

EXPLORING RESEARCH ON ISSUES IMPACTING MATHEMATICS IN
COMMUNITY COLLEGES AND RAISING QUESTIONS FOR FUTURE RESEARCH

June Lundy Gastón

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Abstract

Two-year colleges have an important role in the educational and economic advancement of the United States, particularly during the current economic crisis. They offer access to higher education for economically and/or educationally impoverished students, as well as for those who have simply returned for further study. Two-year colleges provide academic training for those seeking to upgrade their skills to qualify for promotion or a new career. The colleges also have a crucial role in the recruitment, training, and professional development of STEM educators.

How can community college faculty best help such a diverse group of students achieve a level of mathematical proficiency that will help them meet their personal, academic and career goals? What does research suggest about coursework that will facilitate the development of abstract reasoning skills that lead to proficiency in higher level academic and career-related problem solving?

The American Mathematical Association of Two-Year Colleges (AMATYC) indicates that educators should continue to search for strategies to address various issues such as choice of appropriate mathematics content, effective instructional strategies, use of technology, teacher preparation, and professional development for faculty and support staff (2006). Research and recent legislation (America COMPETES 2007) also promotes k-16 mathematics coursework alignment that impels all mathematics educators to know not only the content of the coursework they teach but "...the connections of that content

to other important mathematics, both prior to and beyond the level they are assigned to teach” (National Mathematics Advisory Panel 2008, p. 37).

This exploration is thus guided by long-standing questions from k-16 mathematics educational research; it ends with questions for further research.

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WHY DO THIS EXPLORATION?

The American Mathematical Association of Two-Year Colleges (AMATYC) indicates that educators should continue to search for strategies to address various issues such as choice of appropriate mathematics content, effective instructional strategies, use of technology, teacher preparation, and professional development for faculty and support staff (2006). Research and recent legislation (America COMPETES 2007) also promotes k-16 mathematics coursework alignment that impels all mathematics educators to know not only the content of the coursework they teach but “...the connections of that content to other important mathematics, both prior to and beyond the level they are assigned to teach” (National Mathematics Advisory Panel 2008, p. 37).

This exploration is thus guided by long-standing questions from k-16 mathematics educational research that begins with a reexamination of the k-12 journey to college level mathematics coursework.

WHAT MATHEMATICS MUST K-12 STUDENTS KNOW TO BE PREPARED FOR COLLEGE-LEVEL MATHEMATICS?

The National Research Council advised that “The mathematics students need to learn today is not the same mathematics that their parents and grandparents needed to learn. When today’s students become adults, they will face new demands for

mathematical proficiency that school mathematics should attempt to anticipate” (NRC 2001, p.1).

Mathematics educators have debated which topics should be taught and how they should be organized. One issue thus involves two alternative high school curriculums, one subject-base and the other an integrated sequence. The advantages and disadvantages of each are linked to the expectations of administrators, teachers, students and parents concerning college preparatory mathematics coursework, preference for a stronger link to the prior elementary level or subsequent college level, choice of ways to develop student real-life problem solving skills, and views on international mathematics assessments and global competition (Reys and Reys 2009). In preparation for college level coursework, the National Mathematics Advisory Panel has stipulated topics in pre-algebra, algebra, geometry and measurement for inclusion in either of the two secondary level curriculums. These topics include computations with whole numbers, fractions and decimals; perimeter and area of plane and solid figures; and solving linear and quadratic equations that precede a comprehensive study of functions (2008).

Many high schools and districts offer such college prep courses and curricula. In preparation for college coursework rigorous secondary curriculums stipulate at least three years of study that usually includes algebra and geometry (Reys et al. 2007). The College Board has published detailed standards and objectives illustrating how cohesive mathematics curriculums in middle school and high school provide an appropriate foundation for subsequent study of the subject and consistently promote problem solving skills (2006).

