Technology Solutions for Developmental Math
An Overview of Current and Emerging Practices

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Overview

Many experts in the world of mathematics and beyond contend that we cannot meet our developmental math student success goals without incorporating technology. The implementation of innovative technology in program design and practice, as reviewed in this report, provides us with an initial look at how technology can be used to expand, strengthen, and create efficiencies in the delivery of developmental math practice. Despite an expanding knowledge base in developmental[1] math practice and the rapid expansion of technology in education, critical challenges remain in maximizing the promise inherent in these innovations. These include blending best practices in developmental math with leading technological innovation, developing a more robust and convincing evidence base, expanding development efforts for promising learning technologies, and overcoming the resistance to change that characterizes the organizational culture of many community colleges.

This report looks at the challenges of remediating math skills in community colleges and the potential of technology to address these challenges. It begins with a short review of current instructional strategies in community college developmental math, including the central pedagogical approaches. The paper continues by identifying several categories of emerging curricular innovations and presenting examples of how selected strategies are being implemented in community colleges. The main body of the report focuses on technology and its role in supporting and strengthening the teaching of developmental math, including the current use of technology as well as promising directions for future use. It concludes with a discussion of adoption challenges in moving forward, from both a curricular and institutional perspective. The report is intended as a broad overview of current practices rather than an in-depth study or recommendation of particular instructional methods.

I. Introduction

Math literacy is increasingly becoming a focal point in the efforts of the United States to remain competitive in the global economy. Among the "troubling international comparisons" cited in a new report[2] was a 2007 assessment finding that 15 year olds in the United States ranked 25th among their peers in 30 developed nations in math literacy and problem-solving. According to the report, commissioned by Department of Education Secretary Margaret Spellings, "the sharp falloff in mathematics achievement in the U.S. begins as students reach late middle school, where, for more and more students, algebra course work begins." [3]

This juncture is particularly important for community colleges because pre-algebra and beginning algebra are the levels in which large numbers of community college students are assessed and placed. [4] If we accept the report finding that students who complete Algebra II are more than twice as likely to graduate from college than students with less mathematical preparation, then the ability of developmental math programs to prepare students for college-level math is key to the success of large numbers of students who arrive at college without the skills necessary to succeed.

The alarming status of math skills comes as no surprise to faculty and staff at community colleges, whose mission encompasses the task of raising the skill levels of students who enter college with pre-college skills. The challenge of raising math skills is further compounded by the fact that students who test into remedial math coursework are disproportionately minority and disproportionately first-generation, two characteristics of at-risk students.[5]

In the past five years, the critical role of developmental math in the retention and success of community college students has come under additional scrutiny, partially through the attention and resources of national initiatives, such as the Lumina Foundation for Education's *Achieving the Dream* project, the Ford Foundation's *Bridges to Opportunity* project, the Joyce Foundation's *Shifting Gears* Project, the Charles Stewart Mott Foundation's *Breaking Through Initiative*, a joint project of Jobs for the Future (JFF) and the National Council of Workforce Education (NCWE), and the William and Flora Hewlett Foundation and Carnegie Foundation for the Advancement of Teaching's *Strengthening Pre-Collegiate Education in Community Colleges (SPECC)* project. This attention has been accompanied by several research efforts in developmental education and a parallel policy focus on the implications of this research for higher education policy. The combination of interest from foundations, public policy groups and researchers who view math as the gatekeeper to college success have yielded a variety of new strategies and programmatic innovations, with a parallel focus on evaluating and assessing the promise of these strategies in terms of replication, scalability and sustainability.

Prominent in these innovations is the use of technology in remediation, whether as Computer Assisted Instruction (CAI), web-enhanced, hybrid, or fully online course delivery – as well as the use of Open Education Resources. The integration of technology into instruction is documented as a critical element in literature reviews and policy discussions, but at the same time, it is an area where innovation has clearly outpaced research and evaluation.

II. Current Pedagogical Patterns of Community College Developmental Math

A recent Community College Research Center (CRCC) working paper on developmental mathematics in community colleges identified two major patterns in U.S school mathematics teaching and learning as having the most value:

- Skill efficiency (also known as procedural efficiency), defined as the "accurate, smooth, and rapid execution of mathematical procedures; and
- Conceptual understanding, defined as the mental connections among mathematical facts, procedures and ideas. [6]

In *Principles and Standards for School Mathematics*, revised in 2000, the National Council of Teachers of Mathematics (NCTM) advocates an integrated approach to mathematics content, calling for an increased emphasis on data analysis, the development of meaningful contemporary application, and the use of appropriate technologies, as well as activity-based and collaborative learning.[7] The need for an integrated approach echoes in the March, 2008 National Mathematics Advisory Panel report to Education Secretary Margaret Spellings: "to prepare students for algebra, the curriculum must simultaneously develop conceptual understanding, computational fluency and problem solving skills."[8]

While there is broad agreement on the importance of both computational fluency and conceptual understanding, the issue of which skills should be taught, and in what order, has not been resolved. Additional questions center on the relative breadth and depth of the competencies that should be included in the curriculum. In 2003, the National Center for Education Statistics (NCES) conducted a cross-comparison of mathematics schooling and curriculum in 42 countries. In *Highlights from the Trends in International Mathematics and Science Study* (TIMSS), the authors argue for a coherent curriculum, describing the U.S. curriculum as “a mile wide and an inch deep,” adding that “mathematics standards are long laundry lists of seemingly unrelated, separate topics.”[9]

A look at best-selling community college math textbooks and software packages will show that developmental mathematics curriculum in community college settings (for the most part) replicates approaches in K-12 that may not have served students well. There are notable exceptions in some community colleges, examples of which are discussed in this paper. But the debate over the definition of mathematical proficiency and mathematics content standards has fundamental implications for shaping new directions in the teaching of remedial mathematics. Furthermore, despite widespread agreement that both procedural fluency and conceptual understanding are critical for success in higher level mathematics, there is continued debate on how to effectively teach procedural fluency (including what competencies should be taught) and how to foster conceptual understanding, This tension between the procedural fluency vs. conceptual understanding approach to developmental math instruction emerged as a key theme in the preparation of this report, with corresponding implications for future directions in technology.

