

# The Journal of Mathematics and Science:

COLLABORATIVE EXPLORATIONS

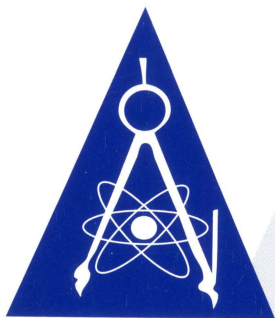
Volume 4, Number 2 Fall 2001

## PART I: SPECIAL ISSUE

**“Fostering a Knowledge-Building Community of Practitioners”**

**Puerto Rico Collaborative for Excellence in Teacher Preparation**

## PART II: REGULAR JOURNAL FEATURES



Virginia Mathematics and Science Coalition

# The Journal of Mathematics and Science:

COLLABORATIVE EXPLORATIONS

## Editor

P N Raychowdhury  
*Virginia Commonwealth University*

## Associate Editors

J Boyd  
*St. Christopher's School*

J Colbert  
*Virginia Tech*

N Dávila  
*University of Puerto Rico*

R Farley  
*Virginia Commonwealth University*

L Fathe  
*George Mason University*

K Finer  
*Kent State University*

B Freeouf  
*Brooklyn College*

S Garfunkel  
*COMAP*

J Garofalo  
*University of Virginia*

W Haver  
*Virginia Commonwealth University*

W Hawkins  
*Mathematical Association of  
America*

R Howard  
*University of Tulsa*

M Leiva  
*U of North Carolina at Charlotte*

J Lohmann  
*Georgia Institute of Technology*

P McNeil  
*Norfolk State University*

G Miller  
*Nassau Community College*

L Pitt  
*University of Virginia*

S Rodi  
*Austin Community College*

D Shillady  
*Virginia Commonwealth University*

S Solomon  
*Drexel University*

M Spikell  
*George Mason University*

C Stanitski  
*University of Central Arkansas*

D Sterling  
*George Mason University*

B Williams  
*Williamsburg/James City Schools*

S Wyckoff  
*Arizona State University*

# **The Journal of Mathematics and Science:**

**COLLABORATIVE EXPLORATIONS**

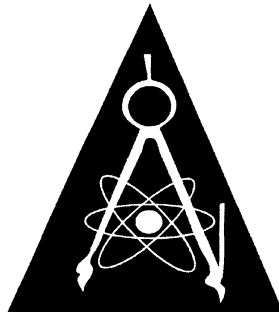
Volume 4, Number 2    Fall 2001

## **PART I: SPECIAL ISSUE**

### **“Fostering a Knowledge-Building Community of Practitioners”**

Puerto Rico Collaborative for Excellence in Teacher Preparation

## **PART II: REGULAR JOURNAL FEATURES**



Virginia Mathematics and Science Coalition



# **The Journal of Mathematics and Science:**

COLLABORATIVE EXPLORATIONS

## **PART I: SPECIAL ISSUE**

**“Fostering a Knowledge-Building Community of  
Practitioners”**

**Puerto Rico Collaborative for Excellence in Teacher Preparation**

Coordinating Editor  
for this Special Issue  
Josefina Arce



# **THE PUERTO RICO COLLABORATIVE FOR EXCELLENCE IN TEACHER PREPARATION (PR-CETP): DEVELOPMENT OF A KNOWLEDGE BUILDING COMMUNITY OF PRACTICE**

---

J. ARCE

*Puerto Rico Collaborative for Excellence in Teacher Preparation (PR-CETP)*

*Dept. of Chemistry, University of Puerto Rico, Rio Piedras,*

S. MACKSOD

*Resource Center for Science and Engineering of Puerto Rico*

## **Extending the Science and Mathematics Education Reform to Teacher Preparation Programs**

Until recently, the predominant practice of science and mathematics education consisted of communicating the results obtained by scientists and researchers to students. While knowledge of these results is important, a lack of understanding of the knowledge building processes followed by scientists and mathematicians hinders the development of conceptual understanding and the capability for the proper application and creation of knowledge. Furthermore, this approach to education thwarts the development of the learning capabilities needed in the global, knowledge-based society in which we live. The Puerto Rico Collaborative for Excellence in Teacher Preparation (PR-CETP) has been a crucial step in overcoming the results-centered view of science and mathematics education, by serving as a catalyst for the transformation of teacher preparation programs on the Island towards the adoption of a constructivist approach to teaching and learning, which asserts that all students can learn if actively involved in the creation of their own knowledge.

PR-CETP is one of several interrelated systemic K-16 reform initiatives in Puerto Rico, co-sponsored by the National Science Foundation and spearheaded by the Resource Center for Science and Engineering of the University of Puerto Rico system, in alliance with the major universities throughout the Island, the Puerto Rico Department of Education, and numerous other public and private organizations in Puerto Rico and abroad. PR-CETP builds mainly on two systemic endeavors: the K-12 reform implemented by the Puerto Rico Statewide Systemic Initiative (PR-SSI), and the Puerto Rico Louis Stokes Alliance for Minority Participation (PR-LSAMP) which focuses on the reform of undergraduate education in science, mathematics, engineering, and technology. The articulation of these systemic reform initiatives into a single coherent strategy has been critical to ensure a synergistic effect that advances the transformation of the K-16 science and mathematics educational system throughout the Island.

