The New American University: Mentorship in the Mathematical Sciences

Carlos Castillo-Chavez
Dept. of Mathematics and Statistics, Arizona State University, Tempe, AZ 85287
chavez@math.asu.edu
Carlos W. Castillo-Garsow
Dept. of Mathematics and Statistics, Arizona State University, Tempe, AZ 85287
cwcg@asu.edu

February 1, 2007

Abstract

For eleven years the Mathematical and Theoretical Biology Institute ($MTBI$) has mentored over *consecutive summers* a highly diverse group of undergraduate students (277) who had not yet been tracked into selective mathematics programs. The goal of MTBI programs is to increase the number of underrepresented US minorities with doctorates in the mathematical sciences. MTBI participants in *general* have been juniors or seniors, have come *primarily* from "non-selective" colleges and universities; and have had either a solid, very good or outstanding academic record. MTBI alumni while undergraduates often lacked access to a high level academic curricula and most often had no clear idea of the challenges and opportunities awaiting for them in the mathematical sciences. Participants have included a high percentage of individuals from underrepresented US minority groups and women but these groups of undergraduate participants have always included members of most ethnic groups and some international participants. MTBI's recurrent system of mentorship has held its critically important summer camp for the past eleven summers with the institutional support of Cornell University($1996-2002$), Cornell University-Los Alamos National Laboratory (2003), Arizona State University-Los Alamos ($2004-2005$) and Arizona State University($2006-$). The results have been equally successful regardless of the location. A summary is provided below. Funding has come from the National Security Agency, the National Science Foundation, Los Alamos National Laboratory, the Alfred T. Sloan Foundation, and the offices of the provosts of Cornell University and Arizona State University. In 2005, MTBI/SUMS alumni received 10 Ph.D.s in the mathematical sciences, 7 of which were awarded to members of underrepresented minority groups. Seven now hold postdoctoral positions (including six underrepresented US minorities) at selective institutions and one a tenure-track faculty position in Puerto Rico. The 2005 class of MTBI Ph.D.'s includes four "Latinas" and one African American woman. Wherever this type of student success becomes systemic is an open question. Why has MTBI's model

worked? What are the best examples of MTBI mentorship efforts? What has MTBI become an important contributor to the efforts that have resulted in the establishment of *large graduate student communities of mathematicians* at Arizona State University, the University of Iowa and Cornell University? These questions will be addressed briefly in this manuscript.

1 Introduction

The goal of the Mathematical and Theoretical Biology Institute ($MTBI$) programs is to increase the number of underrepresented US minorities with doctorates in the mathematical sciences. MTBI not only provides the skills and support required to accomplish this goal but contributes within its model to the development of future scientific and academic leaders-an area where minority representation is abysmal. MTBI continuously highlights the obvious, that is, that *it is possible* to address the problem of under-representation in the mathematical sciences with the current pool of students that we have majoring in mathematics at private and state institutions across the US. This is not to say that we have not had and continue to have large educational lapses and outright failures at the $K-12$ level. But the fact is that we can't wait for somebody to solve these systemic educational problems at the $K-12$ level before tackling the issues where we, college professors and administrators, can contribute immediately. We can increase *dramatically* the representation of US citizens and residents, particularly underrepresented minorities and women, in our graduate programs *today*. There is simply no excuse and, now there is plenty of case studies that prove it, to justify the current status quo. It is inconceivable to understand why some administrators and mathematicians continue to use the arguments of the *past* to justify the record of failures over the past four decades.

For eleven years the Mathematical and Theoretical Biology Institute ($MTBI$) has mentored over *consecutive summers* a highly diverse group of undergraduate students (277). MTBI participants in *general* have been juniors or seniors, have come *primarily* from "non-selective" colleges and universities; and have had either a solid, very good or outstanding academic record. MTBI alumni while undergraduates often lacked access to the scientific enterprise and most often had no clear idea of the challenges and opportunities that were within their reach in the mathematical sciences. MTBI has provided a window into a world that these students did not know. A fascinating world that becomes immediately addictive. MTBI summer program has been a major contributor to the *huge classes* of successful minority graduate students at the University of Iowa, Cornell University and Arizona State University as well as to a small number of graduate students who had or are attending Harvard, Princeton, Stanford, Michigan or other equally recognized institutions. The first "large" crop of MTBI alumni who have completed their Ph.D. degrees in the mathematical sciences are entering the scientific enterprise. Their numbers however small represent a significant perturbation of past steady states. MTBI alumni received 10 Ph.D.s in the mathematical sciences, 7 of which were awarded to members of underrepresented minority