III. Emerging Curricular and Support Innovations in Developmental Math

Since its publication in 2002, Hunter Boylan’s “What Works in Remediation”[10] has been the beacon of best practice in developmental education. Since then, several literature reviews on effective and/or promising practices have emerged, including “Basic Skills as a Foundation for Student Success in the California Community Colleges”[11] (a product of the California Basic Skills Initiative) and the Connecticut community college system’s, “Promising Practices for Community College Developmental Education.”[12] In 2005, a U.S. Department of Education, Office of Vocational and Adult education (OVAE)-funded report, “Strengthening Mathematics Skills at the Postsecondary Level: Literature Review and Analysis,”[13] narrowed the focus to issues in developmental math. The following year, “Building a Foundation for Student Success in Developmental Math,”[14] (funded by the Fund for the Improvement of Post-Secondary Education (FIPSE) to the community college system of Massachusetts) further refined the discussion from a review of the literature to a systemic set of recommendations to improve the delivery of developmental math.

While the literature identifies specific strategies of effective practice[15], when we look more closely at examples of innovation, we are more likely to discover complex models that combine several instructional, programmatic and student support strategies. The examples that follow illustrate this point. We initially categorize these examples by a central component, but as the descriptions demonstrate, these successful program models employ multiple strategies and would be more accurately categorized as holistic rather than as identified by a single characteristic. For the purpose of this report, we list programs based on the key component under discussion.

Intensity

Intensity models have a key component of additional time on task, whether through additional hours, supplemental instruction, tutoring, or classes held on consecutive days. **Foothill College's** *Math My Way* program cites intensity of instruction (time on task) and mastery as key components. *Math My Way* also employs self-paced delivery and technology, using ALEKS math software. *Math My Way* students are periodically assessed and re-grouped according to a strict standard of mastery, with classes held five days a week, two hours each day, approximately double the contact hours of the traditional format. Preliminary outcomes point to a 20% higher success rate in college level math for program completers than for students in previous cohorts. Foothill College mandates that all developmental students enroll in *Math My Way* (Pre-Algebra) or Math 220 (Elementary Algebra), dependent on their Accuplacer assessment scores. Since many students enrolled in Math 220 may have not come from Math My Way, a class element has been included as a "booster" to permit them to refresh their concepts and not fall behind."[16]

Another program that features intensity is **DeAnza College's** Pre-Collegiate Mathematics Pilot, the key components of which include student support, teacher training, and technology using EnableMath's mastery-based homework system. In an April 2006 report, the college observed that the pilot "appears to be having an affect on student learning outcomes, but that it is hard to say the relative effect of each intervention," and the fact that students are in a "special cohort may give them more motivation."[17]

Reduction/redesign of curriculum

Some community colleges are re-grouping and reducing the number of math competencies in an effort to facilitate the development of both procedural and conceptual math thinking. **Pasadena City College** Project Director Brock Klein describes the rationale for this approach in this way: "The content/coverage issue is the single most common reason math instructors give for not transforming their practice." He continues, "They claim that they do not have time to be innovative. They have to cover ten chapters." However, when pre-algebra concepts were reduced by one-third and practical applications for essential concepts were provided to students, retention and success rates increased. In addition, students in courses with "reduced cognitive load" fared as well as students in control groups at the next higher level, beginning algebra.[18]

Pasadena City College cites improved math outcomes in a variety of formats that combine intensity, learning communities, student engagement and curricular redesign, but Klein recognizes that it is difficult to attribute these gains to specific program components. He also cites the importance of the college's faculty-driven inquiry process to create and evaluate a variety of innovative programs to increase retention and success rates. As Klein remarks, "It's not just about program intensity. It's also about how faculty and students interact in and out of the classroom."[19] Technology has not been a key feature of Pasadena's programs, but is expected to play a greater role in the redesigned curriculum.

Project-Based Learning

The Digital Bridge Academy (DBA) at **Cabrillo College**, takes a strength-based and project-based approach, starting with the belief that students from poverty have a deep understanding of social injustice and holding that knowledge is a strength because they are actually "experiential experts in social justice." Students in the DBA collect data as part of a three month primary research project on a student chosen social justice issue. The team-based research project becomes a springboard for motivated study in the "feeder" courses that surround the project: literacy, computer applications, teamwork, movement and career planning. After completing one fully integrated 16.5-unit Bridge semester, students are ready to enroll and succeed in regular college level courses like English and Sociology. According to the NSF evaluator, DBA students showed increased GPAs (3.7 compared to 1.7) and a higher persistence rate in their subsequent semester (50% compared to 28%).[20]

The curricular design of the Algebra Project's (TAP) pilot course for **Miami Dade College** in fall of 2007 utilized cooperative learning in an experientially based format, emphasizing students' confidence in the ability to learn mathematics, as well as development of mathematical knowledge in the form of conceptual understanding and procedural skills. To ensure that the mathematical concepts are meaningful for the students, the entire class engages in activities that form a set of shared experiences. Then, working individually and in cooperative groups, the students analyze observations about their experiences. With guidance from the teacher, some of these observations are chosen for emphasis because their analysis leads to the mathematical concepts which are to be covered in the course. Once the students have had an opportunity to construct their understandings of these concepts, relatively traditional exercises are used to reinforce their understandings and develop the desired procedural skills. In the last week of the course and over an intensive weekend just before the exam, students work on specific problems of the kind likely to be on the exam and on developing their test-taking skills. The course taught traditionally had posted a very low passing rate. In comparison, of the 37 students in the pilot, 34 passed the standardized Florida state exit exam.[21]

Contextual Learning

Contextual learning is generally associated with the blending of academic and vocational competencies, as exemplified in career pathway programs.[22] Contextualization is based on the proposition that "people learn more effectively when they are learning about something that they are interested in, that they already know something about, and that afford them the opportunity to use what they already know to figure new things out.[23] Many of the contextual learning practices in mathematics have been practiced for years in traditional community college occupational programs. For example, what is often entitled "shop mathematics" is a standard part of any apprenticeship program. In other areas, such as machining, the mathematics is embedded in the introductory material -- often consuming more than half of the curriculum. The mathematics curriculum is rarely taught by a mathematics faculty member. Rather, the math instructor is usually the occupational instructor. This practice has existed for years in community colleges and is part of the unique approach to teaching and learning often taken by occupational educators.[24] More recently, contextualized learning has gained attention as a way to increase student motivation and accelerate student learning in the transition from developmental math to college-level skills.[25]

