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EDUCATING MATHEMATICS AND SCIENCE STUDENTS IN URBAN USA AND SUB-SAHARAN AFRICA – LESSONS LEARNED AND FUTURE CHALLENGES

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Abstract. This essay focuses on the challenges of implementing effective mathematics and science programs in in secondary schools in urban America and Sub-Saharan Africa. A successful approach for meeting these challenges is considered which has first been introduced by the New Jersey Center for Teaching and Learning. This approach is based on maximizing the connections between mathematics and science, on developing an open-source software containing the entire curriculum and loading it into a SMART board computer. Integral to the methodology used is the presentation of questions with multiple choice answers. The technology implemented enables students to see the distribution of their answers (without seeing the correct one), and the teacher engages them in discussion and debates about the merits of various answers. The success of the educating-the-educators model supported by the implementation of the SMART system in both urban America and in The Gambia provides a model that can be replicated in diverse settings, and thus should be of interest to the world community of mathematics and science educators.

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1. Introduction. The title of this essay specifies urban USA as the location of noteworthy educational initiatives. In the essay, the term "inner-city" is used interchangeably with "urban." Since this context has characteristics that are unique to the United States, it is worthy commenting on those realities at the outset of the presentation.[1]

During the first half of the twentieth century American urban areas were viewed by many as economically dynamic, attracting and employing migrant populations from small towns, rural areas, and abroad. During the second half of the twentieth century, however, the term urban became a pejorative code word for the problems caused by the large numbers of poor and minorities who live in cities. Such negative associations with the term urban profoundly affect education and shape the nature of urban schooling.

Unlike most other countries where education is a federal or national function, schooling in the United States is decentralized. States are the legally responsible entities but local districts are generally perceived as the accountable units of administration. There were approximately 53 million American children entering public and private schools in the fall of the year 2000. 35% were members of minority groups. One in five came from an immigrant household. Nearly one-fifth were living in poverty. Eleven states accounted for more than half of the children in poverty: California, Texas, New York, Florida, New Jersey, Pennsylvania, Ohio, Illinois, Michigan, North Carolina, and Georgia. All these students were overseen by more than 15,000 local districts with almost 90,000 schools. The 120 largest school districts, generally defined as the urban ones, served 11 million students, most of whom were of color or in poverty.

Since 1962 the achievement gap between disadvantaged populations and more affluent ones has widened. At one extreme, urban school districts graduate half or fewer of their students. At the other extreme, 11% of American students are among the top 10% of world achievers. As one researcher remarked, "If you're in the top economic quarter of the population, your children have a 76% chance of getting through college and graduating by age 24. . . . If you're in the bottom quarter, however, the figure is 4%". Analysis shows that standardized test achievement of white students in reading, mathematics, and science ranks second, seventh, and fourth, respectively, when compared with students worldwide. African-American and Hispanic students, however, rank twenty-sixth, twenty-seventh, and twenty-seventh on these basic skills.

These are some of the challenges for those bringing educational reform to America's urban schools. With this context in mind, we can turn our attention to

[1]Reference: http://education.stateuniversity.com/pages/2524/Urban-Education.html.

the styles teaching of mathematics and science. These styles vary widely across schools. They range from rote learning to highly exploratory discovery learning. In communities having a long tradition of rigorous curricula in these fields, there is likely to be advocacy of more open-ended constructivist learning environments. It should be recognized, however, that what might be appropriate in Bulgaria or Finland, might not be feasible in communities or countries at the bottom of the international spectrum of academic accomplishment. This essay focuses on the challenges of implementing effective mathematics and science programs in the secondary schools of urban America and Sub-Saharan Africa. In urban America, secondary schools have serious deficiencies exemplified by the complete absence of physics courses in many schools. The problems of Sub-Saharan Africa are far more severe, with more than half the school age population having no access to any instruction beyond the primary grades. What both contexts have in common is the need to introduce effective mathematics and science instruction to students who have had no previous opportunity to study these subjects and in locations where there is a severe shortage of qualified teachers. The analysis that follows provides a summary of an outstanding program that is simultaneously addressing the challenges of inner city America, as well as those of Sub-Saharan Africa.