groups. Seven now hold postdoctoral positions (including six underrepresented US minorities) at selective institutions and one a tenure-track faculty position in Puerto Rico. The 2005 class of MTBI Ph.D.'s includes four "Latinas" and one African American woman.

This article articulates some of the elements of $MTBI$'s successful model while demystifying the mechanisms behind its documented successes. The portability of $MTBI$'s model makes it difficult to understand let alone justify the lack of successes in educating US underrepresented minorities by most US graduate programs. $MTBI$'s effort, like all good efforts, requires the participation of committed individuals and the resources from committed agencies, foundations and university administrations. The US has *never failed* at recruiting committed individuals capable of carrying out *successfully* an effort that is considered to be in the *best* national interest. The paradox of our efforts (as well as those of other good models) is that the $MTBI$ model can be implemented and its successes can be replicated at most universities. The major roadblocks lie on our inability to accept that under-representation is a major national priority whose solution deserves the long-term commitment given to similar challenges. There are solutions to the problem of underrepresentation but there is no overwhelming will from our national leadership (political and academic) to implement the large scale solutions that we *know* will do the job. Furthermore, programs that are successful face serious funding challenges in their efforts to expand or replicate their models. This is quite in contrast to our *standard* policy of recommending the continuous support of the most successful scientific projects by panels of experts. It is surprising to see that membership in academia *automatically* qualifies an individual as an *expert* in the development and evaluation of models designed to address our tragic educational shortcomings in the recruitment and retention of Americans (at the graduate level) in the *mathematical sciences*. It is the goal of this manuscript to outline the model that we have refined over the past eleven years and to provide convincing evidence that success is around the corner for *any* graduate program in the mathematical sciences that truly wants to make it its business to increase American representation. Finally, we hope that it is obvious that the model presented here can be easily modified and implemented at multiple levels of mathematical maturity from high schools to the postdoctoral level.

2 Model description

2.1 Common laguage

Students are assumed to be at least familiar with elementary calculus (2 semesters); have been exposed to linear algebra (eigenvalues and eigenvectors); have some "feeling" for probability, basic statistics (probability densities and distributions, random variables, Baye's theorem and expectation), birth and death stochastic processes, and some familiarity with a programming language. However, the cooperative nature of the MTBI environment is such that some weaknesses in these areas is not a critical problem. The first three weeks of the program are devoted to the study of dynamical systems in the context of ecology,

epidemiology, immunology and conservation biology.

Furthermore, students learn thorough carefully prepared computational laboratories on how to program in *Matlab* (The Mathworks Inc.) and *XPP* while becoming proficient with *Maple*, *Minitab* and LaTeX.

The students are responsible for sixteen extensive complex sets of problems that are closely tied in to the lectures. "Review" lectures are provided on the essentials of linear algebra and probability. The preparatory phase ends with a pre-project that forces the students go beyond the material covered in class. Typically, the pre-project involves the study of a dynamical system with identified dynamics at two highly distinct temporal scales. Bifurcation analysis, simulations and the interpretation of model results are at the heart of this exercise.

Students are involved in lectures, problem and modeling sessions and computational labs for an average of five hours per day.

2.2 Salt and pepper

Relevance seems to be the key to motivation and success. A modeling seminar is conducted twice a week by program alumni (undergraduate and graduate students). Alumni describe the process that they followed as participants in identifying and selecting their own project as well as in convincing a group of colleagues (three to four) to join efforts. Alumni put emphasis on identifying a key question; a process that precedes the selection of the appropriate modeling framework. Students have often encountered difficulties when they insisted on using a specific methodology without taking into consideration its appropriateness for their question.