Students in **Community College of Denver's** *Certified Nurse Assistant to Licensed Practical Nurse* (CNA to LPN) program, and **Southeastern Arkansas Community College's** (SEARK) program, which was modeled after the CCD effort, show strong outcomes in skill mastery, retention and certificate completion.[26] Both programs use a holistic approach that includes student support services, a work-based learning community, contextual curriculum, technology and acceleration as central components, while linking math competencies to health care competencies. In a session on contextualized math at the 2007 Breaking Through conference, math faculty from both CCD and SEARK noted that contextualizing pre-algebra math skills with allied health competencies was not difficult, but that the task became significantly more challenging as students moved into the higher levels of remedial math. [27] According to CCD's Brad Sullivan, "We can contextualize, that's not the problem. The problem is we can't do it in the same amount of time that we are given to cover the competencies mandated in the course content guide." [28]

The Joyce Foundation's Shifting Gears Project is piloting a number of contextualized learning projects as part of six-state effort to move low-skilled adults into career pathways. In Indiana, **Ivy Tech Community College** is working to "embed" developmental math skills into the coursework for introductory classes in the college's industrial technology and automotive certificate programs. The goal of the embedded math pilots is for students to increase the level of their math skills within the framework of the existing technical curriculum, with the goal of achieving college math readiness. Tutoring support and advising are also integrated into the program design. Although technical faculty and academic faculty are actively engaged in the development of curriculum, the time constraints of covering both academic and technical content within the span of a single course poses a serious challenge.[29]

Acceleration

Strategies to accelerate the movement through the developmental math sequence is gaining attention as research identifies the negative correlation between time spent in remediation and certificate and degree completion.[30] The following examples demonstrate two different approaches to acceleration - reducing the time spent in developmental courses by offering traditional content in an intensified time frame, and reducing the time spent in remediation by targeting specific skills gaps.

Community College of Denver's FastStart@CCD allows students to complete two levels of remedial math within one semester. The program cites acceleration as its key component, but describes itself as a holistic program that draws its effectiveness from a blend of accelerated instruction, student support, a learning community format, interactive teaching, and career exploration delivered in a first-year experience class. Acceleration is the motivation that students give for entering the program, while the blend of strategies is the reason that faculty and staff give for the program's success. FastStart students post significant differences in course completion and GPA, although retention rates for students in early cohorts was not significant. The most dramatic gains were in the passage of college-level math, where FastStart students had a 40% success rate in college math three semesters after the intervention, as opposed to a 12.5% passage rate for the comparison group after five semesters.[31] The accelerated math classes use a mastery approach, supported by Pearson's My Math Lab software. Initially funded through the Lumina Foundation's Colorado Initiative for Performance, FastStart@CCD has continued with funds from Breaking Through and is moving toward institutionalization, serving approximately 150 students a semester. The program recently added a course combination pairing the highest level developmental math with the initial college-level math course.

Ivy Tech Community College, Evansville, replicated the CCD accelerated model in fall of 2007, with similar initial outcomes.[32] Approximately 150 students enrolled in the Evansville pilot in each of the first two semesters. Ivy Tech anticipates that approximately 25% of its developmental math students will eventually enroll in the accelerated format.[33]

Acceleration is often used in conjunction with assessment and targeted remediation. As more states adopt mandatory placement and assessment policies, efforts have increased to identify and remediate students who may test close to the "cut-off score" as a way to reduce unnecessary time and money spent in developmental coursework.[34] Self-paced, competency-based, and modular courses have proven successful for some students, as have "refresher courses" for returning students.[35] Computerized diagnostics and targeted remediation, delivered in conjunction with the major assessment tests (Accuplacer and Compass), are also being utilized more frequently with students who assess into the upper range of placement tests. There is no clear agreement on how many students may be able to accelerate through targeted remediation, although math chairs at Community College of Denver and Ivy Tech Community College, Kokomo, estimate that between 10% and 35% of students would fall into the category of benefitting from targeted remediation rather than the more traditional format.[36]

Additional acceleration models at Ivy Tech and Colorado Community Colleges Online are discussed further in the technology section.

Learning Communities

Learning communities emerge repeatedly in the literature as one of the most effective strategies in promoting retention and success in first generation students. The term "learning community" is used broadly to include a variety of approaches that enroll a cohort of students in a cluster of different classes. Central to the learning community concept is the "intentional restructuring of student's time, credit and learning experiences to build community."[37] An MDRC study of learning communities, showing significant gains for students who participated in learning communities, is one of the few research studies of developmental students to employ random assignment.[38] Since different examples of the learning community model were included in many of the previously cited innovations, additional examples will not be detailed. However, the frequency with which learning communities appear in conjunction with effective practice reinforces the importance of the strategy as a key innovation, and should be kept in mind as we move from discussion of effective practice to a focus on innovations in technology.

IV. Technology Innovations in Developmental Math

The use of electronic technology in developmental math began decades ago with the introduction of calculators into the classroom. Debates quickly followed over the wisdom of utilizing technology tools that are capable of performing the very skill that the student is trying to learn.[39] While many new technologies have been introduced since then, the same arguments remain today regarding their appropriate use for developmental math students. In 1995, The American Mathematical Association of Two-Year Colleges (AMATYC) established "use of technology as an essential part of an up-to-date curriculum" as one of its guiding principles in the standards for college-level math preparation.[40] AMATYC reiterated the "use of technology" as a basic principle and standard for intellectual development in its follow-up report in 2006.[41]

Most community college faculty acknowledge that all students should be familiar with technology, as it has become an essential skill used in everyday life, on the job, and in pursuing related academic goals. There is little controversy anymore over using technology tools such as word processing software, spreadsheets, presentation software, and e-mail. Some would even see these as essential to a productive learning environment. But increasingly, students need a greater level of technology literacy to take full advantage of academic, job-related, and even social opportunities. In achieving this next level of literacy, technology must be used as more than a productivity tool; it must become a seamless part of the learning environment.