WHY IS IT STILL SO CRITICAL THAT STUDENTS STUDY
ALGEBRA AND ABSTRACT MATHEMATICS?

Students need to learn algebra and higher level mathematics because these courses promote important abstract reasoning skills; are key components of preparation for college; are prerequisites for many college courses; and are indicators of graduation from college, and earning in the top quartile of income from employment (Achieve 2008). In addition, the growth of jobs in mathematically-intensive areas, such as science and engineering, is outpacing overall job growth (National Mathematics Advisory Panel 2008). Since the global economy also demands higher skill levels in a variety of occupations, more workers will need to be mathematically and scientifically capable, even beyond the traditional professions that require specialized STEM training (Carnegie Corporation of New York 2009).

HOW SHOULD K-12 MATHEMATICS BE TAUGHT?
ACCORDING TO RESEARCH, WHAT APPROACHES AND STRATEGIES WORK?

Supportive of earlier findings by the National Research Council and the National Mathematics Advisory Panel, research indicates that “instruction should emphasize inquiry, relevance, and a multilayered vision of proficiency.” These proficiencies are:

- Conceptual understanding (comprehension of mathematical concepts, operations, and relations)

- Procedural fluency (skills in carrying out procedures flexibly, fluently, and appropriately)
- Strategic competence (ability to formulate, represent, and solve mathematical problems)
- Adaptive reasoning (capacity for logical thought, reflection, explanation, and justification)
- Productive disposition (habitual inclination to see mathematics as sensible, useful, and worthwhile, coupled with a belief in diligence and one's own efficacy)

(Carnegie Corporation of New York 2009, p. 24-25)

Developments in cognitive neuroscience have impacted knowledge about how the human brain learns during each stage of life. As a result of the accumulation of information, views of how effective learning occurs have prompted discussions and questions about a range of teaching strategies, from those that focus on drill and practice to those that focus on conceptual understanding (Bransford et al. 2000, 2006).

In a publication suitable for teacher training, Sousa connects developments in cognitive research and neurodevelopmental science to learning k-12 mathematics, and recognizing and resolving difficulties. For example, in his review of the elements of learning, he includes the general criteria for long-term storage of information, that each day working memory can quickly and permanently store information that has survival value and/or an emotional connection. In clarifying the classroom challenge to teach important mathematical concepts and procedures so they will be remembered, he reveals that working memory saves information if it makes sense when connected to past experiences and prior knowledge, and if it has meaning or relevance for the student. It

takes time for the student to establish such connections to prior knowledge and find meaning; time for the brain to establish appropriate neural networks. Since it may be impossible to learn all the new material at one time, the brain may be selective. Of the two criteria, meaning and sense, meaning has the greater impact on the likelihood that information will be stored long term. Sousa analyses the mathematical scenario in which a student may use a formula correctly one session but not remember how to use it the next session. Research on retention shows the greatest loss of new information occurs within the first 18 to 24 hours. If a student cannot recall new material after 24 hours, it was probably never permanently stored. Thus the concept must be re-taught or reviewed. Sousa subsequently discusses the essentials of developing and implementing better k-12 mathematics lessons with strategies to maximize learning and retention (2008).

The National Mathematics Advisory Panel recommends a wide variety of successful, research-based instructional practices. They include the use of Team Assisted Individualization (TAI) that improves students' computation skills, but not conceptual understanding and problem solving skills. TAI involves heterogeneous groups of students assisting each other, individualized problems based on student diagnostic test results, specific teacher guidance, and rewards based on both group and individual performance. The Panel also lists the importance of teachers' regular use of formative assessment to design and to individualize instruction to improve student learning. The report states that mathematically gifted and motivated students, who are capable of learning faster than students proceeding at a normal pace, should be allowed to do so. The Panel's list of recommendations contains instructional practices involving computation and calculators. To help struggling mathematics students for example, explicit instruction is advised

because it has been consistently effective in improving performance on word problems and computation. The Panel noted that calculators may impede the development of automaticity and adversely affect fluency in computation; there is a need for high-quality research on the use of calculators, including their effects on computation, problem solving, and conceptual understanding. With regard to instructional practices using Computer Assisted Instruction (CAI), the Panel indicated that CAI drill and practice is a useful tool in developing student automaticity, thus freeing working memory and enabling attention to focus on more complex tasks. CAI tutorials were deemed useful in introducing and teaching certain mathematics content to specific student populations. The Panel noted the need for additional research to identify goals and populations best served by tutorials, and details about effective tutorials that include the facet of classroom implementation (2008).

