Engagement, Capacity and Continuity:

A Trilogy for Student Success

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September 2004

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Acknowledgments

We especially would like to thank the GE Foundation for their support and for their efforts to help America make better educational decisions.

We also would like to thank those who served as reviewers:

Dr. Daryl Chubin, AAAS
Dr. Beatriz Chu Clewell, The Urban Institute
Yolanda George, AAAS
Dr. Joseph Harris, The McKenzie Group
Peter Kleinbard, Fund for the City of New York
Jo Sanders, Former Director, Center for Gender Equity, Washington Research Institute
Clara Tolbert, Executive Director (Retired) Philadelphia (PA) Urban Systemic Initiative.

Their insights and thoughtful comments did much to improve this work.

Thanks are due as well to Tom R. Kibler, Campbell-Kibler Associates, Inc. for both his many reviews and the layout of this report.

INTRODUCTION

In today's global economy, a few fundamental factors have become clear:

- An individual's ability to enter and succeed in the workforce requires higher skills, more knowledge, and increasingly rigorous academic preparation;
- The competitiveness and success of businesses and institutions requires highly qualified individuals from diverse backgrounds; and
- Every nation's economic prosperity requires a vibrant backbone of diverse groups of individuals, both working in and knowledgeable about quantitative and technical fields.

These factors increase in relevance and urgency at both individual and societal levels with regard to individuals from under-represented and disadvantaged backgrounds, where, despite decades of effort, only slow progress has been made in strengthening academic preparation and increasing workforce representation, especially in the technical and quantitative disciplines. We must find ways to accelerate our impact in significant and sustainable ways.

To do so, we must start from the data on what works, rather than consume time and resources reinventing the wheel. Building from the research base, this report argues that a fairly simple but comprehensive assessment and approach is necessary to create the ecosystem for student success.

Stand-alone efforts that try to improve student academic performance or increase student interest in certain careers will only have limited success. It is the combination of "engagement, capacity, and continuity" that's essential to real progress. The framework makes explicit what exists for successful students so that it can be ensured for students from under-represented backgrounds.

The GE Foundation works to improve educational access, equity and quality around the world. We are pleased to support the continuing work of this team of researcher-practitioners to learn what works and get the data into the hands of those who can make a difference.

All of us, whether teacher, principal, funder or policymaker, have an opportunity and responsibility to address the fundamental inequities in our education system. Our students and our economy depend on it. In the words of the authors, "We don't need to do it all, but we must see that it all gets done." Thank you for joining us on this journey.

Bob Corcoran
President, GE Foundation

About the GE Foundation

The GE Foundation, the philanthropic organization of the General Electric Company, works to strengthen educational access, equity, and quality for disadvantaged youth globally; and supports GE employee and retiree giving and involvement in GE communities around the world. In 2003, the GE Family contributed $140 million to community and educational programs, including $50 million from the GE Foundation. For information, visit www.gefoundation.com.

About the Science Museum of Minnesota

The Science Museum of Minnesota (www.smm.org) is a combined natural history museum with scientific research, collections, and interpretive exhibits and a science/technology center with hands-on learning experiences. The museum is known nationally for producing traveling exhibitions, educational IMAX films, and educational resources for students and teachers.

About Campbell-Kibler Associates, Inc.

Campbell-Kibler Associates, Inc. (www.campbell-kibler.com) is an educational consulting firm specializing in educational research and evaluation, with an emphasis on mathematics and science education and issues of race/ethnicity, gender and disability.

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That success breeds success is an assumption under which most of us operate. Yet in our work to increase the numbers and diversity of those going into the sciences and quantitative disciplines, this assumption does not appear to hold. Programmatic, instructional and curriculum successes have not led to that goal. We are winning some battles but losing the war. Using a new analysis schema, in this report we explore why our successes are not translating into more progress, and more importantly, propose what different stakeholders can do about it.

Setting the Context

> *Taken together, access to science and mathematical literacy are powerful predictors of economic success and gatekeepers for the broadest economic opportunities.*
> (Eric Jolly, 2004).
>
> *"The engine of our national economy, upon which our safety and security, our well being, our quality of life and our global competitiveness, indeed our national preeminence depends, is powered by the technological and scientific discoveries and innovations made by scientists and engineers…. We must assure that the current cohort of scientists and engineers are not only being replaced in sufficient numbers but are increasing."*
> (Shirley Ann Jackson, 2004, p. 3)

Dr. Jackson asks, "Who will do the science of this millennium?" (Broad, 2004, A1). Currently African Americans comprise less than six percent of the workers in mathematical and computer sciences and less than four percent of the engineering and physical sciences workforce. Hispanics make up less than four percent of the quantitative disciplines workforce and Native Americans less than half of one percent (NSF, 2004). Without major changes, it is clear that those who will be doing science will not reflect the diversity that is America.

An examination of data on female and male pre-college students of all races/ethnicities does not make the answer to Dr. Jackson's question any clearer. Progress has been uneven. Over the past 10 years, science achievement has been relatively stable in fourth and eighth grades but has been declining in 12th grade. Overall mathematics achievement scores are up, in spite of a recent decline for 12th graders. However, in mathematics and science, fewer than five percent of fourth, eighth and 12th graders score at the advanced levels (Braswell, Daane & Grigg, 2003; O'Sullivan, Lauko, Grigg, Qian & Zhang, 2003; Braswell, Lutkus, Grigg, Santapau, Tay-Lim & Johnson, 2001). There have been major increases in the percentage of students taking the more advanced courses needed to continue in mathematics and the sciences, but still fewer than 30 percent take physics and fewer than 25 percent take pre-calculus. Not surprisingly, fewer American students are going into the sciences and quantitative disciplines in college and beyond (NSF, 2004).

