. This has been especially prevalent in STEM fields which have been the recent focus of education research [Labov2009] yet have not shown improved student outcomes enough to impact the national need of a skilled and abundant STEM

workforce [Borrego2010]. Many colleges and universities use outdated methods to teach mathematics [Lee2018].

More so, some of these best practices are often not part of teacher education programs [Shadle2017][Vanderlinde2010]. Higher education faces an even greater challenge in addressing this theory to practice gap since most professors and teachers of higher education are specialists in the specific subject matter without formal training or knowledge of the findings from education research; in many cases, there is little motivation for faculty to explore knowledge in education research since it is very rarely acknowledged as part of the rigorous and time requirements to obtain institutional tenure [Kensington-Miller2013][Shadle2017]. While there has been a recent change in a few institutions to reward faculty for their pursuits in teaching, these initiatives are recent and have not supported in closing the multi-decade knowledge gap between education research and practice.

The theory to practice gaps do not support students as they work to overcome barriers for learning that could be remedied by the implementation of best practice. While some, more innovative, theories may not be widely accepted in the field of education research, there are a handful of seminal works that have received general consensus (such as those in Table 1). By focusing on these works, institutions may have the ability to bring some of their learning environments up to date with, at minimum, the theories that have been agreed upon for multiple decades. Even implementation of those works would have great potential in improving student outcomes and reducing barriers for student persistence in STEM fields.

How might an institution select a theory, and determine how to implement its associated strategies? To start, defining a curriculum platform, or philosophy of learning can be helpful [Elrod2016]. This philosophy outlines what an institution, or individual, defines as knowledge, learning, and assessment. It outlines what a learning environment should look, sound, and feel like for students and instructors. Additionally, it discusses the role of the student and the faculty in the learning process. By creating a philosophy for learning, an institution has the ability to focus on seminal works in education theory and support institutional stakeholders, including faculty, to adopt a consistent philosophy. It will also support an institution in developing consistent strategies for instruction and assessment.

Much research has advanced pedagogical theory in recent decades. Many such theories are now well-studied and/or well-accepted. We sought such modern, consensus theories toward closing the gap in UGEM courses. Table 1 shows the identified 7 theories used to develop our philosophy of learning, along with associated seminal works.

Table 1: Matrix of theories translated into practice toward closing the theory to practice gap. The included citations focus on seminal works.

Theory	Citations
Metacognition and Affect	[Dole1998][Mayer1998][Moons2007][Sinatra2005]
Conceptual Change	[Strike1992][Carey1999][Carey2000][Chinn1993][Chi2008]
Social Constructivism	[Vygotsky1986]
Academic Self-concept	[Marsh1985][Bong2003]
Holism	[Dewey1997][Mahmoudi2012]
Systemic Functional Linguistics	[Halliday1992][Holliday1994]
21 st Century Knowledge Framework	[Kereluik2013][Mishra2019]

The theories in Table 1 were selected not only because they are seminal works, but they are also in alignment with the mission and vision of the University. In the next section, we will discuss each of the theories and identify how we determined a plan for instructional feature implementation.

Theory to practice

This section describes the specific education theories used and the feature changes implemented to bridge the theory to practice gap in an early math course.

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:** 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:** 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:** 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:** 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 she/he has sufficient math abilities, including: How the student compares her/himself to peers, a student's past successes and failures in math, how the student feels she/he 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:** 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. In particular, the observation that courses include hidden curriculum - informed by policy, class layouts, tone of text/discussion, and instructor perceptions.
- **Systemic Functional Linguistics:** 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:** 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 went through each feature and determined whether that 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, whatever suggestions identified from this process 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 of the suggestion was not reasonable given other course constraints, such as social constructivism applied to a high-stakes exam. Decisions were then made, for each feature. The suggestions which were implemented for a given feature were noted. Discussion of these decisions and implementation of the guiding philosophies to specific course features is included below.