The American Mathematical Association of Two-Year Colleges (AMATYC) stated that providing better professional development for pre-k–12 teachers to implement mathematics standards has become a priority in many schools. The need is particularly great in the middle grades, where a high percentage of teachers have minimal training based on computational arithmetic. These same teachers are expected to lay the foundations of algebra, teach basic geometry and measurement concepts, and introduce applications of probability and elementary statistics. AMATYC advocates that community colleges and school districts develop collaborations to help teachers better understand the mathematics content and related pedagogy that local and state standards require (2006).

The National Mathematics Advisory Panel called for teacher education programs and licensure tests to support the requirement that teachers know mathematical content from an advanced perspective and be cognizant of the connection to the levels before and after the level of their students. The Panel provided a list of content topics that are a part of appropriate mathematical preparation for prospective teachers at the early childhood, elementary and middle school levels (2008).

WHICH NEW K-12 TEACHERS ARE MOST PREPARED TO TEACH?

HOW CAN OTHERS BE BETTER PREPARED?

The Carnegie Corporation of New York, Institute for Advanced Study, Commission of Mathematics and Science Education highlighted The New Teacher Project (TNTP) and Teach for America for their efforts to fill the recruitment gap. These national organizations have offered alternative routes into teaching for candidates who lack traditional teacher preparation, often appealing directly to their altruistic desires to improve the plight of children and society. Since the programs are highly selective, the recruited teachers generally have higher academic qualifications than other candidates, and their work in high-poverty schools appears to have contributed to higher student achievement in mathematics (2009).

Research from the United States Department of Education (US DOE) indicated difficulties in retaining those teachers who are most academically qualified, and those who are young and inexperienced. Recruiting in mathematics and science is hard because these majors usually have more lucrative job options in business or government

(2004). Thus some programs, such as the New York City Teaching Fellows Program, offer special incentives. This program aims to attract both career changers and new college graduates with strong academic backgrounds. Fellows are placed in full-time, salaried teaching positions in their first year and provided an intensive pre-service summer institute, mentoring by an experienced teacher, and enrollment in a subsidized master's degree program in education through a local university (Carnegie 2009).

The Carnegie Corporation of New York, Institute for Advanced Study, Commission of Mathematics and Science Education also revisited a recommendation from the Conference Board of the Mathematical Sciences (CBMS). It stated that the academic preparation of middle grade mathematics teachers should have at least 21 semester hours in mathematics, including at least 12 semester hours on level-appropriate mathematics concepts. By this standard, at least one-third of the nation's eighth graders are being taught by underprepared teachers (2009).

Fathe and Kasabian have examined the crucial role of two-year colleges in the preparation of science, technology, engineering and mathematics (STEM) educators, particularly at the elementary level. The community college role in improving STEM teacher preparation includes developing courses that will articulate with offerings at four-year colleges, exemplifying good teaching for prospective teachers, and collaborating with school districts to assist with faculty development. The goal is to help break the cycle of inferior teachers who produce inferior students who will eventually be unprepared for college level work (2009).

WHAT MATHEMATICS MUST DEVELOPMENTAL STUDENTS KNOW?

HOW DOES THIS COMPARE WITH MATH RECOMMENDED FOR K-12?