This lack of student advancement in the sciences has not come about because of a lack of productive programs, interventions and reforms. Effective programs to improve student achievement exist, as do programs to increase student interest and to improve teacher knowledge and skill. We have mathematics and science standards that define the skills and knowledge students need to advance in the sciences and quantitative disciplines, we have many thoughtful curriculum development efforts to show us how and what to teach students (e.g., BEST, 2004b; Annenberg/CPB, n.d.; Exemplary and Promising Mathematics Programs, 1999), and we have a variety of exciting hands-on efforts to involve students in the sciences and other quantitative disciplines and increase their interest (e.g., Kinetic City, Try Science and Family Math). Yet they don't seem to be enough.

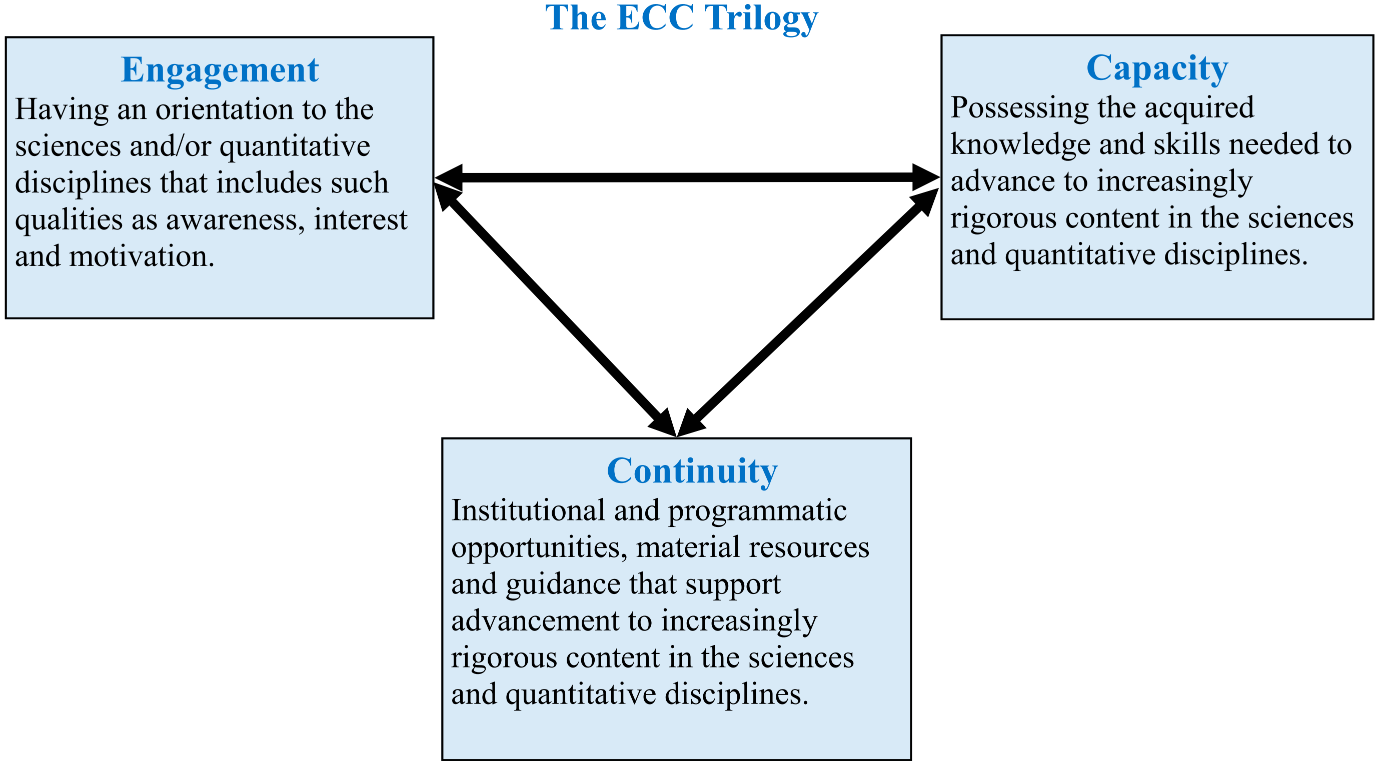
These efforts may not be enough because while they are necessary, they are not sufficient. This may help explain why the variety of exciting and effective educational programs and reforms that have occurred in the past decades have not led to expected dramatic increases in mathematics and science achievement and participation. We may have identified factors that need to be addressed for success, yet success eludes us. This is the case whether success is defined as knowing enough mathematics and science to be an informed citizen, to be accepted into a "good" college or to go on in mathematics and the sciences.

This paper introduces a system to analyze what is needed for individual students to be successful in mathematics and science. It defines the pieces of the analysis system, looks at the earlier research and practice behind the system, applies the system in a variety of programs and practices and discusses implications for relevant stakeholders.

A New Way of Analyzing Student Success in the Sciences and Quantitative Disciplines

In preparing our 2002 report, *Upping the Numbers: Using Research-Based Decision Making to Increase Diversity in the Quantitative Disciplines* (Campbell, Jolly, Hoey & Perlman, 2002), we surveyed much of the research and evaluation of efforts to increase student success in science, technology, engineering and mathematics (STEM). Building on that effort, as we looked at projects and programs that succeeded and those that should have been successful, a pattern began to emerge. Reform efforts, both successful and otherwise, fell into clusters of themes. We then asked a cohort of leaders who were involved in reform in the sciences and quantitative disciplines about their theory of change and looked for commonalities in their responses. Similar work was done with current research on improving science and mathematics education. Each time, a similar pattern of broad-based themes emerged. From this work, we posit that there appear to be three broad factors, which together are essential for students to advance in the sciences and quantitative disciplines.

The ECC Trilogy



The underlying assumption of the Engagement, Capacity and Continuity Trilogy (ECC Trilogy) is that these three factors must be present for student success. Each of these factors is necessary but individually is not sufficient to ensure student continuation in the sciences and quantitative disciplines[1]. The factors are interdependent. The absence of one can have an impact on the

[1]There are of course other factors not directly related to education and educational experiences that affect student success. Success is harder for the hungry student, the tired student, the unhappy student. Basic needs, such as fresh air, clean water, nutritious food, adequate sleep and safety, must be addressed in conjunction with educational factors for the trilogy to be successfully applied to most students (Maslow, n.d.).

degree to which the others are present. For example, without knowledge and skills (Capacity) many individuals will not be able to take advantage of available opportunities and resources (Continuity). However, Capacity is based at least in part on earlier Continuity.