Table 2: Feature differences informed by guiding philosophies before (control) and after (intervention). Each table row includes the guiding philosophies: Metacognition and Affect (MA), Conceptual Change (CC), Social Constructivism (SC), Academic Self-concept (AS), Holism (H), Systemic Functional Linguistics (SFL), and 21st Century Knowledge Framework (21).

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, many places provide instructions or set up a context for students outside of the development of content. This includes documents on how to prepare for the course, directions for how to navigate the course, assignment instructions, classroom announcements, automated messaging, and any other communication that is free from mathematical content. The control’s language 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. Rather than presenting the course environment as a highly rigorous scholarly location,

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 a learner rather than an imposter, and be validated as a whole person.

Remediation

Many students enroll in courses with gaps in their prior knowledge. As a result, remediation is 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 respond to a discussion question in the class forum. A student earns course points for both responding to the question 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], was fully integrated with the homework assignment.

The material was written using a say-show-ask pedagogy. For example, as shown in

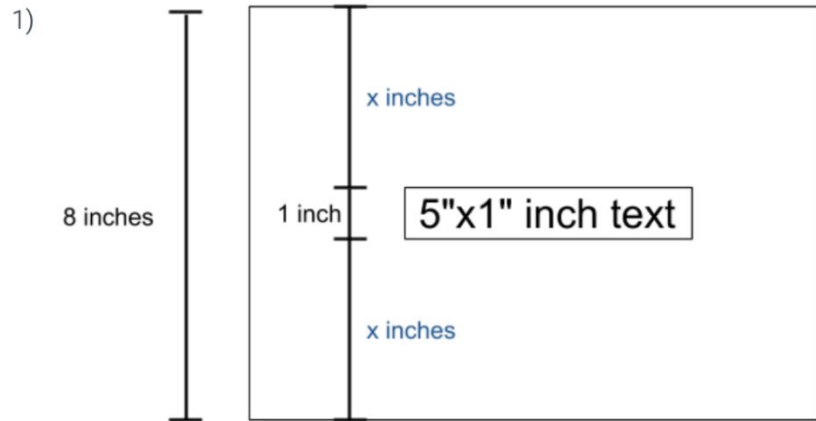
Figure 1: A sub-section begins with saying a few words about the idea, then shows the student a multi-step animation that works through solving an example. The animation incrementally reveals the process of solving, using captions to explain along the way.

A common real-life task that benefits from algebra is centering items, such as text on a page, or a couch along a wall.



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Figure 2: The first of 6 short answer questions, following the content shown in Figure 1. 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.



Above, 5-in wide text was centered horizontally on an 11-in wide page by determining that 3 in. should appear on the left and right sides. The item should also be centered vertically. The text height is 1 in. The page height is 8 in. The equation is thus $x + 1 + x = 8$. What is the value of x ?

inches

Check

[Show answer](#)

The frequent formative activities within the reading supported students as they work 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 treated learning as a conversation, rather than an authoritarian experience, and viewed 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 conditions 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.

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: A randomly generated question for level 2 of a Challenge Activity with 4 levels. The student first must create the equation with x , then solve for x . If either part is answered incorrectly, the student is given an explanation, and then a new randomly generated question of the same difficulty is given.

CHALLENGE
ACTIVITY

5.3.1: Creating equations with x .

Jump to level 1

Complete the equation involving x . Order terms like the physical situation, and don't simplify. Then solve for x .

A soccer goal should be centered in a penalty area. The penalty area is 16 yards wide. The goal is 4 yards wide. How many yards (x) should be on each side of the goal?

Ex: $x + 1 = 16$

$x =$ Ex: 10 yards

1

2

3

4

CheckNext

1

2

3

4

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.

Students received information about their performance, in this case, at delayed intervals. In the intervention condition, 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. Homework assignments, and formative learning experiences, in the intervention condition, were due by the end of the course. To provide a learning frame for students, they were outlined on a weekly cadence and recommended for completion during that week, but 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 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.