The PR-CETP journey began close to four years ago when a group of professors from the main institutions that prepare science and mathematics teachers, most of whom had been involved in PR-SSI and or PR-LSAMP, realized the need to do something about the gap between the K-12 reform and teacher preparation programs. If future teachers were expected to sustain the K-12 reform, the transformation of teacher preparation programs was necessary. The urge to reform teacher preparation was spurred by the evidence produced by evaluation efforts of both PR-SSI and PR-LSAMP, which pointed toward the effectiveness of the constructivist approach in promoting conceptual understanding among students. The conception of PR-CETP was nurtured by many of the experiences, resources, and strategies developed through these initiatives, which were incorporated into the design of PR-CETP through a planning grant from the NSF. The collective dialogue and critical reflection of science, mathematics, and education professors, K-12 teachers, and future teachers on the prevailing situation of teacher preparation programs on the Island served as the foundation for the elaboration of the *Blueprint for the Reform of Science and Mathematics Teacher Preparation Programs in Puerto Rico*. The *Blueprint* sets forth a common vision of the principles and strategies to be enacted in order to ensure the alignment of teacher preparation programs with the local and national standards of excellence for K-12 science and mathematics [1-7]. In 1998, the NSF approved the PR-CETP proposal, which gave way to the full-fledged implementation of the reform of teacher preparation programs in Puerto Rico.

### **PR-CETP: Partners and Strategies**

The teacher preparation institutions brought together through PR-CETP include: the University of Puerto Rico (UPR) at Río Piedras, UPR at Mayaguez, UPR at Cayey, and UPR at Arecibo; the Inter American University System (four campuses), the University of the East of the Ana G. Méndez University System, and the Pontifical Catholic University of Puerto Rico. While each one of these institutions target particular disciplines and educational levels in their teacher preparation programs, they all share a deep commitment to the improvement of science and math education. The diversity of these institutions constitutes one of the strengths of the PR-CETP alliance, as each one brings unique contributions and assets to the reform, thus optimizing the cross-fertilization of efforts. Other fundamental partners in the PR-CETP endeavor are the Puerto Rico Department of Education, the Arecibo Observatory, the International Institute of Tropical Forestry, the Puerto Rico College Board, and local industries including Bristol Myers Squibb, SmithKline Beecham, and AMGEN. The partnership with the Puerto Rico Department of Education facilitates the collaboration of K-12 teachers, and access to the 25+ schools that serve



as Regional Centers for Professional Development and Dissemination of the K-12 Science and Mathematics Reform, developed through the PR-SSI, where exemplary teaching practices are modeled.

The interinstitutional structure of PR-CETP allows for an optimal collaboration level among all members of the alliance. To facilitate this collaboration, the Center for Excellence in Science and Mathematics Teacher Preparation was established at the Resource Center for Science and Engineering, as a central coordinating and communication unit that also provides overall leadership and coherence for the PR-CETP reform. All participant universities are represented in the PR-CETP Interinstitutional Committee, which serves as the steering group for the initiative. Each university has established its own PR-CETP Institutional Committee that integrates participants from science, mathematics, and education faculty, breaking the traditional disciplinary boundaries that segregate the faculty and prevent the cross disciplinary collaboration that is needed to transform the preparation of future teachers; particularly, to articulate the content and methodology of science and mathematics teaching.

The key foci of the PR-CETP reform are: (1) the curricular reform of teacher preparation programs based on constructivist education principles; (2) the enhancement of science, mathematics, and education faculty knowledge and skills in the constructivist approach to teaching, learning, and assessment; (3) the development of student support mechanisms to foster a smooth transition from recruitment to induction into teaching; (4) the establishment of institutional policies and practices to sustain the transformation of teacher preparation programs; and, (5) the evaluation of the processes and outcomes of the transformation of teacher preparation programs. These foci are organized into distinct programmatic components that are closely interdependent and feed into each other. An additional component of the PR-CETP is the NSF Teaching Scholars Program which provides incentives for over 25 outstanding K-12 science and mathematics education students, and supports their development as future leaders of the K-12 educational community.

As with all reform efforts, PR-CETP has had to formulate strategies that are highly effective in facilitating profound changes at all levels. In undertaking this challenge, it has been particularly important to identify and implement strategies that are successful in overcoming the obstacles, and resistance, that are a natural element of all reforms that entail paradigmatic transformations. The main strategy enacted by the PR-CETP to usher these changes has been the creation of a knowledge building community of practice, in which new knowledge is constructed

among members through various collaborative processes coordinated and facilitated by the Center for Excellence in Science and Mathematics Teacher Preparation. Susan Millar, member of the PR-CETP National Visiting Committee, and Director of the LEAD Center University of Wisconsin-Madison, has noted in her 2001 site visit report that the PR-CETP promotes the development of this type of community through activities (retreats, workshops, congresses, project meetings) that foster a sufficiently safe environment in which faculty are able to reflect on shortcomings in their own teaching from genuinely new perspectives [8]. According to Millar, the concept of a knowledge building community of practice as developed by Derry and DuRussell [9] is a useful model for understanding how the PR-CETP works: through processes of negotiation, argumentation, and information sharing facilitated by apprenticeship and mentoring, participants from heterogeneous backgrounds are able to evolve new ideas, methods, and tools that allow boundaries to give way to new constructs, language, and behavioral norms that shape and are shaped by teamwork. As a result of working together, each individual team member's mental models of group tasks, community constructs, and the community itself become more aligned. Using a term coined by Schon [10], she points out that faculty are becoming reflective practitioners of the art and science of teaching. Millar indicates that, "As individual reflective practitioners, they are better able to teach what they know to others, and also more able to abandon practices that do not work, and further develop those that do." [8]

To know more about the efforts and products of the PR-CETP, please visit our webpage at <http://cetp.crci.uprr.pr> or contact the individual authors of the articles.