2. Science and Mathematics Education in Inner City America. A year after Bulgaria broke up with the Soviet Union, I became a visiting scholar at the Bulgarian Academy of Sciences through the Fulbright Program. I was asked to deliver a seminar on American K-12 education. In the course of my presentation I noted that about 25% of American high school graduates had completed a course in physics. Immediately, there was a strange hush in the room. A shaken academician rose and exclaimed "How could this be, America is a great country!"

What I soon learned was that in most of the developed world all students were expected to study physics in secondary school. Physics is seen throughout Europe and East Asia and beyond as a fundamental domain of understanding without which the natural world remains an enigma. In addition, realities of practical life in the 21st century demand a high level of understanding of mathematics and science for employment in an ever increasing number of jobs. Computers and automation have eliminated many jobs that involve routine operations, but have also created jobs for designers and operators of these new technologies.

While public school enrollment in physics in the United States has inched up during the past twenty-five years to over 30%, a recent survey [6] by Columbia University revealed that in New York City our nation's largest school system has only 21% of graduates who have completed a physics course. For minority and poverty students in New York, physics does not reach more than 15% of the student body. Large numbers of New York City high school graduates will be disadvantaged in pursuing both jobs and higher education.

This dire situation in New York City is typical of urban education in America. It is a disgrace that few educational leaders in America address. The United States is out of step with the rest of the developed world. American efforts to improve mathematics, science and pre-engineering education (so-called STEM[2] education) are usually incremental changes starting with what the United States has been doing in the past, rather than striving to emulate world standards.

The barriers to changing this education deficiency are formidable. There is a need for a coherent restructuring of all of K-12 mathematics and science instruction. Mathematics and science courses need to be re-sequenced to provide a smooth path to learning. To accomplish this goal, new textbooks or open source online course materials are needed along with a greatly expanded cadre of teachers. Underpinning this effort must be a pedagogical approach that engages students and effectively enables them to gain mastery of these subjects.

3. The New Jersey Center for Teaching and Learning: An Approach to Mathematics and Science Education in Urban American Schools. Fortunately, a successful model for meeting this challenge has been demonstrated in the urban schools of New Jersey, with proven ability for replication nationally and internationally. This is the Progressive Science Initiative (PSI) and the Progressive Mathematics Initiative (PMI) of the New Jersey Center for Teaching and Learning (NJCTL) [7]. These innovations in education have been designed and developed by Dr. Robert Goodman, who studied physics at MIT and achieved success as a corporate CEO, before turning his attention to these challenging issues.

First, he upended the usual science sequence in most schools in America that has biology in ninth grade, chemistry in tenth and physics in the eleventh grade. While concepts of physics are introduced as early as the sixth grade in many European countries, that is a model that is not been pursued in the United States. Dr. Goodman has placed physics in the ninth grade so that physics concepts can be incorporated into chemistry and then biology courses can employ understanding gained from chemistry. He simultaneously reorganized the curriculum content of mathematics and science, so that science provides a context and

[2]Science, Technology, Engineering, Mathematics. (eds)

practice field for mathematics knowledge-enabled understanding in the sciences, making its meaning and value clear to students. By maximizing the connections between mathematics and science, study of both becomes more successful and student enthusiasm for both is stimulated. For example, as mathematics concepts were available for use in understanding physics, that experience led students to have more interest in studying algebra and trigonometry.

This re-sequenced and restructured course of study is implemented using a pedagogy that has been enormously successful. Concepts are introduced one at a time. Students are then challenged to solve a problem that requires understanding of the new concept. They are encouraged to explore various approaches in collaborative discussion with fellow students. As problems are solved, new problems are introduced. Only when the teacher recognizes that understanding has been achieved, is a new concept introduced. This melding of collaborative education (discussion among students) and mastery education (moving to a new concept only when a current concept has been mastered) provides students with a stimulating and enjoyable context for learning.

A key component of NJCTL pedagogy is the use of SMART boards[3]. The entire curriculum is contained in software that is loaded into the SMART board computer. Teachers are thus able to present concepts and problems for discussion and analysis. Integral to the methodology that is used is the presentation of questions that have multiple choice answers. At appropriate times in the discussions that a teacher has with the class, students are asked to select one from among usually five multiple choice answers. The students do this through a polling device known as a "clicker." When the students make their selections using these clickers, a pie chart is instantly created on the whiteboard showing the distribution of answers from the class, but not showing which answer is correct. Teachers are then able to engage students in discussion and debates about the merits of the various answers. Students are asked to defend their response and can be asked to try to convince other students, with whom they are sitting, of the validity of their choice. This collaborative learning exercise continues with new questions until the entire class answers comparable questions correctly, thus proving their mastery of the concept that is being studied.