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 challenge to engage in skills aligned to the course student learning outcomes.

Pilot: Proof-of-concept

Before fully implementing the features changes across all sections of all math courses, a pilot was needed to provide evidence of effectiveness and proof of concept to institutional stakeholders. We conducted a focus group with key stakeholders and a pilot study of a limited number of course sections. During pilot implementation, we collected data from student attitudinal surveys, student exam performance, and student discussion responses. This data was used to make decisions on next steps.

Focus groups

We conducted semi-structured interviews with all other Associate Deans to understand programmatic needs for math pre-requisite knowledge and perceptions of student needs from the math courses. A key takeaway was that math courses' learning materials were not consistent with what students needed to know.

We also conducted focus groups with Academic Councilors for Business, learning students tended to be fearful of math and did not find math relevant to their goals. Faculty feedback reported student dissatisfaction with the course as well as segmented learning that may have hindered the ability for students to develop functional models of mathematical knowledge.

Pilot study

We conducted a pilot study to validate the feature changes described in sub-section "Practice: Feature changes" before full-scale implementation. This pilot study focuses on descriptive statistics because the course had changed significantly and the study was quasi-experimental, so inferring to the population would not be appropriate.

Method

The control group had 520 students across 11 sections. The intervention group had 152 students across 3 sections.

The course ran for 5 weeks. The control and intervention offerings started in late October 2019.

The following exploratory data was collected:

1. Student experience was elicited via:
 1. A stress survey with 8 questions, shown in Table 3, was administered 1 week before the midterm (week 2 of the course).
 2. A stress survey with 6 questions, shown in Table 4, was administered 1 week before the final (week 4 of the course).
2. Student scores on the midterm and final exams. Exam scores of zero were excluded, unless the student had worked on an assignment that week, indicating the student had really earned a zero. The raw scores were converted to a percentage for ease of interpretation.
3. The attrition rate, i.e., the percentage of students earning an F grade in the course or withdrawing from the course.
4. Student perceptions were from both student responses to discussion questions and weekly student surveys. Both were analyzed for emergent themes.

Table 3: Midterm stress survey questions administered to students. Each question's options were on a Likert-like scale: (Strongly disagree) 1 – 5 (Strongly agree).

Label	Question
Midterm Anxiety	I feel anxious about the upcoming midterm.
Midterm Confidence	I feel confident about the upcoming midterm exam.
Class Enjoyment	I am enjoying this class.
Class Anxiety	I get anxious when I think about this class.
Class Approachable	The material in this course is approachable.
Enough Resources	This course provides enough resources to learn what I need to, as long as I put in the time.
Courseware Success	The courseware contributes to my success in the course.
Text Understanding	When reading the textbook, I am able to understand the concepts being taught.

Table 4: Final stress survey questions administered to students. Each question's options were on a Likert-like scale: (Strongly disagree) 1 – 5 (Strongly agree).

Label	Question
Final Anxiety	I feel anxious about the upcoming final.
Final Confidence	I feel confident about the upcoming final.
Open	I am open to learning math.
Important	Math is important for my future.
Struggle	I think I'll struggle a lot in this math course.
Course Confidence	I feel confident in my ability to do well in this math course.

Real-time data collection interpretation

The following data were collected and interpreted in real-time, enabling administrators to intervene quickly in case the intervention had issues.

The midterm stress survey questions are shown in Table 5. Note that the intervention's mean was higher than the control's mean for every question, except Enough Resources.

Table 5: Midterm stress survey questions' mean (standard deviation) response. Higher is better, except for Midterm Anxiety and Class Anxiety.