### **The Articles**

The articles included in this issue are a sample of the diverse initiatives supported and promoted through PR-CETP, such as: science and mathematics course transformations based on a constructivist approach to teaching and learning; the development of innovative courses for science education majors; creation of new courses for cooperating teachers who supervise future teachers; research on the effectiveness of the NSF Teaching Scholars Program; and the PR-CETP program evaluation. These articles should give the readers a clear idea about what is happening in the PR-CETP promoted reform with specific examples in various areas of science and mathematics. The investigative approach PR-CETP follows in order to improve the effectiveness of our activities is exemplified in the article about the NSF Teaching Scholars—an article that started as a class project. Our Project Evaluator, Milagros Bravo, describes in detail the efforts of

one of the key components of PR-CETP. The assessment and evaluation component has been a major driving force, guide, and cohesive factor of PR-CETP from its beginnings.

We hope that in sharing our successes and our struggles in the implementation of such an ambitious and complex enterprise through the articles presented in this issue, we are able to stimulate and encourage others who are interested in embarking in similar systemic endeavors. ■

### **Bios**

Josefina Arce is Professor of Chemistry at the University of Puerto Rico, Río Piedras and Principal Investigator of PR-CETP. Sandra Macksoud is Coordinator of Planning and External Resources for Education and Research of PR-CETP.

### **References**

- [1] *Blueprint for the Reform of Science and Mathematics Teacher Preparation Programs in Puerto Rico*, Puerto Rico Collaborative for Excellence in Teacher Preparation, Puerto Rico, 1997.
- [2] *National Science Education Standards*, National Academy Press, Washington, DC, 1996.
- [3] *Estándares de Contenido de Ciencias*, Puerto Rico Department of Education, Puerto Rico, 1996.
- [4] *Estándares de Contenido de Matemáticas*, Puerto Rico Department of Education, Puerto Rico, 1996.
- [5] *Estándares Profesionales para Maestros*, Puerto Rico Department of Education, Puerto Rico, 1996.
- [6] *Curriculum and Evaluation Standards for School Mathematics*, National Council of Teachers of Mathematics, Reston, VA, 1989.
- [7] *Professional Standards for Teaching Mathematics*, National Council of Teachers of Mathematics, Reston, VA, 1991.
- [8] S. Millar, Report of PR-CETP National Visiting Committee, March 2001.
- [9] S.J. Derry and L.A. DuRussel, "Assessing Knowledge Construction in On-line Learning Communities," in S. Lajoie and M. Vivet (eds.), *Artificial Intelligence in Education*, IOS Press, Amsterdam, 1999.
- [10] D.A. Schön, *The Reflective Practitioner: How Professionals Think in Action*, Basic Books, New York, 1983.



# THE TRANSITION TO COLLEGE PROCESS IN PR-CETP SCHOLARS

---

E. RIVERA, M. ROSA, A. SANTIAGO, N. TORRES, and M. BRAVO

*University of Puerto Rico, Rio Piedras*

mlbravo@caribe.net

## Abstract

This article describes a study about the experiences of a group of students during the transition from high school to college. The students are future teachers who evidenced a high level of academic achievement in high school and received merit scholarships from the Puerto Rico Collaborative for Excellence in Teacher Preparation (PR-CETP). Two groups of students were compared: those who sustained a high GPA during their freshman year, and those who did not and, therefore, no longer qualified for the scholarship. The study was carried out through focused interviews with eight students, from three universities, four of whom maintained the scholarship and four who did not. Findings indicate that the main problems encountered were academic and social, and that the students received support from their families during the entire process. Regarding formal support, they pointed out that they felt highly satisfied with the services provided by PR-CETP and the universities, but they also pointed out (particularly those who lost the scholarship) that they needed additional services from the universities. They suggested, for example, better tutoring, and social activities among the scholars. The interviewed students, in general, consider that they faced the transition successfully since most of them described their academic, emotional, and social status as satisfactory at the time of the interviews.

## Introduction

Many studies have been carried out to better understand a crucial period during the life of college students—their freshman year. Grayson describes “the swiftness and magnitude of change” and states that this year is one of major adjustments, in which so many changes occur that the initial experience of the undergraduate is a major transition for virtually all students [1]. Although this period is usually difficult for students, for some it is more so. Bushnell indicates that most students drop out voluntarily during this transition for reasons that are not academically related, and only about one-fourth of them do it for academic reasons [2]. Understanding the difficulties that these students face and how they manage them can give us an idea about how to help them, and how to offer support for their academic endeavors, psychological well being, and overall personal development.