Community colleges lag behind public and private four-year institutions in the use of technology for instruction. For example, instructional software (e.g., tutorial) programs have been in use for many years in community college classrooms, yet less than 40% of two-year colleges reported use of a Learning Management System or Course Management System in 2007.[42] With growing demand from students, colleges are struggling to implement the latest technologies, both in IT infrastructure and in academic technology innovations. The degree to which faculty in developmental math departments have embraced basic and advanced technologies varies widely across community colleges.[43]

The 2005 OVAE report reviewed several studies pertaining to developmental math instruction in two-year colleges. While OVAE did not find scientifically based evidence to support new instructional practices, emerging pedagogical themes suggested "promising but unproven" instructional strategies. Among the promising recommendations emerging from the literature were: greater use of technology, integration of classroom and laboratory instruction, offering students a variety of instructional delivery methods, project-based instruction, proper student assessment and placement, and integration of counseling and professional development. The OVAE study further found a general consensus from the literature that "technology should be a supplement to, as opposed to a replacement of, more traditional delivery methods."[44] Furthermore, the study found no clear consensus on the effectiveness of technology-based delivery methods, having reviewed such practices as computer-assisted instruction, Internet-based, self-paced, distance learning, computer algebra systems, use of graphing calculators and spreadsheets.

Course Transformation and the Use of Instructional Software

Computer Assisted Instruction (CAI) traditionally has been used to supplement instructor-led classroom teaching. Students typically access some form of math tutorial/practice software in a computer laboratory setting or online, and work independently to build skill levels while addressing deficits. Many of the products are designed to identify skill deficiencies, and use artificial intelligence systems to help students master increasingly challenging material through continuous assessment. Most are commercial products, available from a variety of publishing and educational software companies. Examples include My Math Lab, Math Zone, ALEKS, Plato, Cognitive Tutor, EnableMath, and Nspire. By some estimates, CAI is used in more than 40% of community colleges nationwide.[45] While scientific evidence through controlled experiments is lacking, there are studies documenting improved results for developmental math students who use CAI.[46]

At the same time, several emerging practices in the field are challenging the assumption that technology is best utilized only as a "supplement" to more traditional approaches. The examples below demonstrate how effective changes can occur when technology is fused with "reconceptualized" instructional strategies.

<u>Program in Course Redesign – The National Center for Academic Transformation</u>

Supported by a grant from the Pew Charitable Trusts, the Program in Course Redesign was created in 1999 to demonstrate how colleges and universities could redesign instructional approaches using technology to achieve quality enhancements as well as cost savings.[47] Key elements of the Program in Course Redesign are whole course redesign (rather than by section), active learning, computer-based learning resources, mastery learning, on-demand help, and alternative staffing (replacing expensive faculty labor with inexpensive labor or technology where appropriate). Among the 30 institutions that have participated in the Program in Course Redesign, 25 have shown significant increases in student learning.[48] Of the 24 that measured retention, 18 showed noticeable increases. Qualitative outcomes have included better student attitudes toward the subject matter and greater satisfaction with the mode of instruction. All 30 institutions reduced costs by 37 percent on average, ranging from 15 to 77 percent.[49] The most important contribution of the Program in Course Redesign is evidence that effective change through technology cannot be achieved by simply "adding on" technology to existing instructional practices. This only adds cost, and little, if any learning gains. Only by redesigning a course completely, aligning technology with learning objectives, and finding the appropriate synergy between pedagogy and technology – can real learning gains be achieved.

Redesign of Developmental Math in Tennessee

As part of a FIPSE-funded three-year project (2006-2009), the **Tennessee Board of Regents** undertook an effort to develop more effective and efficient delivery of developmental math at several colleges: Austin Peay State University, Chattanooga State Technical Community College, Cleveland State Community College, and Jackson State Community College. The project was carried out in partnership with the National Center for Academic Transformation (NCAT), building on lessons learned through the Program in Course Redesign – with a goal to "increase completion rates for students, reduce the amount of time that students spend in remedial and developmental courses, and decrease the amount of fiscal resources students dedicate to remedial and developmental education."[50]

An important feature of the Tennessee Redesign initiatives was a focus on *modularization*. Previously, students were placed in one of three full semester developmental math courses based on how they scored on a systemwide uniform placement testing system. Under this format, students were required to take an entire course even though they may have been deficient in only a small portion of the topics. In the new models, a modularized curriculum was identified as a key strategy in order to offer shorter, more tailored math segments that would enable students to save time and money by only enrolling in modules that addressed their deficiencies.

The redesign of developmental math at **Jackson State Community College** (JSCC) combined three developmental studies courses into one, modularizing the content into 12 segments. Students could enter the sequence where needed and study only those concepts they needed to master. In a spring 2008 pilot course, students earning a grade of C or better increased from 41% in the traditional course to 54% in the redesigned format. Students were able to accelerate their completion with 10 students completing the equivalent of two courses in one term and 25 students completing part of their second course in one term. The mean post-test scores by module in the redesign were equal to (or in most cases better than) those in the traditional course. Except for one module (factoring), all mean gains from the pre-test to the post-test were higher in the redesigned course, frequently by 10 points or more. These gains were statistically significant, according to Carol Twigg of NCAT.[51] Students also indicated reduced math anxiety, which was another of JSCC's goals. Plans for fall 2008 include improving the placement process and requiring student engagement in focus groups.