Question label	Control (N=76)	Intervention (N=51)
Midterm Anxiety	3.9 (1.0)	3.7 (1.1)
Midterm Confidence	2.5 (1.1)	2.8 (1.1)
Class Enjoyment	3.6 (1.0)	4.0 (0.9)
Class Anxiety	3.5 (1.1)	3.1 (1.2)
Class Approachable	3.6 (0.9)	3.9 (0.9)
Enough Resources	4.0 (0.9)	3.9 (1.0)
Courseware Success	3.9 (0.7)	4.0 (0.8)
Text Understanding	3.4 (0.8)	3.8 (0.8)

The final stress survey questions are shown in Table 6. Note that the intervention's mean was higher than the control's mean for every question, except Course Confidence wherein the mean was the same.

Table 6: Final stress survey questions' mean (standard deviation) response. Higher is better, except for Final Anxiety and Struggle.

Question label	Control (N=60)	Intervention (N=54)
Final Anxiety	4.0 (1.0)	3.7 (1.3)
Final Confidence	2.6 (1.0)	3.0 (1.2)
Open	4.1 (0.9)	4.3 (0.9)
Important	4.0 (0.8)	4.1 (1.0)
Struggle	3.4 (1.1)	3.0 (1.1)
Course Confidence	3.3 (1.0)	3.3 (1.1)

The midterm and final exam scores are shown in Table 7. In both, intervention students performed better than the control students. Interestingly, on the final exam, 94% (491/520) of the control students attempted the final, whereas 99% (150/152) of intervention students did. The control offering's attrition was 14.6%, whereas the intervention's was 5.3%.

Table 7: Student scores on the midterm and final exams. SD means standard deviation.

Exam	Control	Intervention
Midterm	N=485, mean=72, SD=30	N=149, mean=78, SD=17
Final	N=467, mean=70, SD=26	N=147, mean=82, SD=19

As shown in Table 8, the emergent themes from student perceptions would that students started with self-doubt about the student's ability to learn math for various reasons. By the last week (week 5), students tended to have a positive perspective of their math abilities and ability to learn math.

Table 8: Emergent themes of students' perceptions.

Source	Emergent Themes from Inspection
Discussion Questions	<ul style="list-style-type: none"> • Initial fear of math. Long time since last course. • "New math" and comparisons to own children's curriculum • Courseware explanations, visuals, and step-by-step approaches help learning • Love the history and tallying • Still need extra support with fractions • Love the relevance • Math is used everyday, but did not realize it until now
Week 1 Attitudes Survey	<ul style="list-style-type: none"> • Positive way the zyBook helps with wrong answers & examples • Nervous and not good at math
Week 2 Stress Survey	<ul style="list-style-type: none"> • Students positive about courseware, but still critical of their own math abilities • Students are beginning to mention specific content (no apparent themes, however)
Week 4 Stress Survey	<ul style="list-style-type: none"> • Students consistently referring to math content as interesting • Students acknowledging different way of learning math
Week 5 End of Course Survey	<ul style="list-style-type: none"> • zyBook positive comments • Content understandable and relatable

A few student quotes from the end of the pilot may help illustrate the student's perceptions:

- I have been doing really good. I feel that the zyBook learning process is great for my learning style. I need the interactive activities since this is not in a classroom setting. I really like the immediate answers that come back and if you aren't right the first time instead of getting the answer spoon-fed to you, you are encouraged to consider thinking the problem through and retrying it. I really surprised myself by knowing a lot of the information from school. I hope to keep this momentum going.
- When my children first introduced me to the new common core curriculum with math, I thought it was stupid and unnecessary. That was me being stuck in my

ways and not fully understanding it. In just this first week my opinion has been altered.

- I found myself dreading the class too but I take it all back. I have learned a lot and understand that I use quantitative reasoning without even knowing it.
- The concepts in this class made me realize that I use math more than I thought. I used to say that I hate math and was scared of it. I am no longer scared of it. I understand it more and can relate to the topics and understanding.