Consider two students with equally high seventh-grade math test scores. Both want to take algebra, but one student has access to algebra in eighth grade and the other doesn't. By ninth grade the Capacity of the two students will no longer be the same. Looking at Capacity without looking at Continuity can lead to blaming the victim and to ineffective solutions.

Previously Engagement, Capacity and Continuity have been addressed separately when, as the following examples indicate, they need to be considered together.

- If a student has succeeded in content mastery (Capacity) and an educational system supports her or his further advancement (Continuity) but the student has no interest (Engagement), she or he will most likely not continue on in the sciences and/or quantitative disciplines.
- If a student has the Capacity and Engagement but the system does not offer such opportunities as calculus, AP courses, or even information on colleges and financial aid (Continuity), then despite interest and ability the student is not likely to advance into the sciences or quantitative disciplines.
- If courses, information and academic supports (Continuity) are available and a student has a high interest (Engagement) but she or he doesn't have the requisite content mastery (Capacity) to move to the next level, then that student simply will not be able to advance.

Each of the factors may affect students' success more at different times in their academic lives. For example in their early years, children are interested in almost everything. It is only later, in middle school and beyond, that students may need external programs and processes to engage or re-engage them in the sciences and quantitative disciplines (Clewell & Campbell, 2002; Fennema & Sherman, 1977). Continuity, or the lack of Continuity, affects children early on and the effects increase over time. For example, Sanders and Rivers (1996) found that after three years of working with good teachers, sixth-grade students achieved 50 percentiles higher than students with weaker teachers. The impact of a lack of Continuity on Capacity or on Engagement can be great enough that it can't be remediated or reversed in such a way as to keep students on the road to a career in the sciences or quantitative disciplines.

Capacity and Engagement in the sciences and quantitative disciplines can be gained both in and out of school; however, to continue on to careers in the sciences and/or quantitative disciplines, it is usually necessary for students to be engaged in the content area in school. There are many stories about students who, while not successful in formal science, excel at informal science and math. However, without a formal science and mathematics background, today there are few careers in the sciences and quantitative disciplines into which students can go. This doesn't mean that there isn't an important role for out-of-school opportunities in student advancement in science and quantitative disciplines. Home experiences, after-school programs, youth organizations such as the Girl Scouts, Boys and Girls Clubs, Campfire and religious groups and science museums can all contribute to one or more of the three factors.

How the ECC Trilogy is applied and how the presence of the factors is assessed is greatly influenced by how success in the sciences and quantitative disciplines is defined. The primary focus of this paper is on a definition of success that focuses on continuation in the sciences and quantitative disciplines toward careers in those areas. Thus most of the examples focus on the completion of appropriate courses and the generation of interest and achievement at levels necessary to graduate from high school and to go on to college and the workforce able to participate in the sciences or quantitative disciplines. The ECC Trilogy can be applied to other definitions of success, including sufficient mathematical and scientific knowledge and skills to make informed decisions. It also can be applied to other content areas.

Defining the Factors of the ECC Trilogy

Engagement

Engagement is about that which draws the learner to study. It can take many forms. The most successful engagement appears to foster positive attitudes and a desire for increased mastery and understanding. The importance of student engagement is well known. Many studies have found consistent correlations between engagement and student achievement (Marks, 2000; Finn, Pannozzo and Voelkl 1995; Connell, Spencer & Aber, 1994). At the college level, student engagement, defined as the time and effort that students that devote to educational activities, is the single best predictor of their learning (Astin, 1993; Pascarella & Terenzini, 1991).

▼

Engagement

Having an orientation to the sciences and/or quantitative disciplines that includes such qualities as awareness, interest and motivation.

▼

Engagement in schooling or overall motivation to learn is not the same thing as engagement in a specific subject area. For example, a student who is strongly engaged in mathematics will tend to spend significant amounts of time studying mathematics and probably will do well on mathematics tests. However, that same student may or may not spend much time on the rest of her or his school work (OECD, 2001).

General engagement in schooling, rather than engagement that is specific to the sciences and quantitative discipline subject areas, is often all that is necessary to get students to take science and mathematics courses in high school. If success is defined as graduating from high school or getting into a "good" college, then many students will take the necessary mathematics and science courses and achieve at the levels necessary to reach that goal. If success is defined to include longer-term commitment to the sciences and quantitative disciplines, then subject area engagement is necessary.

While there is consensus about the importance of engagement, definitions of engagement have varied. Generally, engagement has been found to comprise both academic and social components that include student behaviors directly related to learning as well as student interactions with the teacher or with fellow students (Finn, Pannozzo & Achilles, 2003). Components of engagement also can stand alone, as can be seen in the following examples.

- **Behavioral engagement:** positive conduct and involvement in academic, social or extracurricular activities; a view of the discipline as relevant to the individual's world and social circumstances and seeing success in the discipline as enhancing an individual's social value (Fredericks, Blumenfeld & Paris, 2004).
- **Emotional engagement:** positive reactions to people, content and environment in the academic setting, a view of the discipline as fun, intriguing and intellectually rewarding (Fredericks et al., 2004).
- **Cognitive engagement:** commitment and willingness to master complex concepts, including a sense that when concepts have been mastered, mastery of more difficult and complex concepts is possible (Fredericks et al., 2004; Jolly, 2002).
- **Vocational engagement:** a view of professions related to the discipline as fulfilling an individual's aspirations with a variety of longer-term rewards (Jolly, 2002).

Capacity

> **Capacity**
>
> Possessing the acquired knowledge and skills needed to advance to increasingly rigorous content in the sciences and quantitative disciplines.

The underlying assumption of Capacity is that there is fundamental knowledge that is necessary to advance to more rigorous or advanced levels. For example, one can't become an engineer if one doesn't know calculus, one can't learn calculus if one doesn't know algebra, and one can't learn algebra if one doesn't know mathematics concepts.