Though not formally part of the initial Redesign institutions in Tennessee, **Pellissippi State Technical Community College** also redesigned its developmental math program. Their strategy included a modularized approach with support from Carnegie Learning's CAI product, Cognitive Tutor. Pellissippi's goal was to provide a more customized instructional path for the diverse student population they serve and to focus on a deep conceptual understanding of mathematics. The new approach integrates individualized computer-assisted instruction with classroom instruction. Sections meet one hour per week in the classroom and one hour in the math computer lab. Students are required to spend two additional hours per week working in the lab where instructor/tutor support is available. The curriculum is divided into 9 modules, covering the mathematics topics that were previously covered in three levels of developmental math courses. The new structure treats all developmental math students as being in a single course, but students have different software assignments, depending on their performance on a placement test taken prior to beginning the course. Students progress through this modularized curriculum using the Cognitive Tutor, which emphasizes both procedural and conceptual thinking, meaningful applications and modeling, connections between representations, continuous formative assessment, and mastery learning. The classroom instruction focuses on conceptual understanding of broad mathematical topics and skills needed for college success (e.g., study skills, time management, career information). Preliminary results from the pilot phase of the redesign revealed increased success and retention rates compared to traditional lecture sections.[52]

Transforming Course Design in the California State University System

As part of a system-wide initiative to transform course design in a number of disciplines, faculty members from institutions across the **California State University** (CSU) have been collaborating on an initiative to transform course design in developmental mathematics. The faculty attended the national Redesign Alliance conference, sponsored by NCAT, in March 2008 and began planning for a unique CSU-customized implementation of course redesign. Some of the redesign methods being pursued by team members include:

- Encouraging "time on task" with online homework
- Using student assistants for supplemental instruction
- Replacing some lecture time with small group work
- Individualized pacing with computer-based tutorials
- Focusing on mastery learning of fundamental concepts
- Addressing instructional costs for course success.

The faculty teams collaborate through web-based work spaces, which track tasks by week, and list new content.[53] According to Tom Carey and Jeff Gold, coordinators of the program, "The idea is to get a critical mass of faculty all working on course design as a distributed team in a common area of interest (but not working on a single common course). This allows institutions to invest at a manageable level while enjoying a depth and breadth of investigation which a single institution could not normally achieve."[54]

In partnership with California community colleges and sponsored by the Hewlett Foundation, a new initiative will be launched in fall 2008 to build on the success of the CSU project and leverage the lessons learned: Faculty Collaborations for Course TransformationS (FACCTS). This initiative will engage collaborative innovation teams across institutions in pilot studies in the redesign of developmental mathematics courses, supporting implementation of the instructional principles identified in the California Community Colleges' Basic Skills Initiative. Expected benefits from the project include improved student outcomes in developmental math; greater effectiveness of faculty time in course redesign resulting from collaboration; increased transfer of knowledge; reuse of resources, and creation of open educational resources.

Los Medanos College – Integrated CAI

At **Los Medanos College**, the developmental math curriculum focuses on five core student learning outcomes that dovetail with the National Research Council's definition of mathematical proficiency. Classroom activities, developed collaboratively by college faculty, focus on mathematical modeling instead of the traditional algebra curriculum. Activities are designed to intentionally foster conceptual understanding, procedural fluency, strategic competence and adaptive reasoning. All developmental courses have an integrated lab component. Instructors are encouraged to use Cognitive Tutor, a CAI product that emphasizes mathematical modeling as well as procedural skill-building. For access to Cognitive Tutor students pay approximately half of the usual cost of a textbook plus a nominal fee for the class activity packet.

Innovation in the program is supported by ongoing professional development in the form of Faculty Inquiry Groups (FIGs) that meet weekly to discuss lessons, analyze student work, and revise curriculum based on student performance. According to Myra Snell, professor of mathematics at Los Medanos, "Faculty need structured learning experiences with assignments that require reflection and synthesis; and they need frequent feedback, safety, understanding, and incentives to participate."[55]

Ivy Tech Community College – Online Accelerated Remediation

Funded by the Eli Lilly and Company Foundation, the Ivy Tech Online Accelerated Remediation (OAR) program was designed to offer an alternative form of remediation to students. The program uses My Math Lab, from Pearson Education. Pearson has customized this software to align with Ivy Tech's placement test (the COMPASS exam) and with developmental courses offered at Ivy Tech. Students work through the tutorials, receiving appropriate training and assessment, to allow them to test out of developmental coursework, and more quickly reach college or program level courses.

After taking the COMPASS placement test, students who require remediation in math are referred to OAR staff. Students first must participate in a "pro-active advising session" where staff members act as case managers, discussing scheduling, goal-setting, and providing students with a clear idea of how to proceed in the program. OAR Program staff look for indicators of the student's likelihood of success in an accelerated, online, self-paced model. Indicators include: level of remediation needed, time the student has allotted for studies, and motivation to work independently. Once enrolled in the program, students continue to communicate with OAR staff and tutors for ongoing support. Tutors are responsible for contacting the students and creating a level of comfort by building on the pre-existing relationship formed in the enrollment process. According to Jessica Armstrong, program director, "This program is focused on students who need a refresher course, but may not need a whole semester of developmental coursework."[56] At this point, the number of students who have successfully re-tested after participating in OAR are small. The program leaders are considering adaptations that could strengthen student engagement and retention.

Technology-Based Course Delivery: Online and Distance Learning

A number of studies reviewed in the OVAE report evaluated the impact of delivery method (e.g., traditional lecture, CAI, Internet-based, self-paced, accelerated) on student success in developmental math. The general conclusion was the same as has been documented in hundreds of studies examining the effects of various delivery models on learning outcomes: in most cases, there is no significant difference in learning outcomes based on delivery model.[57] While technology-based delivery methods may not be statistically proven to support improved learning outcomes, it very well may be that student persistence in developmental math is enhanced by having multiple options for delivery. In other words, the flexibility of online course delivery and 24/7 support services is especially valued by developmental student populations, who typically have multiple responsibilities outside of their academic pursuits. The regular class meetings required in a traditional lecture-based course can be a barrier for many students who work and manage family responsibilities in addition to their developmental coursework.

Furthermore, faculty with online teaching experience have reported that online delivery provides a more open and democratic environment, with less likelihood of discrimination based on visual perception. Many students who would not speak-up in a traditional class are less intimated by the asynchronous online setting, and will become more fully engaged in online discussions with their instructor and other students.

In the past, concerns about student access to technology resources, and even a perception that underserved student populations were less capable of using technology -- slowed adoption of new delivery models for fear of excluding the so-called digital "have-nots." While the Digital Divide certainly still exists, the number of Americans connected to the Internet continues to grow. As of April 2008, 55% of adult Americans had broadband internet connections at home, up from 47% who had high-speed access at home in March of 2007. However, growth in broadband adoption was flat for those with incomes less than $20,000 and for African Americans. Those with incomes between $20,000-$40,000 saw broadband penetration increase by 24%, with 45% of Americans in that income range having high-speed internet access from home.[58] While not all students have high-speed Internet access from home, a 2005 Pew Internet & American Life report showed that over 80% of Americans up to age 40, and 75% up to age 60 were going online on a regular basis.[59] Furthermore, progress has been made on student computer ownership, which grew overall from 51 percent in 2002 to 67 percent in 2004. Computer ownership at community colleges jumped from 12 percent to 34 percent during that same two-year period, and grew to 38.5 percent in 2005.[60] The lower ownership rate at two-year colleges underscores the continuing need for up-to-date public computing labs on campuses.