Another interesting comparison is a student's perceptions in week 1 of the pilot (Quantitative Reasoning 1 - QR1) vs week 1 of the subsequent math course (QR2):

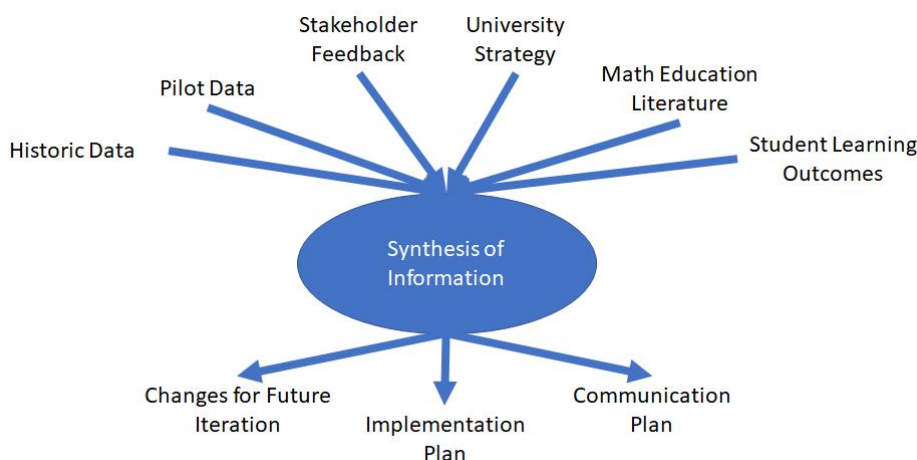
- Student 1
 - QR1, week 1: The next four courses - all math - scare me senseless.... Again - this class almost made me drop out - going to give it my all though.
 - QR2, week 1: I just finished QR I, but had a different professor. I was VERY nervous since I have been out of school for 35 years. I have to say the setup of these courses, makes learning actually enjoyable - NEVER thought I'd say that about math.
- Student 2
 - QR1, week 1: This class will be the first math class I have taken at this school. I have not taken a math class and years and I am very nervous about this course. Math has never been my strong suit and I know that I will have to use every resource available to me.
 - QR2, week 1: I do like how ZyBook breaks down each subject one part at a time and it shows you how to solve the problem step by step. That seems to help me a little more with the math work. I am excited to see what I learn in this course, for some of the things that I need to brush up on or things that I need reteaching on.

Post-Pilot: Apply Theory-to-Practice in Other Math Courses?

Following the conclusion of the pilot, a critical reflection was conducted to determine the next steps at both a course level and then programmatic level. The pilot data validated the feature changes, so implementation across all sections of QR1 and QR2 was pursued. The process of coming to these conclusions was achieved by engaging a programmatic evaluation lens to make sense of and interpret the data collected from the pilot study.

Figure 4 shows the inputs and outputs associated with deciding on moving forward. The inputs included: Historical data, pilot data, stakeholder feedback, the University's strategic direction, best practices from the scholarly field, and intended learning outcomes for students.

Figure 4: The inputs used to decide whether to proceed with implementation across all math courses, and the actions planned as an outcome of the decision to do so.



The pilot data showed that student attitudes and outcomes improved. This contrasted strongly with the historical data, which supported a decision to move forward with changes. However, before moving forward, data was presented to a variety of institutional stakeholders to secure buy-in and limit any potential barriers to implementation. Additional information considered was the alignment of proposed changes to University strategy, mission, and vision. The newer materials were more strongly aligned to the ability for adult learners to have meaningful experiences and aligned to supporting career advancement.

Math education literature was referenced to ensure anecdotal and limited quantitative evidence was consistent with trends reported and generalized by the scholarly field. A subsequent cross-check of student learning outcomes was completed to ensure proposed changes would support students through subsequent programmatic coursework. Once each of the constructs described was assessed, the decision was made to implement the changes to QR1 and QR2. The input information helped to guide decisions about improvements before implementation, the actual implementation plan, as well as the communication/training plans required for the successful roll-out of large-scale implementation.

Each planned action is discussed in subsequent sections.