The major goal of this research was to study the transition to college process of a group of students, specifically students who are future teachers of science and mathematics. These students (called teaching scholars) are members of a group who evidenced high academic performance during their high school studies and received a merit scholarship awarded by the

Puerto Rico Collaborative for Excellence in Teacher Preparation (PR-CETP), funded by the National Science Foundation. To study this process, two groups of students were compared: those who sustained a high GPA during their freshman year, and those who did not maintain a GPA high enough to keep their scholarships. In comparing the groups, we seek to identify elements that may contribute to a more successful transition to college among future teachers.

The topics and specific questions that the study focused on were:

- Pre-college experiences: What were the pre-college experiences of these students like, including their career selection?
- Entry situations: What situations did the students face upon entering college, how did they manage them and what feelings did these evoke?
- Informal support: What support did these students receive from informal resources (family, friends, and peers)?
- Formal support: What support and other institutional resources did they receive from the universities they were enrolled in and from the PR-CETP Program?
- Outcome of the transition: How well did these students consider themselves to be doing in academic, personal, and social terms during their sophomore college year?
- Recommendations: What recommendations did they offer to the institutions, and to PR-CETP to facilitate the transition to college?

## **Method**

Based on a qualitative perspective, a focused interview was used as the primary strategy to examine the problem.

## **Participants**

The population of this study included 22 students who received PR-CETP scholarships in 1999 and at the time of the interviews were in their sophomore year in college. They were divided into two groups for the study: students who kept the scholarship and those who lost it after completing their freshmen year (because they failed to obtain a  $GPA \geq 3.0$ ). In the first group, there were ten females, whereas in the second group there were eight females and four males. Within each of these two categories, four students were selected for a total of eight participants. A description of the study's participants is provided in Table 1.

**Table 1.** Description of the sample of participants in the study.

Gender		Age	
Female	7	19 years	6
Male	1	20 years	2
<b>Total</b>	<b>8</b>	<b>Total</b>	<b>8</b>
University <sup>1</sup>		Program of Studies	
UPR-RP	4	Science Education	6
PUCPR-Ponce	2	Mathematics Education	1
UPR-Cayey	2	Elementary Education	1
<b>Total</b>	<b>8</b>	<b>Total</b>	<b>8</b>

<sup>1</sup> UPR-RP: University of Puerto Rico, Río Piedras; PUCPR: Pontifical Catholic University of Puerto Rico; UPR, Cayey: University of Puerto Rico, Cayey.

A larger number of females than males were interviewed since the first group only contained females; and, only one male from the second group was available for the interview, since two others refused to be interviewed. Half of the participants came from one (out of seven) of the PR-CETP participant institutions. We did not attempt to include students from all universities since accessibility was a factor in the selection of participants.

### Collection and Analysis of Data

The interviews were carried out through the use of a protocol that included four parts: (1) demographic data; (2) background of the situation (i.e., prior experience as a student, preparation for entering college, and career selection); (3) college life (e.g., situations faced, ways of handling them, and institutional context) and, moment of the interview (i.e., academic performance, emotional state, family, friends and peer relations); (4) reflection about the discussed topics, particularly the significance granted to college life and recommendations they would offer to the institutions and PR-CETP to promote a successful transition to college. Participants were contacted by telephone to schedule the interview. The interviews were conducted at the institution or the residence of the interviewee. The interviews were recorded and transcribed *ad verbatim*. Four doctoral students in education conducted the interviews.

The first phase of data analysis consisted of creating *a priori* categories, codes, and preliminary definitions based on a review of the literature and research questions. Once the

information from the interviews was examined, the research team added inductive codes and categories. A search for similar patterns, themes, observations, and opinions was carried out. The research team met several times to review and define the codes and to reach a consensus. This process helped to strengthen the results of the analysis. The interviews were analyzed using the *Ethnograph* software, version 5.0.

### **Results: Prior School Experience and Career Selection**

The academic preparation students receive prior to entering college is a critically important factor for their success [2]. The first research question for this study sought to examine this important factor. Students interviewed narrated mostly positive experiences that represented achievements in their precollege stage. They indicated they were good students in the elementary as well as secondary schools. They pointed out that they had been actively involved in extracurricular activities, such as the Science Fair and athletic competitions, in addition to belonging to several school clubs. These positive experiences were conveyed in expressions such as the following: “...in elementary school I was the most outstanding athlete”; “...I was President of the graduating class, I wrote stories, and participated in the Math Olympiads”; “...I participated in the Science Fair.” They also spoke about personal or academic difficulties they faced during this stage. For example, some students said: “...my father became ill”; “...eighth grade was a difficult period...”; “...my grade point average dropped in my junior year because I had problems with English.”<sup>1</sup>

Both groups, those who had a higher academic performance and those who had academic problems during their freshman year, generally narrated similar experiences related to their life in school before entering college. On the other hand, some differences regarding how prepared they felt to enter college were observed. Those students who had academic adjustment problems indicated that they did not feel prepared, as expressed in the following: “...during the senior year I didn’t take mathematics”; “...I had problems with English”; “...I was never good in mathematics.” Those who were most successful stated that they felt prepared, through answers such as, “...I was in the advanced group, I was prepared.”