Capacity is often described in terms of that which is measured by tests, but that is backward. Test content should reflect needed content and skills rather than define them. Capacity may be in different areas such as:

Logical-mathematical: number, categorization, relations

Spatial: accurate mental visualization, mental transformation of images

Naturalistic: recognition and classification of objects in the environment

Linguistic: syntax, phonology, semantics, pragmatics (Gardner, 1983).

It also may be measured at multiple levels, including hierarchical levels such as those found in Bloom's Taxonomy:

Knowledge of terminology: specific facts, ways and means of dealing with specifics, defined here as the remembering of appropriate, previously learned information.

Comprehension: Grasping (understanding) the meaning of informational materials.

Application: Using previously learned information in new and concrete situations to solve problems that have single or best answers.

Analysis: Deconstructing information into its component parts, examining and trying to understand the organizational structure of information to develop divergent possible conclusions by identifying motives or causes, making inferences and/or finding evidence to support generalizations.

Synthesis: Creatively or divergently applying prior knowledge and skills to produce a new or original whole.

Evaluative[2]: Judging the value of material based on personal values/opinions, resulting in an end product, with a given purpose and without real right or wrong answers. (Bloom, 1956).

Capacity can be generated outside of the formal educational system as well as in it. Indeed, over 70 percent of the students studied in eight colleges indicated they learn better through hands-on projects and real-world application than through classroom or textbook instruction (Swail & Kampits, 2004).

Continuity

Continuity is a pathway or system that offers resources necessary for advancement. Ideally it is a fully articulated system where the skills, knowledge and information students need to move to advanced levels are known and are provided at each earlier, less advanced level. Some aspects of Continuity can be provided outside of formal systems, such as the guidance and information provided by a caring and knowledgeable adult. Continuity tends not to be the responsibility of the individual student. Rather, it is a part of the system in which the student participates.

Access is the key to Continuity, and the results of access can lead to increases in Engagement and/or to increases in Capacity. Access to skilled teachers with high student expectations, which can lead to higher Capacity (Sanders and Rivers, 1996) and Engagement (Lumsden, 1994), falls under Continuity. Overall, in the ECC Trilogy there is a focus on the individual student's experiences and capacities as the unit of measure, but for Continuity, the measures are of the system and individual student access to the aspects of it.

▼ **Continuity**

Institutional and programmatic opportunities, material resources and guidance that support advancement to increasingly rigorous content in the sciences and quantitative disciplines. ▼

There are many ways in which Continuity is important:

- If the courses in the sciences and quantitative disciplines aren't available, then students can't take them.
- If teachers don't know the content or don't know how to teach it, most students won't learn it.
- If students don't know they need to take the SATs/ACTs to go to college, they won't take them.
- If students don't know how to apply to or pay for college, they won't go to college.
- If students don't know that a particular career in the sciences and/or quantitative disciplines exists, they won't explore or enter that career.

Aspects of Continuity can include:

Higher-level curriculum requirements/course availability: A core curriculum where almost all students take the same, mostly academic courses has been associated with

[2]Bloom's original classification was titled Evaluation. However, since his early work, popular understanding of the term has changed to such a degree we felt that the word Evaluative was a better current reflection of his definition.

higher student achievement independent of race/ethnicity, gender or income level (Lee, Burkham, Chow-Hoy, Smerdon & Geverdt, 1998) and distinguishes high-performing schools from other schools (Bradley & Teitelbaum, 1998)

High school to college articulation: Schools where most students go on to college provide their students with a variety of resources including college counseling, college fairs and parent and student information sessions on admissions and financial aid. Providing low-income, minority students these types of resources, including college visits and funds to pay for tests and other application fees, dramatically increased the number of students going on to college in the sciences (Campbell et al., 1998). The GE Foundation's College Bound Program also found that adding college visits, college counseling and SAT/ACT preparation courses increased the number and percent of low-income students going on to college (Bailis, Melchior, Sokatch & Sheinberg, 2000).

Out-of-school opportunities: Access to out-of-school activities is a component of Continuity that is not often considered. Yet a meta-analysis of 56 studies found that participation in out-of-school programs can significantly increase students' mathematics and reading achievement. The best results were found for high school student mathematics achievement and for higher quality programs of all types (Lauer et al., 2003).

Teaching force capacity: While studies vary about the teacher characteristics that are highly correlated to student achievement, there is general agreement that teacher quality has an impact on student achievement (Rivkin, Hanushek & Kain, 2001; Darling-Hammond & Ball, 1997; Greenwald, Hedges & Laine, 1996). This appears to be particularly true in mathematics, where the students of teachers with strong mathematics backgrounds have higher standardized test scores than do other students (Wenglinsky, 2000; Goldhaber and Brewer, 2000). Teachers in highly effective elementary schools have been found to be more apt to possess quality indicators such as teacher attendance, advanced degrees, higher attendance and more college-level mathematics and science courses (Clewell, Campbell & Perlman, 2004b). Simply put, if the teacher doesn't have the knowledge and skill to teach a subject, student Continuity is diminished.

Applying the ECC Trilogy

Educational programming and even reform may be designed to advance one or more aspects of the ECC Trilogy, as long as the experience of every student includes all three areas. Key to success is the degree to which the effort matches variations in student needs. For example, a student with high Engagement whose education provides strong Continuity may only need to be involved with efforts to improve her or his Capacity, while a student with high Capacity and Continuity may need assistance to be more engaged in the sciences and quantitative disciplines.

Systems can support Engagement and Capacity and their presence can be measured in student populations, but averages are of little use. At the core of the ECC Trilogy is the degree to which each of the factors is present in each student not the average scores for groups or subgroups of students.

For efforts to be successful, it is necessary to assess the degree to which each student has needs in each of these factors and to provide opportunities to meet those needs. Program efforts can target groups, but needs assessments must be at the individual student level and must include all three factors. There must be coherence between programs and beneficiaries, so that the factors that are critical to success can be identified for every student and lacks in an individual's experience can be addressed.