Changes for Future Iteration

As a result of information collected as part of the pilot study, minor modifications were made to update the course materials. Faculty feedback was used to enhance some of the mathematical concepts introduced in the course readings. For example, the way that exponential functions were described was changed to ensure consistency and comprehension within the student experience.

Additional directions for students were included to support their navigation through specific course features as a result of student feedback. Naming conventions of assignments were modified to promote clarity. While none of these changes were large, by themselves, the pilot information supported their implementation to best maximize the student and faculty experience.

Course Implementation Plan

We had all QR1 and QR2 sections use the pilot's course implementation with the enhancements discussed in the previous subsection. Then, we planned to assess the full implementation's outcomes. An analysis of the results of the course implementations for QR1 and QR2 is discussed in the Study of Course Implementations section below. Then, if the outcomes were positive, we planned to modify 6 other UGEM courses with varying degrees of theory-to-practice.

Institutional Communication

Having fully implemented the features changes, there were still 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, such as: Academic rigor is equal to the amount of time spent, remediation before the course helps student success, independent remediation contributes to student success, and 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.

Study of Course Implementations

We implemented the course changes in all sections of QR1 and QR2. 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.

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 MTH/215T): January 2019 – October 2019 compared with December 2019 - October 2020. QR1 did not have a December 2018 offering.
- QR2 (course number MTH/216T): 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.

Attrition rates

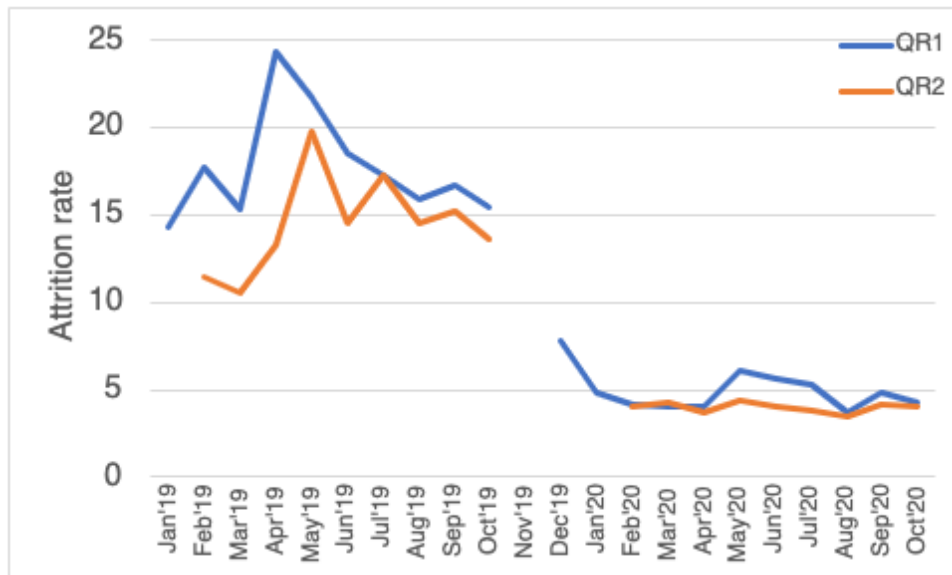
Student attrition rates were defined as the percentage of students earning an F grade in the course or withdrawing from the course. As shown in Table 9, QR1's attrition rates reduced from 17.5% before the course's features changes to 4.7% after the changes. Similarly, QR2's attrition rates reduced from 13.9% to 4.0%.

Table 9: Attrition rate (and student count) before and after feature changes for QR1 and QR2.

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

Figure 5 shows each offerings' attrition rate. Attrition rates before changes were around 15-20%, whereas attrition rates after changes were around 4-5%. Note that the high attrition rate around May'19 is a typical annual phenomenon.

Figure 5: Attrition rate of each QR1 and QR2 offering. Before the changes are shown on the left, and after the changes are shown on the right.