Humans interact with their environment developing new behaviors in the process. Personal characteristics influence the outcome of these interactions. Brown [3] identified five basic elements related to the college student’s development, one of which is the personal

---

<sup>1</sup> In Puerto Rico, Spanish is generally the language of instruction; English is taught as a second language.



characteristics and traits of the student upon entering college. The expectations that a student has regarding college life are an important characteristic [4]. Related to this aspect, the students interviewed said: "...I felt prepared because I knew it would be difficult"; "...I knew that it was more complicated and that it took more effort"; "...I knew that I had to study every day and stay up all night."

Other characteristics that may have great impact on the successful transition to college are the student's study habits and social skills [5]. Upon asking students which skills of this type they possessed, they pointed out that, "...ever since I was small I liked to review my classes every day"; "...I've always had good study habits"; "... I'm very sociable, dynamic and if I have questions, I dare to ask." These expressions were offered mainly by those students who were more successful in their academic performance in college.

The selection of a career is the peak moment in the occupational development of a person [6]. Many times, students base their decisions on models they have in their lives during their early years. Most of the students mentioned that they had close family members (mother, father, uncle), or teachers, who were their models. Some of their comments on this aspect were: "...my uncle is a science teacher and I used to help him correct tests"; "...my chemistry teacher was an example for me"; "...my mother is a teacher and when I was small I wanted to be a teacher."

An adequate academic counseling and guidance process can contribute greatly to a smooth transition to college [2]. In high school, guidance for the transition should include support for students as they select the course of studies they wish to pursue at the college level. Guidance for the transition is initiated in high school, but should continue in college. Therefore, it should be adequately provided on both levels, and requires good communication between guidance professionals from both academic levels [2].

The interviewed students mentioned that they could discuss their doubts about a teaching career with their teachers and some indicated that they were counseled by people sent by the universities or by the school counselor. In relation to this, they said: "...they came from the university to offer guidance"; "...they asked me what I wanted to study"; "...the teachers helped me"; "...my biology teacher helped me." Although they received counseling, some students wished that they had received more detailed information about the professions and the universities they could select. Therefore, it can be established that the high schools these students

came from did not always fulfill their function of providing students with adequate academic and occupational guidance.

Upon asking about the positive elements they perceived in the teaching career, most of the students mentioned that facilitating learning was the most important aspect of that career. About this, they said they were able to: "...transmit knowledge and socialize"; "...direct what happens in the classroom"; and, they stated, "the teacher accompanies students in the learning process." Negative elements mentioned regarding the teaching career focused on concerns about relationships with students and their parents. For example, some of the concerns they mentioned were: "... that students do not respect you"; "...sometimes parents complain; sometimes students can be very difficult, one has to have control"; "...that parents could be aggressive." They also mentioned the profession's "...lack of prestige." It can thus be stated that the negative elements of the teaching career that worry future teachers the most are the management of relations with students and parents, and the lack of prestige of the profession.

### **Results: Entry to College**

Grayson describes the changes that are present during college life as a "mini life cycle." [1] He describes the freshman year as one of major adjustments. It is during this moment that:

...students separate from their parents and other family members, their home, their friends, and their community. ... It is a time of adjusting to new friendships, and they become exposed to people from diverse backgrounds ...the academic load increases usually at the same time as academic competition increases...it is a major transition for virtually all. (p.99)

Some students mentioned having faced difficulties in the area of social relations:

Um..I was with different people in all of my classes. Almost always one has a group during the freshman year...my sister had a group, not me, the world was different. I was alone, it was hard for me to meet people and that really affected me. I found it a little difficult because I am shy to relate to other people, I didn't dare too much with my fellow students.

And, "...social life, well, I didn't know anyone and the social part affected me quite a bit."

Nevertheless, the major difficulties confronted by the interviewed students were apparently of an academic nature. Several stated that their major problem had been their mathematics courses, especially for one of the students belonging to the group who lost the scholarship and who indicated that the course was in English. They described these difficulties as:

Teachers who speak in English, it was hard. You have to adapt your ears to English, it helps. ... The science, mathematics, and calculus teachers teach in English.

The mathematics class was much more advanced than what I had taken in high school. What really helped me was the intermediate school level mathematics class. The [name of the high school] really does not prepare us for college, they do not offer chemistry.

In relation to their emotional state upon entering college, three students (two who lost the scholarship and one who still had it) mentioned that they experienced feelings of loneliness and sadness: “[Feeling] homesickness, sadness, nervousness, the most difficult was that I was alone. Everything, yes, but it is a phase of growing”; “...a little nervous, that’s all.”

The five remaining participants indicated they felt fine during their freshman year. Some of their comments were:

I felt happy, because I said, “Wow, I’m big already. One can become independent.”

At the beginning, I was happy for having entered and as I found difficulties in the classes I became frustrated but later. Now I have recovered my enthusiasm. Well, they were all good. I made many friends as soon as I entered. We formed study groups. The experience was always positive.

Upon asking them how they had handled the new and/or difficult situations during that year, they indicated that they could handle them because they sought support or help from a family member, a counselor, and dealt directly with their emotional states. This could be seen in comments such as:

I consulted with my mother all about feelings and with the counselor about the academic aspect. I had good results.

Keeping myself positive. Each time I had an obstacle, thinking that I could overcome it helped me stay on track.

Trying to control my nervousness, loneliness, when I went to appointments, talking with persons who agreed with me, and then I would talk with my parents and they advised me. Seeing things from a positive point of view.