Student demand for fully online courses[61] continues to grow at an astonishing rate. Nationally, 3.5 million students took at least one online course during fall 2006; a nearly 10% increase over the previous year. The 9.7% online enrollment growth rate (24% for community colleges) exceeds the 1.5% growth of the overall higher education student population.[62] Because of the gravitation of enrollment toward the online medium, it becomes even more important that educators in developmental math begin exploring delivery models and support mechanisms that enable students to be successful in this learning environment.

<u>Colorado Community Colleges Online: Fully Online Accelerated Developmental Math</u>

Beginning in 2007, **Colorado Community Colleges Online (CCCOnline)** combined two of three developmental mathematics courses and offered them back to back, in an online, accelerated format – all in one 15-week semester. The advantage for students was that they could quickly complete two levels of developmental coursework without the interruption of a semester break, and more quickly gain the skills needed for college level math. Important aspects of this innovative delivery model include:

- Advising structure to assess student readiness (e.g., experience with online learning, Accuplacer scores on the higher end of the cut score range, time available for coursework.)
- Building appropriate levels of interaction and support within the course design (e.g., group work, discussions).
- Academic and student support services available 24/7. SmartThinking tutoring services are used for academic support. A technical support help desk is available to CCCOnline students 24/7.
- Cohort learning community established between two courses, as well as faculty continuity.

For Spring 2007, student success rates (passing with a C or better) grew from less than 50% in the traditionally paced semester to over 70% in the accelerated model. Fall 2007 data showed similar differences in success rates. These differences are expected to decrease; however, as some of the support structures available for the accelerated students have now been implemented for the regular online developmental math courses as well. The entire sequence of three developmental math courses is the fastest growing area at CCCOnline, with over 50% enrollment growth in 2007-2008, indicating a clear demand from students for this type of delivery model.

Future Technology Directions: Open Education Resources, Digital Game-Based Learning, Social Networking, Virtual Worlds

Most students are entering colleges and universities with increasing knowledge of the online world and competence in using a number of "web 2.0" technologies.[63] With a growing level of sophistication and ease, they frequently interact with social networking websites (e.g., My Space, Facebook), video and photo sharing websites (e.g., YouTube, GoogleVideo, Flickr), Blogs and/or Wikis of interest, and even Virtual Worlds (e.g., Second Life, Croquet). A now three-year-old Pew Internet & American Life report showed that 84% of Americans ages 18-24 were using the Internet, with higher percentages coming in at younger ages. In the 29-40 age bracket, 87% of Americans were engaged in online activities. Somewhat surprising was that 81% of teens (ages 12-17) were playing online games, and doing so at a higher rate than any other online activity.[64] Growing in popularity among young people are not just games, but Massively Multiplayer Online Games (MMOG). These three-dimensional worlds have engaged millions of users, who can interact with other players within the environment. Perhaps the most prominent example is *World of Warcraft*, which claims more than six million users worldwide. Each of the technologies mentioned above has unique characteristics and potential benefits for learning, but they share a common theme: they help people connect with each other via the Web.[65]

In higher education, a relatively small number of "early adopter" faculty members have begun integrating these Web 2.0 technologies into the instructional space. Some faculty maintain blogs, or participate in collaborative research through Wiki-like work spaces. It is not uncommon to find faculty investigating or creating video clips through YouTube, and making these part of student assignments. A significant number of institutions or academic departments have purchased real estate in Second Life, usually to deliver lectures or discussions, but also for the purpose of attracting prospective students.[66] Some colleges have even established MySpace or Facebook pages for the same purpose. In an effort to engage students through technology, more and more faculty are seeking out the best learning materials available in their disciplines through Open Education Resource (OER) content providers, such as the MIT Open Courseware Initiative, the National Repository for Online Courses (NROC), as well as multi-media content repositories, such as MERLOT, Connexions, and discipline-specific repositories.

Few examples exist that can show the potential benefits of these Web 2.0 technologies for use in developmental math. It may be, however, that this is where the greatest opportunity lies. Proponents of digital game-based learning have long argued that the drill-and-practice type of games that make up the majority of instructional math games could be effective for higher levels of learning if designed and implemented well. Between the growing popularity of games with the "Net Generation" and the growing body of research on its effectiveness on engagement and learning, Digital Game-Based Learning (DGBL) could eventually become an effective technological solution to the challenges facing developmental math learners.

DGBL experts tell us that games are effective partly because the learning takes place within a meaningful context. What you must learn is directly related to the environment in which you learn and demonstrate it. Furthermore, games thrive as teaching tools when they create a continuous cycle of cognitive disequilibrium (foiling expectations) and resolution without exceeding the capacity of the player to succeed. The most immersive and engaging games are currently in the entertainment or "edutainment" space, not necessarily designed for serious academic pursuits. In fact, some DGBL proponents worry about the dangers of "academizing" (i.e., taking the fun out of) games. They say past attempts to build educational games were stunted by academicians who had little understanding of the art, science, and culture of game design.[67] In spite of efforts dating back to the early 1980s, research and development of digital games in online learning is still considered to be in its infancy. As stated by leading experts Gibson, Aldrich, and Prensky, "We are just beginning to understand and document, through a blend of IT and social research, how game and simulation elements can take advantage of global network infrastructure to add live data, new social contexts, and distributed processing. . . These promising new capabilities allow the player to be part of an extended, living community of inquiry and practice."[68]

One of the challenges for implementation will be reconciling what we know about "Net Generation" learner profiles with what we know about the developmental student population. Researchers at Pennsylvania State University have suggested that the "game generation prefers doing many things simultaneously by using various paths toward the same goal, rather than doing one thing at a time following linear steps. They are less likely to get stuck with frustration when facing a new situation; on the contrary, they push themselves into a new situation without knowing anything about it and prefer being active, learning by trial and error, and figuring things out by themselves rather than by reading or listening."[69] The degree to which this type of learning style corresponds to developmental learner needs is not yet determined.