The report of the 100% Math Initiative indicates how developmental mathematics can be improved so that nationally more community college students can gain the knowledge and skills they need to successfully pursue their academic goals. The report contains detailed lists of curriculum and instructional objectives for three different levels of developmental mathematics, Foundations of Mathematics and Foundations of both Algebra I and Algebra II (2006). These objectives are generally consistent with the previously mentioned recommendations provided by the National Math Advisory Panel for k-12 preparation for the study of algebra. For example, both documents include the study of fundamental mathematics comprising operations with whole numbers, fractions, decimals and percents, proportions, basic geometry and measurement; and the study of algebra comprising symbols and expressions, linear equations, quadratic equations, functions, and operations with polynomials. The Math Panel includes additional topics such as combinatorics and finite probability.

AMATYC states that desired student outcomes for developmental mathematics courses should be developed in cooperation with partner disciplines. The organization suggests that the content for these courses also address mathematics anxiety, develop study and workplace skills, promote basic quantitative literacy, and create active problem solvers. AMATYC recommends that topics in algebra, geometry, statistics, problem solving and technological experiences be integrated throughout developmental courses; the organization nonetheless stipulates that students should be able to perform single digit arithmetic without the use of a calculator. AMATYC advocates less attention on

algebraic topics, such as factoring, radicals, and operations with rational expressions, and more attention on modeling, communication, and quantitative literacy and reasoning (2006, p. 41-42).

WHAT CAUSES HIGH FAILURE RATES IN DEVELOPMENTAL MATH?

HOW SHOULD DEVELOPMENTAL MATHEMATICS BE TAUGHT?

The 100% Math Initiative states that one out of every three college developmental mathematics students will fail the course on their first attempt; many will fail once or twice before they finally pass the course. Students who never bother retaking the course drop out of college (2006, p. i).

Research reveals that there are many reasons for high failure rates in developmental and freshman-level mathematics courses. In addition to inadequate high school mathematics preparation, the list includes improper student attitudes and expectations toward mathematics coursework and use of technology; poor attendance, time management, study and test-taking skills; lack of alignment between high school exit and college entry criteria; and unawareness of, or unwillingness to utilize, college support services such as advisement and tutoring (Conley 2005 and Nolting 2008).

The 100% Math Initiative provides a long list of suggestions for improving instruction in community colleges. The report suggests that instructors vary their classroom methodology and employ a broad range of pedagogical approaches to actively engage students in the learning process. The 100% Math Initiative promotes the presentation of information graphically, numerically, symbolically, and verbally. The

recommendations include the incorporation of real world applications of the material taught, and promoting student study skills by integrating these skills directly into course and classroom activities. Instructors are encouraged to be more aware of different student learning styles so that they can adjust their instructional approaches accordingly. They are advised to clarify specific competency-based expectations on assessments such as portfolios, projects and examinations, that measure student proficiency. Professors are urged to convey the value of homework by regularly assigning it, checking it, and offering incentives for work well done. They are also encouraged to attend professional development workshops that address strategies for accommodating different learning styles, integrating study skills into instruction, using technology, creatively engaging students, and advising students. Where possible, instructors are encouraged to regularly collaborate with specialists and support staff that work with learning-disabled students. The 100% Math Initiative also recommended that faculty receive support to understand, be familiar with, and implement the range of instructional strategies required to effectively teach developmental mathematics students, especially in a variety of lecture, small group and self-paced instructional settings (2006).

Epper and Baker have examined technology use in developmental mathematics. They found that instructors use technology in many ways, including those that facilitate acceleration of coursework, transform entire developmental courses by offering traditional content in a shorter time, and target specific skills gaps. At some institutions, such as the Community College of Denver and Ivy Tech Community College, technology has been part of holistic academic programs that include student support services and career exploration in addition to accelerated coursework. Although instructional

technology has been used for many years in community college mathematics classrooms, the report noted that an AMATYC survey had found that less than 40% of two-year colleges used a learning management system or course management system in 2007. Technology is used mostly to supplement rather than replace traditional instructional methods because available studies show no clear consensus on the effectiveness of technology-based instruction (2009).