When asked if they had used substances such as, tobacco, alcohol, drugs, or pills, all the interviewees indicated that they had no need to. Only one student answered, "...yes, coffee, sometimes I have had to drink coffee because I fall asleep with my face buried in my books."

The interviewed students, in general, thus indicated that they confronted only minor difficulties during their transition to college, contrary to what is stated in the literature. Several reasons can explain this finding. First, all were high achievers in their high schools. Moreover, most of them lived at home, only one of them boarded, and all of them indicated having the support of their families.

### **Results: Support from Informal Resources**

The literature about adjustment to college underscores the importance of using sources of support during the transition process. In a study by Hurtado, Carter, and Spuler [7], it was found that the persons who usually provided support to the students were: peers, family members, friends, administrative personnel, faculty, and high school teachers and counselors.

In our findings, both groups of students mentioned family as the main source for emotional support, for help in studying, and for providing transportation. For example, some students said:

I consult with my mother everything related to my feelings.

My father helps me study. He explains things to me.

Everyone [in my family] uses the same transportation. We coordinate our schedules. Everyone is picked up. Besides, we live at home.

Some people also recognize the support provided by their friends indicating that, “my friends have always supported me, they are always checking up on me. My friends and I tell each other everything that happens to us, we support each other. We get along well.”

This support also was evident among students when they met to study in groups: “We form study groups. We help each other clarify doubts and we go to the library.”

Two interviewed students (one with the scholarship and one without it) mentioned their companion and spouse as sources of support. For example:

I travel with my boyfriend and we agree on the same class schedule.

My boyfriend takes me and brings me to activities. He supports me in gaining knowledge.

### **Results: Institutional Context and Formal Support Resources**

The college environment affects all transition experiences and the adjustment to college life [7]. The post-secondary education system should promote the development of an environment that allows people to reach their educational and professional goals. Hence, higher education institutions should become aware of the effect of the environment on students, in order to create high quality education.

According to the interviewed students, they received support in the transition to college from the PR-CETP staff, from professors, tutors, and guidance counselors. Guidance for transition to college begins in high school and continues in college. In college, guidance should support students so that their transition is successful. The process of exploring interests continues, since most students arrive at college without having made a firm decision, or without knowing their options. In addition, the adequate selection of courses is important since it can cause delays or failures when finally choosing the program they will major in. The interviewed students mentioned that some counselors were concerned about them and offered them academic counseling in addition to providing them information and options to enroll in courses: “They have

been good because they have helped me to get my classes. They tell me, for example, which classes I need to take and which are requirements for other courses.”

Personal and social guidance and counseling assumes critical importance because college environment is less structured and family support weakens, which usually happens at the stage when they enter college. In this aspect, the collaboration among professors and counselors is also necessary. Yet, students mentioned that counselors concentrated in offering academic counseling only.

The interviewed students mentioned repeatedly that they received support from the PR-CETP staff and that they participated in several enriching activities. They mentioned that the liaison staff at the PR-CETP central level maintained continuous and stimulating communications with them “...[the liaison officer of PR-CETP] was always with me, we had continuous communication and I needed it. It stimulates me.” Also, they indicated that the program offered workshops, tutoring, mentoring, and extracurricular activities that helped them in the academic area. These services were evidenced through the following comments:

...they gave us science, mathematics, and communication workshops. Also, study habits and how to make a portfolio.

...I learned a lot at the trip to the Las Cabezas Lighthouse.

...they looked for tutors and mentors to help us in our classes. [The mentors] were graduate students and professors who got us tutoring and helped us.

The interviewed students mentioned that receiving the PR-CETP scholarship was beneficial for them. One of the interviewees stated that: “...it helped me a lot and I was able, among other things, to buy a computer, pay for my board, and buy other materials and books.” Another interviewee said: “it was a help that I could not describe.”

Some less successful students, however, pointed out deficiencies in the tutoring system. For example, they indicated that they did not have English tutoring, that the tutors arrived toward the end of the semester, and that they did not dedicate enough time. The interviewees mentioned that:

...The tutor assisted more than three persons, and I need them to be with me.

In my mathematics class, I looked for help from the institution's tutors, but they didn't know that much.

The tutors arrived when the semester was almost over.

They offered tutorials, but they were not that good. I prefer the ones offered by Natural Sciences, above all the ones in mathematics.

Two of the students who lost the scholarship were not satisfied with the services they received from the PR-CETP at the institutions. They indicated that:

They didn't meet with us, they didn't really help us. ..When they had meetings in San Juan, then they met with us, not even with the other students in CEPT, they didn't meet with us.

When they asked us in San Juan, we never knew what they were talking about because they weren't giving us the guidance they were supposed to. When they asked us over here, then the Science and Education directors met.

Another difficulty faced by some students was that they received the mail about PR-CETP activities too late, and could not attend the meetings. For example, one of the students commented about the support that wasn't helpful:

...About the institution, the mail arrives late, I don't know if it is late reaching the Program, and I couldn't fill out an application to attend a laboratory in the United States.

There are many opportunities within the college context to impact the development of students. According to Brown, one of the important environmental factors that affect developmental patterns is the relationship with professors [3]. The students participating in the study mentioned that some of the professors at the institutions offered help or support. *Some of the examples of the help they received is evidenced in the following comments:* "...The

mathematics professor helped us during office hours”; “...the English and science teachers have helped me a lot”; “...the mathematics professor always wanted to help so that I could make it.”