Although attrition rates are a key outcome, we wanted 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):
 - The new materials are an improvement from the previous materials.
 - The new materials support students with developing mathematical content knowledge.
 - The new materials support positive student attitudes and self-efficacy.
- An open-ended question: Please provide any feedback or comments you have about the new course materials for the course...
 - The open-ended question was analyzed for themes.

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

Table 10 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 10: Faculty to the respective course were surveyed for the number of times the faculty member had taught the course.

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

As Table 11 shows, faculty tended to have a positive perspective on the new course materials, having responses half-way between “Neither Agree nor Disagree” and “Agree”. However, the relatively high standard deviation indicates that faculty perspectives were quite diverse.

Table 11: Mean (and standard deviation) of faculty perspectives on the new course materials on the scale Strongly Disagree (1) to Strongly Agree (5).

	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)

Some faculty comments were positive about the course's feature changes, writing:

- The students - me too - REALLY enjoy the concept of starting with the problems and learning the logic behind the solutions. Then, learning how to solve the problems becomes much easier.
- There have been nine start dates, the last one was the [QR1] pilot. What I find consistently across the [QR1], [QR2] and [College Algebra] classes I've taught is that students like the zyBook approach over the previous math labs.
- New material is significantly better than old ones
- Very nice selection of topics, practical and appropriate for this level course.

Although the majority of feedback from faculty was positive, there were some faculty who had concerns about the level of rigor in the courses:

- Topics are very practical, but the level is middle school.
- The overall content is reduced from the previous course materials.

Rigor is a construct with an inconsistent definition within many faculty and education practitioners. An outdated definition is often described as the ability for students to complete tasks. Some faculty report their measure of this construct by the number of challenges students report encountering when completing a task. So, when many students are struggling in a course or showing signs of learning difficulties, faculty with this definition may assume the course is rigorous. On the contrary, when students are frequently able to successfully demonstrate learning, faculty with this definition may assume the course is not rigorous enough.

When defining rigor in this process, the University used a standard-referenced, philosophy-based definition of rigor rather than an outdated norm-referenced view of rigor. The intervention condition defined rigor as the students' ability to apply a concept at increasing levels of cognitive complexity. As students were required to engage in increasing levels of cognitive challenge, the revised courses actually required students to demonstrate higher levels of cognitive rigor than the previous courses did.

However, as students demonstrated higher levels of rigor, they were doing so in an environment that was optimized for the learning. This resulted in students feeling positive and confident as they achieved student learning outcomes rather than frustrated and overwhelmed. The faculty comments about rigor provided insights about potential development opportunities that might be made available to ensure faculty used the same operational definition of rigor and were aware of how to implement it into practice in the math courses.

Differing Degrees of Translation: Other UGEM Courses

QR1 and QR2 had a high degree of translation, as shown in Table 2. The other 6 UGEM courses had lower degrees of translation than QR1 and QR2. 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 MTH/219T): February 2019 – October 2019 compared with February 2020 – October 2020.
- College Algebra (course number MTH/220T): March 2019 – October 2019 compared with March 2020 – October 2020.
- Calculus 1 (course number MTH/280): March 2019 – September 2019 compared with March 2020 – September 2020.
- Calculus 2 (course number MTH/290): 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 MTH/217): September 2019 – October 2019 compared with September 2020 – October 2020.
- Statistics 2 (course number MTH/218): September 2019 – October 2019 compared with September 2020 – October 2020.

As shown in Table 12, each UGEM course had a lower attrition rate after the feature changes were implemented in the respective course.

Table 12: Attrition rate (and student count) before and after feature changes for the other 6 UGEM courses.

	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)

As will be discussed in the subsequent section, some real-world limitations (e.g., time) may reduce the degree of translation. However, even reduced degrees of translation yielded significantly reduced attrition rates.