The various mathematics and science courses developed by NJCTL are all open-source. This eliminates the need for textbooks. While a SMART interactive board, polling devices and computer are required, this implementation does not require more than one computer per teacher – rather than one computer per

[3]Systems using computer projection onto a whiteboard, which is effectively turned into an interactive touch-sensitive computer screen.

student, as in the case of many other interventions. The result is that the program is extremely cost effective.

As teachers and schools utilize these curricula, they are able to make suggestions for changes that they find desirable. Through interaction with NJCTL those changes can be implemented. Hence a process of continuous improvement of instructional materials becomes possible.

The NJCTL has been implementing this approach in inner city schools in New Jersey with great success. Some of the schools in which they are active have more than 90% of the students receiving subsidized school lunches[4] and are more than 90% Hispanic and Black.

Where NJCTL is active, the percentage of graduates who have taken a physics course generally rises into the 90–100 range, while the percentage who have also taken Advanced Placement [4] physics, an exam program that is discussed below, often approaches 20%!

4. Advanced Placement Examinations. The Advanced Placement (AP) examination program is uniquely American. Secondary schools in the United States, generally, do not offer courses that are as advanced or rigorous as those in European lycées. It is also the case that in the United States there are no national examinations that are administered by governmental organizations. In fact, the United States Constitution reserves the organization and administration of education to state and local governments. This was a clear choice in the founding of the country – that education not be a responsibility of the federal government[5]. School systems in the various communities are under the authority of local school boards of education that are regulated by departments of education in each state. This organizational structure has promoted the establishment of approximately 16,000 separate boards of education in the United States!

In response to this diversity, the colleges and universities have established independent private (nonprofit) testing organizations in order to provide tests that allow the higher education organizations to access, in an objective and uniform manner, the ability and knowledge of incoming students. A leading organization engaged in that pursuit is the Educational Testing Service, located in Princeton, New Jersey. This organization is often referred to as ETS and is well

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[4]In the United States Schools, subsidized school lunches are a measure of poverty.

[5]The United States federal government does not have any direct authority over education in the United States. There is no national ministry of education and no education framework law or laws in United States. (eds)

known internationally, since it administers the widely used Test of English as a Foreign Language or TOEFL Exam.

An important component of the ETS testing initiative is the Advanced Placement Program. These are courses that go beyond the basic curriculum content of most secondary schools in America. They are formulated by experienced teachers in various subject areas and are recognized by the colleges and universities as being rigorous. In many cases, colleges and universities will provide credit to incoming students for college courses based upon scores in AP examinations.

The number of students taking the algebra based Advanced Placement Physics exam in the United States in 2014 was less than 200,000 out of approximately 3.2 million students who graduated high school that year. That is a national participation rate of about 6%. Thus, the enrollments approaching 20% in advanced placement physics at inner city, high poverty schools of the NJCTL program is truly extraordinary.

As more schools provide these offerings, there is a problem in finding physics teachers. Few are now graduating from United States colleges and universities. The NJCTL has tackled this problem by offering teacher certification that is recognized by the State of New Jersey. A teacher who is already certified in any field can become a certified physics teacher by completing a NJCTL 300-hour training program that uses NJCTL's student materials and teaching methods. The NJCTL has found that individuals who have proven themselves as teachers can become effective physics teachers in this manner. The shortage of physics teachers and the popularity of this approach has resulted in NJCTL becoming the largest producer of newly certified physics teachers in the United States [1]. The NJCTL certifies about 24 new physics teachers each year. In comparison, all the colleges and universities of New Jersey graduate about 10 new physics teachers each year. The national number for all new physics teachers produced at colleges and universities is a mere 300.

While formal studies of the efficacy of this approach to training teachers are limited, evidence is accumulating through the impact of the classroom performance of these newly certified teachers. Increasingly, their students are completing AP level courses and are sitting for the AP examinations.