However, they mentioned limitations in the support or help they received from the professors. They pointed out, for example, that the help was offered only for their class, that the time they were available was too limited, or simply that they did not help them. “...The professor tried to help me, but sometimes she didn’t have time because she was working on other things, as coordinator or something like that...”; “...My Spanish professor sat down with me to explain how to prepare an oral report. But not all of them are that way.”

Classroom experiences also have an impact on the students’ development [3]. Blocher [8] identified several elements that should be considered in any learning environment to facilitate the cognitive, academic, and personal development of the student. These are: engaging, challenging, and supporting them, as well as providing structure, feedback, and integration. The curricular innovations that promote this type of environment are, therefore, important for the successful transition toward college life.

The interviewed students gave diverse answers when they were asked about the innovative courses offered at the institutions in the disciplines of science, mathematics, and education. About the science courses, the students who maintained a high GPA, as well as those who didn’t, expressed diverse positions. This is evidenced in the following comments: “...In the chemistry class, no. The laboratories included all the steps, it’s traditional”; “...In physics, yes. The student is given some information and has to look for additional information. The professor gives examples from everyday life”; “...In biology, there was a lot of interaction.”

Upon formulating the same question in relation to the mathematics courses, most of the students, the successful ones as well as the less successful ones, mentioned that innovations were not used. Some of the interviewees pointed out that: “...There is no interaction between the teacher and students. There is no participation, we hardly talk”; “...In mathematics, the class is traditional.” However, one successful student, as well as one who was not as successful, mentioned innovations in the mathematics class:

...I am actually taking a course in *Calculus II* that is based more on technology. They use a lot of transparencies and cooperative learning groups.



....The *Precalculus II* class, he [the professor] does not write on the blackboard. It is all by computer. We have a computer and what he [the professor] writes appears on ours.

About the use of innovative strategies in the education courses, the interviewees, regardless of whether they were successful or less successful, indicated that, these courses were different and that the professors always integrated innovations in the courses. They made comments such as the following:

They have a lot of variety in the class, you participate, and there is a lot of conversation between the students and teacher.

In education they do [integrate innovations], in *Language Skills*, *The Exceptional Child*, and *Psychology*. I love it. It is a way of expressing what you know in a different way. It is not what they [professors] say, but what you know how to do or say.

The successful as well as the less successful students agree that they obtain better results in the courses that incorporate innovations:

...They are excellent. They have very good results. I expected to get a "C" or a "D" because the class [*Calculus II*] was difficult, but I got a "B."

...They're great because that way we don't waste time writing on the board, because the professor brings everything from home and just installs it in the computer, and we see it and can go faster.

...I think that I was able to do better in the innovative courses, in my grades as well as in my learning.

The universities should acquire greater responsibility for using strategies and techniques that promote changes in students' thought, behavior, and knowledge. Bushnell indicates that cooperative learning is one of the useful strategies to improve academic performance and social interaction, and promotes student retention [2]. This strategy is being used to some extent in the

classes taken by the interviewed students: “they do a lot of cooperative groups”; “...but they are different. In education, the work is cooperative and you talk about your experiences.”

In general, both groups of students recognized the importance of the support received by the institution, and particularly, from PR-CETP. The help offered by professors, guidance counselors, and the PR-CETP staff were determining factors for the group of successful students. Whereas for the group of students who were not as successful, the support offered by the institution was not enough to help them achieve their academic goals.

### **Results: After the Transition Year**

Most of the students described their situation at the time of the interview as positive in academic as well as personal terms. Six of the eight participants indicated that they are fulfilling their expectations in academic terms. They described their current situation with phrases such as, “it’s going well,” “very well,” and “super well.”

On the other hand, two students maintained that they were still encountering difficulties in some courses; one of them still has the CEPT scholarship, and the other one lost it. They indicated: “...this semester is difficult because I dropped out of a class last semester, and I have to compensate this semester”; “...I didn’t do well in mathematics, I got a “C-”.”

All the interviewed students indicated having good relations with their parents and that they received a lot of help from them. They described their current relationships with their families: “My parents talk to me, they always ask, what’s going on? You’re not that way, let’s talk...My father, in mathematics and chemistry, sat down to analyze the exercises until we found the right answer, my little brother, too.”

Both groups of students also indicated receiving help from their friends and their companions. For example, “My boyfriend brings me and takes me to activities.” One of the students said she was married and she received a lot of help from her spouse since they were both studying. The student told us, “...he helps me a lot because we have a child. That way, when I have a test, he stays with the baby, and when he has a test, I take care of the baby.” Another student mentioned the fact that although he does not see his friends often, he maintains positive relationships with them. The rest also agreed that they maintain a good relationship with their friends. These results suggest that students overcame difficulties of a social nature during their second year.

The participants described their college experiences in very diverse ways. However, they agreed that these had been very positive and also indicated feeling motivated to continue their college studies, regardless of whether they continued to have the scholarship. Some students who lost their scholarship, indicated: "...I lowered my GPA, but I like it"; "...I am very motivated and very proud of having entered college." Those students who kept their scholarship indicated that: "...I feel well emotionally"; "... I keep a very high self-esteem and I feel good about myself"; "...the college experiences have been very positive."