Discussion

The process of implementing theory to practice in our UGEM courses began with recognizing that our student outcomes were not optimal and that student aversion to mathematics was common and perpetuated by the course. A thorough review of course offerings and the current state of courses helped identify potential opportunities for improvement. Once this assessment was completed, scholarly literature in the field of learning theory, online instructional practice, and math education was reviewed to develop a philosophical framework to guide course revision plans.

As this philosophy was solidified, the University searched for a vendor partner with a shared philosophy to work with as a collaborator in completing a redesign of the entire UGEM portfolio of courses. Once collaboration began, course content was developed and course experiences were designed. To test the initial impacts of these dramatic changes, a pilot study was conducted to gather quick feedback and determine the feasibility of full implementation and additional course revision opportunities.

The pilot study provided evidence to affirm moving forward and information to further enhance future plans. Full implementation was planned and additional courses were prepared for revision. As the new philosophical framework was implemented at scale, student outcomes began to improve. At this time, it became apparent that additional internal training was required to support institutional stakeholders with understanding the philosophical paradigm shift that was occurring to best support productive advisement of students.

An internal training about math education and the new paradigm was created and deployed to various departments for student-facing services. Additional conversations

continued with leadership from multiple academic units and colleges. Mathematics is now talked about differently at the institution, which reflects the learning experiences students will have. Additionally, student outcomes have increased and attrition has remained improved.

Need Scalability and Sustainability: Differing Degrees of Translation

Translation of theory, as represented by our philosophical framework, 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 rather than the framework in its entirety.

These partial translations were implemented and monitored to determine if improvements in student outcomes were acceptable, or if full framework implementation would be required to achieve results. Data from the initial implementation of partial translation showed improvements in student outcomes, though not as great as full framework implementation. Data will continue to be monitored. However, the University now has a model that describes what outcomes can be expected with differing degrees of translation.

Introductory courses had the highest amount of translation, and mostly full framework implementation, because of their foundational nature. Additionally, these courses were the ones that students struggled most with additional misperceptions and misconceptions about mathematics, and we wanted to resolve those early.

Higher-level courses tended to have fewer attrition issues, so received fewer translations as we knew if students made it to high-level courses, students likely faced fewer challenges with success, regardless of the instructional environment. This does not mean that we did not implement our philosophical framework in these revisions. However, we did implement less of it.

Table 13 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 14 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 13: Degrees of translation (high, medium, and low) for each theory.

Theory	Degree of Translation		
	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		
21 st Century Knowledge Framework	x		

Table 14: Degrees of translation (high, medium, and low) for each course feature.

Features	Degree of Translation		
	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 process of implementation and intuitional paradigm-shifting was complete, reflection was done to generalize a blueprint that could be used for future changes of this magnitude.

This model will be used for translating theory to practice in other disciplines such as science at the institution. The summarized blueprint is shown below. Further discussion of the processes follows.

Figure 6: A blueprint for a process to translate theory into practice at an institutional level.



Step 1: Create Philosophical Framework

A philosophical framework is a set of educational theories that are used to guide implementation decisions. When adding a theory to your framework, validate compatibility with your other theories, and seek (and keep a copy of) evidence for that theory's efficacy. Such evidence is invaluable for later discussions with institution stakeholders, as well as developing ideas for how to implement the theories. 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. Frankly, we found it much easier to think about how to apply 1 theory to many features than apply all theories to 1 feature. In fact, after you have drafted implementations for 1 feature, the subsequent features tend to be much quicker. Table 2 lists each theory in each course feature, as descriptions of the implementations are throughout the section "Practice: Feature changes".

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, like ours that started with focus groups of stakeholders and then was followed by the implementation in a single section of a course. The pilot may have frequent scrutiny, like ours that had weekly check-ins (including student surveys and course performance) while the pilot course was running. 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. So, attention should 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

The shortage of the skilled STEM workforce has been noted. A key challenge to resolving that shortage 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 research 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 of Phoenix.

Moreover, attrition significantly 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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