It is not enough to support efforts in Engagement, Capacity and Continuity. We must assure that these efforts are overlapping sets in each student's experience. Efforts must build on "where students currently are." For example, efforts to increase student Capacity must build on existing student knowledge and skills. Efforts to increase Engagement must ask, "Engagement in what areas and for what purposes?" These considerations can help identify both the focus and evaluation of reform activities. Not every education effort needs to address all three factors, but all three factors need to be addressed in each student's experience.

If our assumptions about the ECC Trilogy are correct, then as long as social and health problems are being addressed where they exist, programs, reforms and even school districts that address all three factors should be successful. Efforts that focus on one or two of the three factors for students who already have the remaining factor(s) also should be successful.

Applying the ECC Trilogy to Educational Reform

Mathematics Reform

The National Council of Teachers of Mathematics (NCTM) has been involved in the reform of mathematics for the past 15 years. Engagement, Capacity and Continuity are encompassed in the first three of NCTM's seven goals:

Goal 1: To promote excellence in school mathematics curriculum, instruction, and assessment

Goal 2: To stimulate students' interest, achievement, and confidence in learning mathematics

Goal 3: To promote high-quality mathematics teaching and ongoing professional development throughout the preparation and careers of teachers of mathematics (NCTM, n.d.)

Goals 1 and 3 deal with Continuity while Goal 2 deals with both Engagement and Capacity.

Applying the ECC Trilogy to Educational Issues

Women in Engineering

Applying the ECC Trilogy to the issue of the low percentage of women in engineering can help to put the data into perspective. After the passage of Title IX, the number of women receiving engineering degrees increased greatly, growing from about one percent to over 12 percent in less than a decade. Title IX opened up many schools of engineering to women. The women who went into engineering majors at that time were already very interested in engineering and had the needed prerequisite skills and courses. Thanks to Title IX there were many more engineering programs open to them. According to the ECC Trilogy, the women had the

Engagement (interest) and Capacity (knowledge and skills) and Title IX gave them Continuity (access to engineering programs). Having all three factors in place permitted dramatically larger numbers of women to enter engineering majors.

But this pattern of dramatic increase did not continue. Between 1990 and 2001, women's presence stalled at 18 to 19 percent of the total number of entering engineering students[4]. In 2003, two percent of girls taking the SAT or ACT were planning to major in engineering compared to seven to 10 percent of boys[5] (College Board, 2004; ACT, 2004). To increase women's recruitment and retention in engineering, numerous residential, mentoring, summer bridge, study groups and academic support programs were based at universities across the country. Some showed high rates of success, defined by retention, such as the University of Michigan WISE-RP and Stevens Institute of Technology's Lore-El Center for Women in Engineering and Science (BEST, 2004a). However, women's enrollment remained stalled throughout the decade.

Walnut Hills High School

Several years ago, Walnut Hills High School in Cincinnati, Ohio, with the assistance of Ohio State University, instituted an Introduction to Engineering Course to increase student interest in engineering. At Walnut Hills, a public school where students must pass an academic entrance exam, students had the Capacity for engineering, but the Continuity was not there. The elective course attracted students who already had the Engagement and provided Continuity. The first year it was offered, 59 students took the course. The number of Walnut Hills students who applied that year for engineering at the two closest engineering schools increased from 32 to 57. Subsequent courses, taught without Ohio State assistance, continue to enroll 40 to 60 students (Campbell & Perlman, 2004).

Applying the ECC Trilogy to this data can provide some insight. Title IX increased Continuity, but did not address issues of Capacity or Engagement. Today, Continuity, at least within schools, seems comparable for young women and young men. They go to the same schools, have similar access to courses and in-school experiences, and in general have access to the same colleges and the same funding opportunities. And at least for predominately white and middle-class students, Continuity is increasing as more AP and other advanced courses in the sciences and quantitative areas are being offered and as program opportunities in science and quantitative areas increase (AP Central, 2002). Again for predominately white and middle-class students, Capacity in mathematics is up and is basically comparable for young women and men. Standardized achievement test scores in mathematics are higher as is mathematics course taking, and gender differences are small or nonexistent[6] (Clewell and Campbell, 2002; Cole, 1997; Huang, Taddese and Walter, 2000).

However, there are clear differences in Engagement. Boys report more positive attitudes towards science and mathematics than girls (i.e. Weinburgh, 1995; Steinback & Gwizdala, 1995, Greenfield, 1997; Martin, et al., 2001). Girls have been found to be less apt to see science as useful or to aspire to science careers (Catsambis, 1995) and less likely to be involved in extracurricular physical science experiences (Greenfield, 1997).

[4]Data derived from Engineering Workforce Commission, Engineering and Technology Enrollments, Fall 1990 through 2001. www.wepan.org

[5]While the percentage of girls planning to major in engineering has remained fairly stable, between 2001 to 2003 the percentage of boys taking the SAT who planned to major in engineering varied between 7% and 11%.

[6]One exception is in college admission tests. Over the years there has been a fairly constant difference in SAT: Mathematics scores, which show about a third of a standard deviation favoring boys, and a small difference favoring boys in the ACT mathematics section.

It appears that while we certainly need to continue to improve Continuity and Capacity for all students, to get more young women involved in engineering, as well as other science and quantitative areas, we need to focus strongly on their Engagement.

Mathematics and Science Achievement Gaps

The ECC Trilogy can be used to help analyze achievement gaps in mathematics and science between white students and African-American and Hispanic students. The gaps are large. For example in 2003 on the National Assessment for Educational Progress, 43 percent of white fourth graders scored at proficient or advanced levels of mathematics, compared to 10 percent of African-American students and 16 percent of Hispanic students. In eighth grade, 37 percent of white students were at proficient or advanced levels as were seven percent of African-American and 12 percent of Hispanic students (Braswell, Daane & Grigg, 2003). In science, last measured in 2000, 38 percent of white fourth graders, seven percent of African-American fourth graders and 11 percent of Hispanic fourth graders scored at proficient or advanced levels. In eighth grade, the respective percentages were 41 percent, seven percent and 12 percent. At 12th grade, the respective percentages were 23 percent, three percent and seven percent (NCES, 2001). Mean scores in mathematics are increasing for all racial groups and the gaps are declining somewhat. However, this is not the case in science.