In addition to the challenge of building developmental math products that currently do not exist, there are significant infrastructure needs that would have to be addressed by colleges before a DGBL approach could be widely implemented. Games require high bandwidth and high-end computers, with powerful sound and video cards, and sometimes speakers and headsets. Most community colleges and developmental learners would be ill-equipped to support and use this particular learning technology in the near future. Longer-term visioning, however, probably includes the eventual creation (through OER models) and adoption of this technology for developmental math instruction.

National Repository for Online Courses (NROC)

The National Repository for Online Courses (NROC) is a library of high-quality online courses for students and faculty in higher education, high school and Advanced Placement©. Supported by The William and Flora Hewlett Foundation, NROC is an Open Educational Resource (OER), facilitating collaboration among a community of content developers, teachers, and students worldwide.[70]

NROC maintains and grows the repository by working with content experts drawn from the member community and elsewhere. Through a process called "social authoring," content experts join the NROC editorial, design, and technical development teams to build high quality course materials for the NROC library. The content is distributed free-of-charge to students and teachers at public websites including www.HippoCampus.org. *Institutions* wishing to use NROC content are asked to join a fee-based membership organization, the NROC Network. According to Gary Lopez, Executive Director of the Monterey Institute for Technology in Education, "The future direction for NROC will be in the development and integration of 'Web 3.0' technology into NROC courses. This will include kids building projects together online, using social software and massive multi-player online games."[71] He indicated that developmental math will be a priority subject area for new NROC development efforts.

The Open Learning Initiative – Carnegie Mellon University

Using intelligent tutoring systems, virtual laboratories, simulations, and frequent opportunities for assessment and feedback, The Open Learning Initiative (OLI) builds high quality college level web-based courses that are intended to enact dynamic, flexible, and responsive instruction that fosters learning. OLI is an OER project supported by the William and Flora Hewlett Foundation. Each of the OLI courses is developed by a multidisciplinary team composed of learning scientists, faculty content experts, human-computer interaction experts and software engineers.

As learners work through the open and free OLI learning environment, OLI uses technology to collect real-time interaction level data of all student use. OLI uses this data to create four positive feedback loops: 1) immediate and targeted feedback to learners; 2) feedback to course designers so that the course is improved with each version based on actual use; 3) feedback to learning science researchers so they can validate and refine learning theory; and 4) feedback to instructors so they can use class time in ways that are most supportive of the students' needs. While this report has discussed many advantages to using technology to support developmental math programs, OLI demonstrates that one of the most powerful features of the technology is that it allows developers to embed assessment into every instructional activity and use the data from those assessments to create the powerful feedback loops described above. OLI has shown that using technology in this way can support learners to learn on their own and even support dramatic acceleration in learning.[72]

V. Challenges for Widespread Adoption

The challenges to adoption are a combination of the general challenges to the adoption of innovation that characterize community colleges culture, the challenges of adoption in serving a developmental education population (more specifically, a developmental math population), and the challenges in the adoption of technology innovations.

The general challenges to adoption in community colleges include an organizational culture that favors traditional formats over innovation, the accepted practice of relying on adjunct faculty to teach developmental courses, the lack of professional development resources and/or lack of articulated plans for professional development, the constant fiscal constraints that favor investment in transfer-level courses over developmental courses, the lack of institutional research capacity to track outcomes and support institutionalization of effective practice, and the general failure of the strategic planning process to link outcomes with long-term cost effectiveness.

Within the more specific developmental education math community, there is an overwhelming reliance on procedural fluency to the general exclusion of the conceptual math approach.[73] The reasons for this may be partially rooted in a reliance on adjunct math faculty, who often don't have advanced degrees and are not connected to professional development opportunities that might provide them with alternative curricular approaches. Susan Forman, a national expert in community college developmental mathematics, describes the dilemma of community colleges as "caught in a squeeze between high schools and four year colleges, where they are expected to do the job that was not done in the high schools in half the time, while preparing students for college mathematics."[74] With pressure to do the job quickly, and the lack of professional development to expand teaching strategies, faculty tend to revert to teaching the way they were taught.

An additional factor in the dominance of procedural fluency is the large number of competencies that characterize developmental math courses and the accompanying time constraints. The notion that there is not enough time to teach both fluency and conceptual thinking is the most frequent reason given for the failure to teach both, despite the agreement of national reports on teaching mathematics that both are necessary for success in higher level math courses.[75] Proponents of a constructivist approach, such as the Algebra Project's Ed Dubinsky, dispute the argument that there is not enough time to teach both procedural fluency and conceptual thinking, saying that students who are given a conceptual understanding of math will attain procedural fluency more quickly and will retain these skills more effectively.[76] At present, innovations that look at the reduction of competencies or an expansion of the time (and credits) that would allow both skill sets to be taught represent a major departure from the way in which most developmental math courses are delivered.

In addition to these general challenges, there is evidence that developmental math students have a higher incidence of learning disabilities. Foothill College's *Math My Way* program identified approximately 25% of its lower level math students as having been registered as learning disabled, but estimated that the real percentage was probably between 50% and 70%, based on further evidence. This is particularly significant because of the role of memory in mastery learning.[77]

Finally, there is a consensus that rigorous and thoughtful professional development is critical in the adoption of any proposed innovation, whether content-based, classroom-based, or technology-based. As noted by Myra Snell, "Whatever your approach, it is guaranteed to fail if not wrapped in intense professional development."[78] In the last few years, faculty inquiry groups (FIGs), championed by the Carnegie Foundation for the Advancement of Teaching and funded by the Hewlett Foundation's SPECC initiative have emerged as a powerful tool in engaging both developmental education and college level faculty in improved practice and in fostering innovation.[79] Another aspect of professional development is its role in changing the beliefs of math faculty about student learning. As stated by Wade Ellis of the Academic Senate of the California Community College System, "Getting teachers who believe students can do the work and have high expectations, holding their students to it, is the most important change."[80]