During the first weeks, distinguished researchers provide sets of two-to-three 90 minute connected lectures which are supplemented with relevant problem sets. These lectures highlight interesting "pure" mathematics or non-trivial applications.

Throughout the process students are continuously assisted by graduate students and resident faculty while they are encouraged to describe their work together.

Following the general "Oberwolfach" mathematical model, the lectures, seminars and talks are followed by a community dinner where students are encouraged to interact with faculty and graduate students. Paper table cloths serve a double function, that is, they are also used as a writing or drawing pads-napkins are not sufficient in these learning communities.

2.3 Absence of hierarchies

By design, the research agenda of this summer institute is set by the undergraduate participants. This tradition was begun in 1997 when the institute was in its second summer. Today, it is not uncommon to see students arrive with their own projects at the beginning of camp. Such students spend most of their first three weeks trying to sell their projects

to two to three additional participants. There are no rules regarding the formation of such groups except that they should include three to four individuals. Once the groups have been formed (no faculty supervision) students begin to present orally their projects to a group of faculty and graduate students. The initial role of these sessions is to help students narrow the scope of their project. That is, efforts to identify a doable question are at the heart of these sessions where no effort is conducted to alter the overall goal of the students project. Typically initial suggestions are: What is the impact of alcohol on brain activity? What are the dynamics of eating disorders? What conditions will guarantee the survival of the monarch butterfly? What are the effects of different social structures on disease spread? Once a question that captures the essence of the students project is selected, efforts to build an appropriate model are carried out. These modeling efforts may move us into the world of networks or dynamical systems broadely understood to include stochastic processes or simulations. In the process, the students are assigned a faculty advisor and graduate student support. The incorporation of these individuals is based on the desire of the faculty to get involved in the enterprise and the interest of the graduate student in the project.

The dynamics associated with project, group, question, model, faculty and graduate student selection are driven by the undergraduate students. Consequently, the students are working on problems for which faculty participants do not have the answer. Faculty, graduate students and undergraduate participants become collaborators, and partners in crime.

2.4 Meeting Expectations

The following next three weeks are driven by the intensity of the participants to provide an answer to a relevant question. Regular open meetings are conducted were each group presents and defends their effort. On some occasions, students have had to make dramatic changes to their models. Most of the students experience some progress which is not surprising whenever their model or models fit the question posed by the undergraduate participants.

After three weeks a series of results (numerical, analytical and statistical) that throw some light into the question of interest are completed. Students then work hard on writing a technical report ($25-45$ pages) that captures the problem, the model, the methods, and their results.

2.5 The product

The participants conclude their efforts with a technical report (111 in eleven years), prepare a 30 minute presentation and highlight their research in a poster. This year, the program began on June 6 of 2006 and concluded on July 29. Seven groups of participants made oral

presentations of their results at the join meeting of the Society for Industrial and Applied Mathematics (Life Sciences Group) and the Society for Mathematical Biology which was held in Raleigh North Carolina from July 30 to August 4, 2006. Seven posters were also presented. These posters will be presented at the annual SACNAS meeting in Tampa, Florida (27 of October, 2006) and at the annual AMS meeting in January of 2007. An average of 3 awards per year have been given to MTBI projects. Students regularly have presented their research at their universities and at local conferences during the academic year that follows the completion of the project.

3 Support

MTBI/SUMS efforts have not been carried alone. MTBI received extraordinary support by the Cornell University's administration[1], the Center for Applied Mathematics and the Biological Statistics and Computational Biology Department. MTBI/SUMS has had no less support at ASU[2]. We have established a highly effective partnership with ASU's Hispanic Research Center[3]. ASU's Mathematics and Statistics Department has not only embraced our efforts but has actively joined them. MTBI/SUMS successes have been possibly because of the leadership and hard work of all our partners, supporters, its staff and its summer faculty. However, at the end of the day it is the continuous funding by NSA, NSF and the Sloan Foundation[4] that have kept this effort alive long enough to make a difference.