Applying the ECC Trilogy, it is clear that from the beginning of their schooling, African-American and Hispanic students have lower Continuity indices than do white students. They disproportionately attend schools with lower quality teachers (i.e., teachers with less experience, fewer certifications and even lower attendance at their teaching jobs) and less background in mathematics and science (Lankford, Loeb & Wyckoff, 2002; Education Week, 2003). A recent survey of California teachers found that rundown facilities, overcrowded classes and shortages of qualified teachers were most prevalent in schools with high populations of African-American and Hispanic students (Harris, 2004). These and other gaps in Continuity contribute to the later gaps in Capacity in science and quantitative disciplines for African-American and Hispanic students in terms of achievement, course taking and persisting in the sciences and quantitative disciplines (NSF, 2004).

The Gateway to Higher Education

The Gateway to Higher Education is a program in the New York City Public Schools designed to increase the number of minority students in the biological and medical sciences. Gateway fosters increased student Capacity through programs such as an extended school day and double periods of math or science, laboratory components for all courses, after school tutoring and summer programs. These programs are examples of a coherent system of support that provides Continuity in learning opportunities for students. Gateway deals with other issues of Continuity by having AP and other advanced courses available to students and providing students and parents with information about college, including college visits, an annual college fair, SAT I and II prep, and seminars on college financial aid. To increase student Engagement, students participate in internships, are exposed to science professionals, participate in field trips to museums and even experience the theater, the opera and the symphony. A 1998 study found Gateway students took more advanced mathematics and science courses, did better on them, and moved on to college in the sciences in greater numbers than did comparison students (Campbell, Wahl, Slater, Iler, Ba & Mueller, 1998).

Minority students, particularly African-American students, are engaged in science and mathematics. In 2000, fourth grade students from all racial/ethnic groups were equally apt to agree they liked science, while at the eighth and 12th grade levels African-American and white students were more positive about science than were Hispanic students. In mathematics African-American fourth and eighth grade students were more apt than white students to agree with the statement "I like mathematics" (NSF, 2003).

College of Engineering, Morgan State University

The College of Engineering at Morgan State University in Baltimore began a summer mathematics review program for entering students in an effort to increase student Capacity. Students, all of whom were volunteers, had at least some Engagement as indicated by their application to the college's engineering program and their willingness to volunteer for a noncredit summer mathematics program. Since they already had been accepted to the College of Engineering there also was Continuity. Students who took the summer program enrolled in calculus at twice the rate of a comparison group of entering Morgan State Engineering students with similar SAT mathematics scores (38% vs. 15%) (Campbell & Perlman, 2004).

Engagement gets students started and keeps them coming back, but Engagement without Continuity and Capacity leads to nowhere, creating expectations without reality-based possibilities.

Identifying Student Needs Using the ECC Trilogy

For the ECC Trilogy to be of value, student Engagement, Capacity and Continuity all need to be assessed. Yet assessing the degree to which individuals possess necessary amounts of each of the three factors is not an easy task. There are no existing "one size fits all" measures available and in most cases multiple measures will be needed for each of the factors. As the following examples indicate, appropriate measures will vary depending on a variety of areas, including definitions of success in the sciences and quantitative areas, student age, academic levels and, of course, culture.

Measuring Engagement

In our definition, Engagement includes awareness, interest and motivation. Researchers have identified a wide assortment of engagement indicators, including:

- Classroom behaviors such as homework completion, attendance, following classroom rules, time on task, effort, asking questions to get information and persistence in subjects in the sciences and/or quantitative disciplines;
- Student factors such as ability to perceive oneself as a mathematician or scientist, seeing the utility of the sciences and/or quantitative disciplines, voluntary participation in both in- and out-of-school activities in the sciences and quantitative disciplines;
- Positive attitudes toward subjects in the sciences and quantitative disciplines and toward careers in these areas (Fredericks, et al., 2004).

There are a number of existing measures in these areas. For example, the National Assessment of Educational Progress (NAEP, n.d.) asks students the degree to which they agree or disagree with the following statements:

I like mathematics.
Mathematics is useful for solving everyday problems.
If I had a choice, I would not study any more mathematics.
I am good at science.
Science is boring.
Science is difficult.
Science is useful for problem-solving.
If I had a choice, I would not study any more science in school.

A second measure, the Fennema-Sherman Attitude Scale, was developed and validated to study students' attitudes towards mathematics (Fennema & Sherman, 1976) and adapted for use with the sciences (Doepken, Lawsky & Padwa, 1993). To test attitudes about the usefulness of science (or math), students rate the degree to which they agree or disagree with the following statements:

Knowing science will help me earn a living.
Science will not be important to me in my life's work.
I'll need science for my future work.
I don't expect to use much science when I get out of school.
Science is a worthwhile, necessary subject.
Taking science is a waste of time.
I will use science in many ways as an adult.
I see science as something I won't use very often when I get out of high school.
I'll need a good understanding of science for my future work.
Doing well in science is not important for my future.
Science is not important for my life.
I study science because I know how useful it is.

It must be remembered that Engagement is likely to vary greatly across cultures and therefore the measures of Engagement also may vary. Who is identified as a role model, how individual or group aspects of Engagement are identified and how students are inspired to find meaning in a field of study will relate to how that field is perceived in their own community.

Measuring Capacity

The major indicator of Capacity is student knowledge and skills. There is a variety of standardized tests that adequately measure knowledge and skills at different levels in the sciences and quantitative disciplines. However, there are limitations to the use of standardized tests to assess Capacity in the sciences and other quantitative areas that include:

- A focus on individual performance: much of the work done in the sciences is done in teams.

- A dependence on literacy skills: low literacy skills can mask high mathematics and science skills.
- An emphasis on speed in answering questions: a more deliberative person, who considers all aspects of a problem, may not have the time to show her or his skills on a standardized test.