Technology adoption issues carry similar themes, though there are somewhat different adoption issues for technology as a delivery method and technology integration into the instructional model itself. For delivery methods through online learning, barriers to adoption were laid out in the 2007 Sloan Consortium study of online learning:

- Academic leaders cited the need for more discipline on the part of online students as the most critical barrier, matching the results of the 2006 survey.
- Faculty acceptance of online instruction remains a key issue. Those institutions most engaged in online did not believe it was a concern for their own campus, but did see it as a barrier to more wide-spread adoption of online education.
- Higher costs for online development and delivery were seen as barriers among those who were planning online offerings, but not among those who already had online offerings.
- Academic leaders did not believe there was a lack of acceptance of online degrees by potential employers. [81]

The more challenging barriers to widespread integration of technology in developmental math relate to the need for a complete transformation of course design. Most attempts to use technology are simply "add-ons" to the otherwise unchanged instructional process. This approach may bring marginal but not dramatic improvements. As shown in the NCAT Redesign projects, whole course redesign is a required component, including an examination of faculty roles. Tinto reminds us in a recent article that "we must stop tinkering at the margins of institutional life, stop our tendency to take an 'add-on' approach to institutional innovation, and stop marginalizing our efforts and in turn our academically underprepared students, and take seriously the task of restructuring what we do."[82] But, there are a great many faculty in departments across all disciplines waiting for scientifically validated research studies that prove technology's value to enhance student learning. In other words, when "no significant difference" becomes a collection of hundreds of studies showing significant improvement in student learning, only then will some faculty consider new models. Meanwhile, technology innovation continues forward, and early faculty adopters will continue to explore its potential use in developmental math. And students will continue to gravitate toward more flexible instructional models that meet their learning and scheduling needs.

There is also the significant challenge of cost, both for students and institutions. Student computer ownership at community colleges is not where it should be relative to four-year colleges; and unfortunately, the IT infrastructures pale by comparison as well. Most of the CAI math software packages used by community colleges are available only in the commercial market. An OER solution that reaches from the procedural to the conceptual realm in student learning would not only improve the learning experience, but produce significant savings for a population of learners who struggle both educationally and financially.

Finally, evaluation and research that can validate innovative practice remain a huge challenge. While numerous innovations are being implemented, experts in the research community, such as Davis Jenkins of the Community College Research Center, note that valid research requires "large enough numbers, the ability to track students over time, and to compare participants with like people who do not participate to make sure that the groups are similar."[83] At the same time, community college institutional research departments are organized primarily around data reporting to state and federal agencies. With the increased emphasis on accountability and national efforts such as the Lumina Foundation's "Achieving the Dream" project, program evaluation and a concomitant focus on student learning outcomes are becoming a research priority in a growing number of colleges. However, without additional resources, the capacity of community colleges to track student outcomes as part of a continuous improvement process remains a serious challenge.

As stated earlier, innovation continues to outpace research in the use of technology in community college settings, and the results from learning research often do not inform innovation. Experts say this is because learning research as traditionally conducted does not fit with the current context. The scientific "gold standard" of randomized assignment to condition (treatment vs. control) has the advantage of controlling variables to enable more valid inferences. But, such tightly controlled settings have other limitations: they can be shorter in duration and lack the authenticity of regular classroom settings. More "authentic" or holistic classroom studies (such as several discussed in this report) offer the benefit of students learning in classrooms under less constrained conditions. However, such studies have their difficulties too, including a lack of control over relevant variables, which limits potential inferences that can be made about what really worked.

Technological interventions can support a resolution to part of this research dilemma by giving us fine-grain data of student learning activities, collected over long durations in authentic learning contexts. Using embedded assessment, technology allows rigorous research because the online resources can be as controlled as in a lab environment, but be used in the authentic classroom environment. As stated by Candace Thille, Director of the Open Learning Initiative at Carnegie Mellon, "Time is of the essence, and we cannot afford to wait through the long cycles of struggling to translate basic learning research into the real world practice or struggling to derive transferable principles from anecdotal practice. Rather, we can view research and application as synergistic enterprises. The technology enables us to collect the data to do research and innovation at the same time so that we can combine theory and practice to develop effective educational technology and refine learning theory."[84]

V. Conclusion

The pedagogical divide between procedural fluency and conceptual math reasoning, fondly referred to by some as "the math wars," will continue to be played out in mathematics education, in which developmental education is but a sub-set of the playing field. At the same time, the literature on research and effective practice in developmental math, as well as the implementation of innovations in the field, demonstrate that both approaches can be utilized effectively to move students through the developmental sequence.

At this juncture in time, there is insufficient longitudinal data to determine which approach is more effective with developmental math students. Instead, what we do have is evidence of effective practice that is rooted in both pedagogies. As we look more closely into the examples of effective developmental math programs, what stands out is not necessarily the pedagogy of the instruction as much as the presence of other practices that have been identified in the research as effective in promoting the success of developmental students.

For example, Foothill College, DeAnza College, Ivy Tech Community College, and Community College of Denver all implement program models based on mastery learning; while Los Medanos College, Pasadena City College and Cabrillo College all anchor their designs in a more constructivist approach. What these colleges have in common is a multi-faceted holistic approach that combines research-validated strategies that support the non-traditional learner, such as interactive learning, the use of multiple learning modalities, and alternative delivery of instruction, learning communities, technology, and student support services. While further research might move the field in one pedagogical direction or another, there is an overall consensus that both skill sets are necessary. Given that, the primary challenge is to investigate and move forward with technology that will support both traditions of practice.

There is also an increasing awareness that there simply is not enough time to deliver the curriculum *without* technology. Mandates to reduce the time students spend in developmental courses are common, so any expectation that there will be additional time allotted to the task is unrealistic. As an example, the City University of New York (CUNY) will allow only two semesters of developmental work.

At this point in time, the technology applications that support procedural fluency are clearly more prevalent than the technology that would support conceptual thinking. This is partially a response to the status of the developmental math education market, which is still heavily competency-based, and partially because of the relative ease of developing products for a competency-based approach over a conceptual thinking approach. If both skill sets are important, and only one appears to correspond to the present market demand, then funding for innovation emerges as a key component in moving forward.

Endnotes

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