4 Goals and Successes

4.1 Increasing diversity in the sciences

The first and easiest goal for MTBI/SUMS [5] to achieve is simply to increase the number of under-represented minorities in the mathematical sciences at the graduate level. MTBI focuses on encouraging minority students to attend graduate school by providing them with a genuine research experience (often sequential research experiences) in a diverse environment.

[1]Malden Nesheim, Don Randel, Biddy Martin, Frank Rhodes, David Call, Hunter R Rawlings III and W. Kent Fuchs.

[2]Michael Crow, Milton Glick, David Young, Maria Allison, Marjorie Zatz, Jon Fink, Andrew Webber, Peter Crouch, Elizabeth Capaldi and Marjorie Zatz who have done everything possible to help the goals and the vision of MTBI/SUMS.

[3]Albert McHenry, Gary Keller, Antonio García and Michael Sullivan are the kind of university citizens that every university dreams to have.

[4]The encouragement and confidence given to MTBI by Barbara Deuink, LLoyd Douglas, Ted Greenwood, Jim Schatz and Michelle Wagner have played a critical.

[5]The Institute for Strengthening the Understanding of Mathematics and Sciences or SUMS, its MTBI's partner institute and both merged in 2005. SUMS is the winner of a 2003 *Presidential Award for Excellence in Science, Mathematics and Engineering Mentoring*

As such, MTBI/SUMS has been a resounding success. MTBI/SUMS has mentored 2,095 high school students through its Mathematics Science Honors Program (MSHP). Sixty percent of the student participants have been female, while *Hispanic and Native American students account for the largest ethnic minority group percentage, at fifty-one and eighteen percent, respectively.* Thirty-one percent of the students who participated in MSHP attended two or more summers consecutively, earning up to twelve credits in the three summers prior to attending ASU as freshmen. Almost sixty percent of MSHP participants have attended ASU after high school graduation. There are currently over 350 MSHP students attending ASU, with fifty-six female students and forty nine percent Hispanic students representing the largest gender and ethnic group respectively. The Ira A. Fulton School of Engineering has the highest percentage of enrolled MSHP students at thirty four percent, followed by the College of Liberal Arts and Sciences at twenty four percent. Students who participate in MSHP tend to have higher grade point averages and retention rates than those who did not participate in it. The standard grade point average (GPA) for a current non-MSHP ASU student is 3.01 while the average GPA for a current MSHP ASU student is 3.15.

MTBI/SUMS has sent 130 students from *underrepresented minority groups* to graduate school over its *first ten years*[6] and a total of 169 students overall. Furthermore, 52% have been females, including 65 from minority groups.

In the years 2001 and 2002, prior to MTBI/SUMS producing Ph.D. graduates, the U.S. awarded an average of 10 Ph.D.s to Latinos[7]. MTBI/SUMS efforts have significantly increased the national rate of production of U.S. Ph.D.'s among underrepresented minority groups. In 2005, MTBI/SUMS alumni received 10 Ph.D.s in the mathematical sciences, 7 of which were awarded to members of underrepresented[8] US minority groups. This is almost *a fourth* of the national total output for that year. Of those, 6 were Latino, *one third* for that year (6 out of 18). Of the 10 total MTBI/SUMS alumni Ph.D. graduates in 2005, 7 (six underrepresented US minorities) took on prestigious postdoctoral positions. The remaining minority student became an Assistant Professor at the University of Puerto Rico, Mayaguez campus. Looking at female graduates, MTBI helped produce *one third* (5 out of 15) of the total female underrepresented minority groups for 2005. Four of those five were Latinas, over half of the national production (4 out of 7).

MTBI/SUMS alumni are incredibly prolific, they have coauthored 111 technical reports over the past eleven summers. These reports are often continued or extended during the academic year. Several reports have served as instigators of highly innovative research. The

[6]This number does not include the admission to graduate school of members of the summer of 2006 MTBI class. However, we are to a good start. eight MTBI/SUMS alumni from the 2006 class will be attending graduate school in the fall of 2006 or the Spring of 2007.