The key is for tests to have content validity; that is, the knowledge and skills they measure reflect the knowledge and skills necessary to go to the next level in the sciences and quantitative disciplines. While the same performance-based outcome should be expected for all groups of students, the demonstration of that Capacity may occur in differing ways. When assessing a student's Capacity, extraneous factors such as time orientation, language or attitudes toward public versus private achievement should not undermine the assessment. If a measure does not give students an opportunity to demonstrate what they know and can do, it is not an adequate measure of Capacity.

Measuring Continuity

There are several different ways one can go about assessing Continuity, including developing a set of feasible research-based indicators that can be changed and that correlate with achievement such as:

- Processes and policies to ensure that each student is able to navigate the system for continuing advancement, by means of
  - Course flexibility that allows students to accelerate at different points of their schooling (Campbell & Perlman, 2004a);
  - SAT/ACT preparation, including scholarships to pay for tests as needed;
  - Assistance in college financial aid planning (Campbell et al., 1998).
- A rigorous curriculum including advanced mathematics and science courses as the standard curriculum (Lee et al., 1998; Barton, 2004).
- Courses taught by qualified teachers (Clewell et al., 2004; Wenglinsky, 2000).
- A knowledgeable adult who is willing to provide students with information and advice (Werner & Smith, 1992).
- After-school and out-of-school programming (Miller, 2003).

As with Engagement, there can be cultural variability along the dimensions of Continuity. It is important to identify both the formal and informal systems of education and guidance that help students navigate throughout the system. For many under-represented minority students, for example, the high school-to-college transition often involves an intermediate step through a community college. Additionally, many under-represented students, including Native American students, step in and out of college programs several times while in pursuit of a degree (McAfee, 2000). McAfee adds "stepping out", or stopping out, as an additional classification to traditional constructs of dropouts and matriculates.

Applying the ECC Trilogy: Some Examples

Using the ECC Trilogy to Solve a Known Problem

In a large high school, relatively few students are taking calculus. Data collected under the ECC Trilogy can help clarify the problem and suggest solutions.

Sample Engagement Data:

The perceptions of calculus held by students in prerequisite mathematics courses include the degree to which they agree with the following statements:

Taking calculus will benefit me in the future.

Taking calculus will involve too much work for what I will gain from taking it.

Calculus is an interesting subject.

Analysis

- If students who pass the prerequisite course(s) don't see calculus as valuable then the problem is one of Engagement and also may be one of Continuity.
- If students who pass the prerequisite course(s) see calculus as valuable, then the problem is one of Continuity.

Sample Capacity Data:

The proportion of students who pass the prerequisite course(s) and take calculus.

Analysis

- If relatively few of the students who pass the prerequisite course(s) go on to calculus, the problem is probably not one of Capacity, since those who can do the work don't go on. The problem may be with Continuity, Engagement or some combination of the two.
- If few students pass the prerequisite course(s) but most of those who pass go on to calculus, then the problem is primarily one of Capacity. Those who have the skills and knowledge go on; those who don't, don't go on.
- If few students pass the prerequisite course(s) and even fewer go on to calculus, the primary problem is Capacity but there could also be problems with Engagement and/or Continuity.

Sample Continuity Data:

The knowledge and skill of the person teaching the calculus course.

Electives and other courses against which calculus has to compete for students.

Using the ECC Trilogy to Improve Data Collection

A fourth-grade teacher needs a better way to assess individual student strengths and needs. Collecting individual student data in each of the ECC Trilogy areas can provide teachers and others with more comprehensive diagnostic information for developing strategies to increase student success.

Sample Engagement Data:

Teacher rating of student effort for each subject area.

Teacher rating of student time on task for each subject area.

Student attitude.

Student attendance.

Sample Capacity Data:

Individual student test scores by subject area, broken out by major subject area skills and knowledge.

Sample Continuity Data:

Principal or other supervisor rating of teacher content knowledge by subject.

Principal or other supervisor rating of classroom discipline.

Principal or other supervisor rating of teacher teaching skill.

Student access to tutoring.

Using the ECC Trilogy for Program Planning

A science museum wants to design a science program targeting urban middle-school students. Using the ECC Trilogy as the basis for conducting a needs assessment for the target population can provide direction for the components that should be a part of the new science program.

Sample Engagement Data:

The results of focus groups with urban middle-school students on the following areas:

- *Their friends' attitudes toward science.*
- *Science areas and activities their female and male friends like.*
- *Science areas and activities their female and male friends don't like.*

Sample Capacity Data:

Achievement test scores, disaggregated by race/ethnicity and sex, and broken out by grade and by school by different science skills and concepts.

Sample Continuity Data:

Focus groups with urban middle-school students on the following areas:

- *What students need to do to be able to go to college.*
- *Science career pathways.*

Implications of the ECC Trilogy for Different Populations

The following section briefly examines some implications of the ECC Trilogy for different stakeholders.

Educational Policy Makers

▼ Educational policy makers can use the ECC Trilogy to help ensure that their policies and grant programs have better chances for success by clearly addressing all three areas of the ECC

Trilogy in their efforts. To do this, policy makers can refer to the three factors in their policies.

Sponsors

▼ Those who fund projects and programs can explicitly address the ECC Trilogy by requiring that any proposed project or program include a needs assessment of targeted populations addressing areas of Engagement, Capacity and Continuity. They also can review funded projects to determine if project partners have the skills and resources to address student needs in ECC Trilogy factors.

Curriculum/Program Developers

▼ Prior to the design of any program, an assessment, disaggregated by race/ethnicity and sex, should be done of the target population's needs focusing on Engagement, Capacity and Continuity. The results of the assessment should be used to determine program components. The program should meet target student needs as identified by the assessment, or, if student needs can't be met through programming, by partnerships established to extend the program's capabilities.