5. Praxis Examinations for Teachers. Studies are also ongoing that utilize the results from the ETS Physics Praxis [5] examination. This is an examination designed to evaluate the content knowledge mastery of teachers or physics. It is a 2.5-hour test that includes topics on:

- Mechanics
- Electricity and Magnetism
- Optics and Waves
- Heat, Energy and Thermodynamics
- Modern Physics and Atomic and Nuclear Structure
- Scientific Inquiry, Processes and Social Perspectives

The first two categories constitute about 32% and 19% of the examination while the remaining each constitute about 12% or 13%.

The Physics: Content Knowledge test is designed to measure the knowledge and competencies necessary for a beginning teacher of secondary school Physics. Examinees have typically completed or nearly completed a bachelor's degree program with appropriate coursework in Physics and education.

The development of the test questions and the construction of the test reflect the National Science Education Standards (NSES) and the National Science Teacher Association (NSTA) standards and recognize that there are conceptual and procedural schemes that unify the various scientific disciplines. These fundamental concepts and processes (systems; models; constancy and change; equilibrium; form and function) are useful in understanding the natural world. Insofar as possible, then, the test questions have the primary objective of evaluating the content areas by using questions that focus on conceptual understanding, critical thinking, and problem solving in science. The test content is developed and reviewed in collaboration with practicing high school Physics teachers, teacher-educators, and higher education content specialists to keep the test updated and representative of current standards. In many of the States, the Physics Praxis examination is used as part of the process of teacher certification in a specific field. It thus provides a national norm.

The NJCTL studies to compare the efficacy of their preparation for the Physics Praxis with traditional programs are quite promising. A key result, in a recently completed analysis [9], finds that NJCTL graduates had passing rates on par with other test takers. The NJCTL scores are somewhat lower than the national averages, which is to be expected given that they have had less exposure to physics content courses than the other test takers. The fact that the NJCTL teachers reached comparable levels of expertise in their knowledge of physics after just a single year 300-hour program is striking.

A second key finding is that those completing the NJCTL program are much more diverse in terms of race and gender. The NJCTL graduates are 37% minority (not white or Asian) and 48% female, while those figures for other test takers are 13% and 38%. Hence, the NJCTL teachers are more representative of the identities of the students they teach in urban schools than teachers who have completed traditional preparation programs. This is consistent with the reality that the traditional path draws its candidates from the pool of college physics majors, which is not very diverse, while the NJCTL program draws its candidates from the population of urban school teachers, which is quite diverse.

Approximately 80% of students in low income schools in the United States are not provided with education in physics and therefore do not have access to a robust mathematics and science curriculum. This deficiency is exacerbated by a shortage of teachers of these subjects [8, 11]. The approach taken by NJCTL in remediating this problem in urban schools in the United States has the potential of being adapted to meet needs anywhere there are similar shortages and educational deficiencies. While the educational shortcomings in schools in Sub-Saharan Africa are vastly greater than those in high poverty urban schools in America, the NJCTL strategy has applicability. The transferability of their approach was recognized by the World Bank. A test of this hypothesis was implemented with a pilot program in The Gambia. The following sections outline the educational need in Sub-Saharan Africa, the Pilot Project in The Gambia, and an overview of possibilities for future expansion of this strategy in The Gambia and elsewhere in Africa.

6. The Need for Vastly Expanded Mathematics and Science Education in Sub-Saharan Africa. Sub-Saharan Africa's educational deficiencies are so great that the problem is difficult to capture in a summary fashion. An effective analysis published by the Brookings Institute provides an excellent analysis [10]. A particularly salient statistic presented by Kevin Watkins is that there are 127 million children of primary school age in Africa and that half of these children – 61 million in total – will reach adolescence without basic learning skills needed to escape from unemployment and poverty. One in four of these children of primary school age are not enrolled in school and many who are in school do not have effective teachers, lack textbooks and are learning little. He notes that in South Africa, which is a middle income country, one-third of the children fall below the basic learning threshold, reflecting the large number of failing schools in areas servicing predominantly low-income black and mixed race children. In South Africa, children from the poorest households are seven times more likely than from those from the richest households to rank in the lowest 10% of students.

Given the shortcomings in primary education in Africa, it is not surprising that Sub-Saharan Africa has the lowest enrollment percentages of the available age group in the world. Places in schools are only available for 36% of the secondary school age children.