A literature review by the U.S. Department of Education, Office of Vocational and Adult Education indicated that research was inconclusive in ascertaining whether technology-assisted or technology-based instruction is superior to instructor-led approaches. Conclusions of various studies were based on different definitions of success, such as receiving a passing grade, persistence to higher-level mathematics, or scores on final exams. However there is general agreement that, while students may not necessarily be more competent with one particular type of instructional mode, their persistence in developmental math and beyond may be enhanced by the option of instructional choice. Several researchers contend that allowing students to choose the instructional method that they feel best suits their particular learning style makes them more likely to complete the course and perhaps take higher-level mathematics (2005, p.28).

WHAT TECH TRENDS ARE HELPING BRIDGE ARITHMETIC AND ALGEBRA,
AND SPUR STUDENTS TO PURSUE HIGHER LEVELS OF MATHEMATICS?

Epper and Baker have discussed general trends that include open education resources, digital game-based learning, social networking, and virtual worlds. Discussing the use of Web 2.0 technologies in developmental mathematics, they also note that advocates of digital game-based learning believe appropriately designed mathematics drill-and-practice games could be effective for even higher mathematics. Student attraction to games and research on effectiveness of Digital Game-Based Learning (DGBL) may prove such math games appealing and helpful to developmental mathematics students. The report notes research efforts to relate game generation profiles with profiles of the developmental student population; Penn State University researchers have found that the game generation prefers doing many things simultaneously by using various paths toward the same goal, are less likely to become frustrated when facing a new situation, prefer being active, learning by trial and error, and figuring things out by themselves rather than by reading or listening (2009, p. 15-16).

There has been increasing use of open courseware for mathematics. The National Repository of Courseware (NROC) provides a courseware library. The content is distributed free-of-charge to students and teachers at public websites. Web-based mathematics learning initiatives include the Open Learning Initiative (OLI) of Carnegie Mellon University which uses intelligent tutoring systems, virtual laboratories, simulations, assessment and feedback. OLI builds college level web-based courses that are intended to provide effective instruction that promotes learning. Britain's Open University offers a broad range of mathematics courses online. Most courses are text based and can be viewed online or downloaded to a computer.

Progressive educators utilize not only course management systems and websites, but wikis, videos, podcasts, Facebook and Twitter to improve mathematical skills and performance. These resources provide for better communication, more prompt identification of difficulties, and greater accessibility to a variety of support. The focus may be on specific areas of developmental or advanced mathematical content, study skills, homework, projects, test-taking tips, time management, team or group work.

QUESTIONS FOR DISCUSSION AND FUTURE RESEARCH

What student mathematics projects best facilitate and/or support the transition from arithmetic to algebra? What student mathematics projects best facilitate and/or support algebraic (or higher level) conceptual and procedural skills? What are the essential elements of such projects? What guidelines would help mathematics educators in the development of such projects?

Exactly when and how should technology, such as calculators, computational software and spreadsheets, be introduced in the mathematics classroom so that students will appreciate and use it as a tool rather than a crutch? When and how should technology be a part of mathematical assessments? How can alignment in the use of technology in k-16 mathematics curriculums be achieved?

Are there proven advantages in teaching certain topics before others, especially in consideration of the timely integration of technology in mathematics coursework?

Are there other directly related topics that could be added or removed to recommended mathematics curriculums to give students more depth of understanding of any of the current topics?

Are there alternative curriculums for students unable to achieve satisfactory algebra skills? In the interest of equity, what policies would need to be in place to allow such students access if they later prove capable of pursuing a more rigorous mathematics curriculum?

With respect to the developments in cognitive neuroscience, how does a person learn to become an effective mathematics educator? What does the learning process involve at each teaching level? How is the process shaped by the qualities of the individual educator and the demands of the teaching level?

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