[7]The data for national Ph.D. graduates was obtained from the AMS notices http://www.ams.org/notices/200602/05firstreport.pdf

[8]US Residents who are Latino (the overwhelming majority are Mexican Americans or Chicanos and Puerto Ricans but there are some whose heritage is from Peru or El Salvador) or African-American or Native Americans.

bibliography includes a list of 10 *recent* refereed publications where MTBI alumni played a fundamental role. This collection of articles is but a fraction of the research instigated by MTBI/SUMS over the past decade.

Four Presidential Award for Excellence in Science, Mathematics and Engineering Mentoring have been associated with MTBI/SUMS. The first (1996) to the late Joaquin Bustoz Jr, founder of SUMS, the second (1997) to Carlos Castillo-Chavez, Director of MTBI/SUMS, the third (1998) to Armando Rodriguez, Professor of Electrical Engineering and a strong contributor to MTBI/SUMS and the fourth (2003) to SUMS itself.

Finally, now that MTBI/SUMS alumni are beginning to take on faculty positions, evidence of future patterns of secondary recruitment have begun to emerge. The establishment of the *Applied Mathematical Sciences Institute, http://www.amssi.org/* by MTBI alumni Erika Camacho and MTBI graduate mentor and former summer Director Steve Wirkus in 2005, provides a vivid example.

4.2 Creating infrastructure to sustain an increase in diversity

As successful as MTBI has been at increasing diversity in the mathematical sciences, MTBI is still only one program. Unless the changes that MTBI has created become self-sustaining and self-generating the impact will be short-lived. To this end, we believe that creating a large community of minority scholars that is committed to the issues associated with the problems of under-representation in the mathematical sciences is but the only ay. Such a community will provide the environment where minority success and minority recruitment into the sciences is natural – the norm rather than the exception.

Although this is a longer term and more ambitious goal, the indicators of success are visible. Twenty-four MTBI alumni have enrolled in a mathematical sciences program at Cornell University, MTBI's previous host school. Current data strongly suggest that about *ninety percent* of MTBI alumni will complete their Ph.D.s at Cornell University. The mathematics department at MTBI's current host school of Arizona State University includes 24 US Latino and 5 African-American graduate students who are also MTBI alumni. In addition, fourteen underrepresented minority students have enrolled in a mathematical sciences program at the University of Iowa[9]. These large groups of minority students with a common experience form the nuclei of a community of minority scholars. They all know each other, they get together at annual professional meetings and they have created a network that will seriously impact the training of future mathematicians, particularly those from underrepresented minority groups.

The self-generating aspect of the MTBI program can be seen in evidence of secondary recruitment. The establishment of the *Applied Mathematical Sciences Institute*[10] by MTBI

[9] Its mathematics department is a winner of a 2005 Presidential Award for Excellence in Science, Mathematics and Engineering Mentoring

[10] http://www.amssi.org/

alumni Erika Camacho and MTBI graduate mentor and former summer Director Steve Wirkus are indicative of things to come. As MTBI produces more minority faculty, the number of recruitment programs such the Applied Mathematical Sciences Institute can only increase.

4.3 Encouraging the development of the New American University

MTBI/SUMS philosophy adheres to the principles of the *New American University*[11] that is, MTBI is an institute that, like its home institution, ASU[12], wants to be judged by the quality of the research and academic accomplishments of its students and alumni rather than by the academic pedigree or prior access to *selective* educational settings of its participants. Encouraging the development of this perspective is critical to the goals of MTBI because it directly addresses the disadvantages that many underrepresented minority students face.

MTBI wants to be an institute whose alumni, while pursuing their scholarly and scientific interests, "also consider the public good"[13]. MTBI wants to be an institute whose students, alumni, faculty, and staff "transcend the concept of community service to accept responsibility for the economic, social, cultural, and environmental vitality of the communities they serve."[14]

Communities that systematically recruit and support minority students and that are capable of generating new learning communities such as those instigated by the Applied Mathematical Sciences Institute in California will become the norm as long as there are university models that show that *access* and excellence can not only coexist but that in fact reinvigorate each other within the model of the New American University.

The success of MTBI in creating excellence in the context of social responsibility is best illustrated by the work of Erika Camacho and Steve Wirkus who, only a few years after graduation, have begun to give back massively to the the mathematical community. Erika and Steve have set up a model learning community in just two years.