It is useful to examine secondary school enrollments in several of the largest and most prosperous countries of Sub-Saharan Africa. The percentages are based on the ratios of the secondary school enrollment numbers to the total population of the relevant age group in the country. The population figures are for the total population of that country.

	Secondary School Enrollment Ratio	**Country Population (in Millions)**
Ethiopia	14%	94
Uganda	21%	38
Nigeria	26%	173
Ghana	46%	26
Kenya	49%	44
South Africa	62%	53

We see that these three countries alone have a combined total population of 428 million, which significantly exceeds the population of the United States of 319 million.

The total population of Sub-Saharan Africa of 800 million exceeds that of the European Union which is 508 million.

We see that the only country in this group of large countries with more than 50% of the relevant population enrolled in secondary school is South Africa [2]. Given that there are 3.1 million teachers in the United States, the shortage of teachers in Sub-Saharan Africa is certainly well over one million. Clearly, traditional approaches will not be able to remedy this situation in the foreseeable future. Highly innovative methods are needed if populations in Sub-Saharan Africa are going to be able to participate in the high tech economies of the 21st century.

7. World Bank Pilot Project with NJCTL in The Gambia. The World Bank perspective on the NJCTL Program can be summarized as follows.

The Progressive Science Initiative (PSI) and the Progressive Mathematics Initiative (PMI) of the New Jersey Center for Teaching and Learning (NJCTL) has demonstrated success in both effective classroom learning and in teacher training. The pedagogical methods used are based on research that has demonstrated the efficacy of direct instruction interwoven with social constructivism. The approach is mastery based with continuous formative evaluation of classroom success. The outcomes have been validated through the student achievement on national standardized tests that are comparable to the British A level examinations. The parallel drawn between the British A level examinations and the American Advanced Placement exams provides an effective rationale for the NJCTL program in an international setting. The British A levels are commonly used in countries that were previously British colonies.

The program makes effective use of interactive digital technology, but only requires one computer in a classroom equipped with a SMART board. Some have argued in the past that ubiquitous computing was needed in order to take advantage of technology in classrooms of Africa. The NJCTL approach provides an alternative model.

By embedding the full curriculum into the presentation software, there is no need for a textbook, thus creating an added economic advantage. Using a digital implementation of the curriculum provides a cost effective model.

The curriculum materials are open-source and can be used without any fees or charges. As the program is implemented in new locations, feedback is invited thus enabling continuous improvement. While there are skeptics regarding the efficacy of the NJCTL model, the fact that it implements open-source and does so in a context of continuous improvement means that critics have the opportunity to revise and enhance the NJCTL materials in a process that constantly seeks positive revision.

A pilot project for introduction of NJCTL materials and methods into The Gambia was initiated in 2012. The Gambia provided a small country, having a population of 1.7 million, as provided a manageable test site for implementation of an education innovation in Sub-Saharan Africa. Another advantage of working in The Gambia is that it has education statistics that are typical of many Sub-Saharan African countries [3]. The share of the relevant age group enrolled in primary schools is 79% while the share of the relevant age group enrolled in secondary schools is 33%.

With World Bank funding a thirty-month pilot project for the training of an initial cohort of 12 physics teachers and 12 mathematics teachers was implemented in The Gambia for two regions. Physics and mathematics teachers were trained in teaching both basic and advanced versions of those subjects. These teachers then instructed Upper Basic and Senior Secondary classes in these subjects.

Some of the teachers from this first cohort became the local trainers of a second cohort of 12 physics and 12 mathematics teachers from regions outside of the first two. The NJCTL assisted with that training, but the objective was to have the local trainers take on the lead role during the course of that year of training.

In order to further promote institutional development in The Gambia beyond the direct impact of this program on Upper Basic and Senior Secondary schools, eight additional participants extended the impact of this program. Two were from the higher education faculty of the University of The Gambia (UTG) and two from Gambia College (GC). Further, four recent graduates from those higher education institutions participated in order to extend the program to post-graduate study.