Evaluators

▼ The ECC Trilogy can help to frame evaluation designs and contribute to our understanding of "what works for whom in what context." Having ECC indicators at the individual student level can help explain why some students are positively affected by some projects and others aren't. If a project that focuses on building student Capacity is unsuccessful in increasing enrollments in AP science courses, it may not mean the project strategies are ineffective. They may just be incomplete based on whether the targeted students have the interest and motivation (Engagement) and access to the courses and money to pay for the exams (Continuity) as well as the skills to continue or persist. Regardless of the focus of the program being evaluated, the evaluation should include measures of all three factors and should periodically reassess the program and participants to look for impact as well as to determine if needs have changed.

▼ Studies designed to look at the effects of promotion and retention polices, standards-based reform programs, summer programs, and teacher reforms and professional development can be strengthened if the three ECC factors are included in the data collection and the results used to help understand why different policies and reforms are or are not working.

District/School Administrators

▼ The ECC Trilogy has implications for district/school administrators, both programmatically and in terms of accountability. Programmatically they need to ensure that efforts they support address all three areas of the ECC Trilogy; that students participating in their educational system have easy and equal access to the resources that support each factor and that students utilize those resources. Any accountability system needs to include data from all three factors as well.

Teachers

- Teachers can apply the ECC Trilogy in their classes, assessing where individual students are in the ECC Trilogy and using that information in curriculum and other decision making. They can use the ECC Trilogy to help answer such questions as:

  Which of my students are engaged in what areas?

  Do my students have the skills and knowledge to continue on in the area?

  Do I have the skills and resources, including content knowledge, curriculum materials and teaching skills, needed to move my students up to the next level?

Museums and Other Informal Science Institutions

- Museums and other informal science institutions are often seen as focusing primarily on Engagement. While this can be the case, they also have the potential to support student Continuity and create student Capacity.
- Informal science programs can coordinate programming with others skilled in addressing different ECC factors. For example, a museum can present engaging activities that are intentionally related to a student's school-based core subject and can work with others to bring mentors into the school to increase student Continuity.

In Closing

"If my intentions are good and my heart is pure, then I must be doing the right thing." [7]

The "pure of heart model" often speaks to what motivates and inspires many of us in education reform. We have for decades wanted to do the right thing, to inspire, to teach and to create pathways and opportunities for every child's success. Enough passion, in the right circumstance, can lead to success but too often it does not. The passion that drives educational reform must be matched by a will to assess and cooperatively deliver an environment in which every child, regardless of race/ethnicity or sex, has the Engagement, Capacity and Continuity necessary to succeed.

There are many programs that when brought forward in the right conditions have contributed to student success. Unfortunately as conditions change so often does the level of success. The ECC Trilogy implies that even the best and finest programs aimed at only one or two factors will not succeed in the absence of an adequate presence of the remaining factors.

We've often said to children, "You can be whatever you want, as long as you work hard enough." But children need access and support in order for that to happen. The ECC Trilogy focuses on not just the child's will, but on the structures that are needed to support that will, to ensure that all children do get to become whatever they want.

We don't need to do it all, but we must see that it all gets done.

[7] The pure of heart model was developed by Tom Kibler to help explain why so many people are hesitant to collect and use data about the programs they love.

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Appendix

Refining the ECC Trilogy: Research, Application and Extension

In this report, we have presented a new theoretical structure under which to analyze and evaluate student success in the sciences and quantitative disciplines. The ECC Trilogy is currently a tool for analysis. After additional empirical support, such as that described below, it may be able to be used as a predictor.

Research

As indicated earlier, the ECC Trilogy has been supported through a search for examples, counterexamples and supporting literature. However, research also needs to be done to test the boundaries of these factors and the efficacy of this organizational scheme as a predictor. The two questions below are examples of ways to test the predictive validity of the ECC Trilogy:

- Do 12th grade students who are planning to pursue college majors in the sciences and quantitative disciplines have higher levels of Engagement, Capacity and Continuity than do other 12th grade students who are matched by school, sex, race/ethnicity, socio-economic status and overall grade-point average (GPA)?
- Do middle-school students who are planning to accelerate in mathematics or science and quantitative disciplines in college have higher levels of Engagement, Capacity and Continuity than do other middle school students who are matched by school, sex, race/ethnicity, socio-economic status and overall grade-point average (GPA)?

The following three questions are examples of research questions that can be used to refine the ECC Trilogy:

- Must there be a minimal level (threshold) of attainment in all three factors before students plan to major in the sciences and quantitative disciplines? Are there different threshold levels within subgroups for predicting continuation in higher education? For example, do men and women differ on the level of Engagement needed to persist to degree?
- What school-wide and/or system-wide characteristics of curriculum options and teacher quality (degree in field, certification and teaching experience) predict student scores in Continuity and Capacity?
- Does participation in science-related out-of-school programming lead to higher scores in Engagement and Continuity?

There remains a greater potential for this analytic tool to be tested as a model in a way that could advance our understanding of how reform projects might work or fail. Although programs already exist, often independently and unrelated, that foster Engagement, Capacity and Continuity, what doesn't exist is a way to determine which of these and to what degree they are needed by individuals to increase their success. There are significant research questions that can advance the application of the ECC Trilogy as a model for developing and testing educational reforms. A controlled research design could help administrators more clearly identify what factors are necessary and sufficient within a system to promote mathematics and science advancement for each student. The model that the ECC Trilogy suggests implies that even the best and finest programs aimed at only two factors will not succeed in the absence of an adequate presence of the third factor. We must test the completeness of our categories and the conditions under which these predictions are accurate or not.

Application

Research for validation and modification of this model can lead to the development of new sets of tools in support of educational programming. This report has identified implications for a variety of groups that arise from the application of the ECC Trilogy. Such applications will require the development of new instruments for evaluation, new protocols for program review and new approaches to assess need at both at the organizational and individual levels.

Extension

In this report we have focused specifically on advancement in the sciences and quantitative disciplines. This is due in large measure to the original focus of our research and literature review. However, the logic model behind the ECC Trilogy is not necessarily bounded by disciplinary domains. It seems as plausible for language learning, art or history as it is for mathematics and the sciences that students must be Engaged, have Capacity and need Continuity to advance. In the future, this ECC Trilogy might be illustrated through examples of reform efforts in reading, language arts, and social studies.

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