5 Acknowledgments

The research and mentorship activities in this project have been partially supported by grants from the National Science Foundation (NSF - Grant DMS - 0502349), the National Security Agency (NSA - Grant H98230-06-1-0097), the Alfred T. Sloan Foundation (ASU-Sloan National Pipeline Program in the Mathematical and Statistical Sciences) and the Office of the Provost of Arizona State University.

[11] http://www.asu.edu/president/newamericanuniversity/arizona/

[12] Here, we are paraphrasing ASU's mission but in the context of the work that is being carried out at MTBI.

[13] http://www.asu.edu/president/newamericanuniversity/arizona/

[14] http://www.asu.edu/president/newamericanuniversity/arizona/

References

[1] Baojun, S., Garsow-Castillo, M, Marcin M., Henso, L., and C. Castillo-Chavez Raves Clubs, and Ecstassy: The Impact of Peer Pressure *Journal of Mathematical Biosciences and Engineering* Volume 3, Number 1, January 2006 pp. 1-18.

[2] Gjorgjieva, J., Smith K., Chowell, G., Sanchez, F., Snyder J., and C Castillo-Chavez The Role of Vaccination in the Control of SARS. *Journal of Mathematical Biosciences and Engineering* Volume 2, Number 4, October 2005 pp. 753-769

[3] Kribs-Zaleta, C., Lee, M., Romn, C., Wiley, S., Hernndez-Surez, C.M. The effect of the HIV/Aids epidemic on Africa's truck drivers *Journal of Mathematical Biosciences and Engineering* 2, (4), 771-788. 2005.

[4] Chowell, G., Cintron-Arias, A., Del Valle, S., Sanchez, F., Song B., Hyman, J. M. and C. Castillo-Chavez Homeland Security and the Deliberate Release of Biological Agents *In: Modeling The Dynamics of Human Diseases: Emerging Paradigms and Challenges. Gumel A. (Chief Editor), Castillo-Chavez, C., Clemence, D.P. and R.E. Mickens* American Mathematical Society (in press).

[5] Yakubu, A-A, Saenz R., Stein, J., and L. E. Jones Monarch butterfly spatially discrete advection model, *Journal of Mathematical Biosciences and Engineering* 190, 183-202, 2004.

[6] Rios-Soto, K.R., Castillo-Chavez, C., Neubert, M., Titi, E.S., and A-A Yakubu. Epidemic Spread in Populations at Demographic Equilibrium. *In: Modeling The Dynamics of Human Diseases: Emerging Paradigms and Challenges. Gumel A. (Chief Editor), Castillo-Chavez, C., Clemence, D.P. and R.E. Mickens,* American Mathematical Society (in press).

[7] Sanchez, F., Engman, M., Harrington, L. and C. Castillo-Chavez. Models for Dengue Transmission and Control. In: Modeling The Dynamics of Human Diseases: Emerging Paradigms and Challenges *In: Modeling The Dynamics of Human Diseases: Emerging Paradigms and Challenges. Gumel A. (Chief Editor), Castillo-Chavez, C., Clemence, D.P. and R.E. Mickens,* American Mathematical Society (in press).

[8] Del Valle, S., Morales Evangelista, A., Velasco, M.C., Kribs-Zaleta, C.M., Hsu Schmitz, S.F. Effects of education, vaccination and treatment on HIV transmission in homosexuals with genetic heterogeneity *Journal of Mathematical Biosciences and Engineering* 187, 111-133. 2004.

[9] Gonzalez, B., Huerta-Sanchez, E., Ortiz-Nieves, A., Vazquez-Alvarez, T., Kribs-Zaleta, C. Am I too fat? Bulimia as an epidemic *Journal of Mathematical Psychology* 1.47, 515-526, 2003.

[10] Chowell, G., P. W. Fenimore, M. A. Castillo-Garsow and C. Castillo-Chavez. SARS Outbreaks in Ontario, Hong Kong and Singapore: the role of diagnosis and isolation as a control mechanism *J. of Theoretical Biology* 224, 1-8, 2003.