This World Bank pilot project thus began a process of introducing the content and methods developed by NJCTL into to the teacher education infrastructure of The Gambia. The impact of this initiative was multi-faceted. It was observed that the teachers and students were quite receptive to the NJCTL approach. This was the case for both teacher training and classroom implementation initiatives. What was not immediately apparent to the NJCTL team was the need for the systematic, structured approach to the content matter in Physics and Mathematics that were presented via the NJCTL curricula. The NJCTL team learned through pretesting of the teacher trainees that their level of physics content knowledge was quite limited. The combination of an appealing pedagogy and solid conceptual frameworks engendered some unanticipated consequences.

One of these outcomes was seen in the results of the West African Senior School Certificate Examination (WASSCE). These examinations in specific subject areas are widely used in English speaking West African Countries as a measure of subject mastery, much like the use of ETS exams in the United States. High scores on the WASSCE exams are needed in order for students to gain admissions at international universities. Prior to the NJCTL program in The Gambia, very few students achieved high scores in physics or mathematics, just over 10. The number was effectively zero. However, in the years immediately following the introduction of the NJCTL program, the number of students obtaining scores that merited international recognition increased to above 70. This was apparently due to the informal diffusion of knowledge and understanding that was being spread by those teachers who had received NJCTL training. While the numbers are small, a change from 10 to 70 achieving high passing grades in physics and mathematics was a noteworthy development.

In addition to the WASSCE results, all qualitative evaluation of the program by teachers, the Ministry of Education, observers from the World Bank and others has all been quite positive. Given the prior low level of student achievement in mathematics and science and the failure of other interventions at improvement, there is significant interest in expanding the NJCTL initiative both in The Gambia and in other African countries.

During the next several years, it will be possible to analyze the results of WASSCE exams taken by students who have had the full benefit of the NJCTL intervention in The Gambia, but these preliminary results have been sufficiently encouraging to stimulate planning for new initiatives.

Discussions are underway with the Islamic Development Bank for a program to expand the World Bank NJCTL pilot to all secondary schools in The Gambia and with the World Bank to bring the program to other African countries.

Given the challenge presented by the extreme shortage of qualified physics, chemistry and mathematics teachers in Africa, creation of mechanisms for effective, large scale, train the trainer programs need to be developed. As Robert Goodman and his colleagues and collaborators move forward they need to test the use of online instructional formats that incorporate appropriate amounts of face-to-face follow-up as well as on-site mentoring during implementation.

The potential exists to develop teacher training programs in Africa that could be implemented in the United States as well. While the numbers of teachers needed in the United States is much smaller than in Africa, it is still far in excess of that which colleges and universities in the fifty states have been able to produce. What is most unusual about the NJCTL program is the systems nature of the undertaking. Most interventions accept the curricula that are in place in the target schools. In the case of NJCTL, the sequencing and interconnection of courses are crucial components of the intervention. Mathematics underpins understanding in the sciences and knowledge in one science provides the basis for understanding the others with physics leading into chemistry and chemistry providing a context for understanding biology. The NJCTL changes the traditional sequencing of science courses for American schools and does it in a fashion that links the knowledge base of one course with courses that follow in the curriculum.

8. Summary and Future Challenges. The NJCTL has demonstrated that its approach to SMART system implementation, with scripted lessons that facilitate collaborative, mastery based learning can be replicated in diverse settings. The success of the train-the-trainer model that it supports in both urban America and in The Gambia provides a model for use in school systems everywhere, that are starting from having few, if any, courses in physics. Since physics is the lynchpin of a coordinated math-science curriculum, opportunities for rapid expansion of education for students, who have been stymied from embarking on paths to successful 21st century careers, is a major educational breakthrough.

The major challenge facing NJCTL today is that of scaling up to implementations of large numbers. It is hard to imagine remedying gaps in education in large American school systems such as New York and Chicago or in African countries that have extremely limited secondary school infrastructures without using online programs combined with strategic use of face to face follow up and facilitation.

Thus, expansion of NJCTL programs is a work-in-progress. However, a model has been created and curriculum materials are freely available, for other educators from around the world, to join in expanding this initiative. Science and mathematics educators everywhere in the world have access to this material and can explore the efficacy of the materials and the methods. Advanced countries that have successful programs in science and mathematics will probably prefer to maintain the approaches that they have in place today. However, all mathematics and science educators should take a close look at the work of NJCTL. The world community of educators in the fields of science and mathematics should consider joining in an effort to bring these promising curricula and teacher training methods to populations where the current levels are woefully inadequate.

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