As can be seen from the above, the interviewed students consider, in general, to have made a successful transition to college since they describe their current status at the moment of the interview in mainly positive terms. They expressed that they felt motivated to continue their college studies.

### **Results: Recommendations for Universities and PR-CETP**

In this study, it was important to know what recommendations students who had already made a successful transition to college could offer their institutions and to PR-CETP to facilitate the transition for others.

The PR-CETP has included many areas to help promote the development of future teachers. The interviewed students recommended that the program broaden and continue offering workshops, extracurricular activities, tutoring, and mentoring during the semester, which were beneficial according to the students:

Their help is, I don't even know how to describe it, because they are always looking after us, they help us so that we can develop well. They give us many workshops that are excellent. It has been very good, a very good help.

They also recommended that the PR-CETP and the college institutions broaden the activities at the high school level to motivate future teachers and help to recruit participants. Particularly, one student indicated:

I believe that universities must organize to go more often to high schools, to start orienting students. So that when they arrive at college they do not feel intimidated by everything they are told. ...so they can help the students to work

things out...I think that this program should start a year before students enter college.

On the other hand, some students believe that the program should promote social interaction among students. Besides the workshops, students wish to share with all the program participants, in local meetings at the institutions, as well as at the Island-wide level. They requested to meet at least once a month in the institution: "They should carry out activities at the institution, those who are at the same institution don't even see each other unless they take classes together. To meet, offer workshops and activities within the institution."

Also, they recognized that to be successful, it is important to strengthen the support of the institutions. For example, they recommended, "that the institution provide us more support because sometimes they don't give it." One of the participants recommended that the institution expand the curricular offerings so that students could make adequate use of their free time in the activities. That is:

Well, like motivating them and having many programs at college, educational, to develop skills so that students are always occupied doing something. So that during their free time they are motivated to do something.

The students recommended that tutors should be assigned time at the beginning of the academic session, and students should have a fixed schedule to receive those services in a more organized way. One specific comment by a student who lost the scholarship was: "...the tutors arrived when the semester was almost over."

## **Conclusions**

In light of the findings of this study, we can reach the following general conclusions:

- Most of the interviewed students felt prepared to face college life;
- However, they pointed out that the guidance they received in the process of selecting their careers during high school was not totally adequate;
- Upon arriving at college, the main problems faced were of a social and academic nature; the level of difficulty of some courses, especially mathematics and English, was the main academic obstacle confronted;

- The emotional reactions that some experienced during the transition to college were feelings of loneliness, shyness, and nervousness;
- The family was the main source of support that students had at this stage; friendships and partners were also important sources of support;
- The support services provided by PR-CETP were crucial for their academic achievements;
- The students, especially those who did not maintain a high level of achievement, pointed out that the support received from the institutions in which they studied was not adequate or sufficient enough for them to achieve their academic goals;
- The students interviewed feel that they have successfully overcome the difficulties of the transition to college life.

### **Limitations to the Study**

One limitation that should be mentioned is the difficulty in selecting the students to be interviewed. One did not keep the appointment, and another decided not to participate. The result was that most of the students interviewed were female. Also, not all of the institutions that are part of the PR-CETP alliance were included in the sample and that limits the generalization of the findings. Moreover, given that the study focused on a group of high performing students in high school, who received special treatment for being members of the group of scholars, the findings cannot be generalized to the entire student population that enters college in Puerto Rico. Nevertheless, if these privileged students faced the academic and social difficulties they described, how much more difficult is it for students who do not enter college under such favorable conditions? This study, even though it did not consider them directly, gives us a glimpse of their situation. ■

### **Bios**

Emilda Rivera, Mari Rosa, Alfredo Santiago, and Noel Torres are doctoral students and Milagros Bravo is Professor in the Department of Graduate Studies in Education, University of Puerto Rico, Río Piedras Campus. The latter is also Coordinator of the Evaluation Component of Puerto Rico Collaborative for Excellence in Teacher Preparation (PR-CETP).

**References**

- [1] P. A. Grayson. "College Time: Implications for Student Mental Health Services," *Journal of American College Health*, **33** (1985) 198-204.
- [2] J. Bushnell. *Retention at the Community College Level*, ERIC ED 331571(April, 1991).
- [3] R.D. Brown. "Key Student Development Concepts," *College Student Personnel Administration*, Charles C. Thomas, Springfield, IL, 1982.
- [4] F. Pérez Rentas. "Elementos del ambiente universitario y el éxito en los estudios: Implicaciones para el consejero como investigador," *Asociación Puertorriqueña de Profesionales de Orientación*, **13**(2) (1998) 2-9.
- [5] L. Kalsner, "Issues in college student retention," *Journal Citation-Higher Education Extension Service Review*, **3**(1) (1991) 3-9.
- [6] I. Alvarado and H. Acevedo, *Desarrollo y Consejería Ocupacional*, Prime Printing, San Juan, PR, 1999.
- [7] S. Hurtado, D.F. Carter, and A. Spuler, "Latino student transition to college: Assessing difficulties and factors in successful college adjustment," *Research in Higher Education*, **37**(2 ) (1996) 135-159.
- [8] D.H. Blocher, "Campus learning environments and ecology development," *Campus Ecology: A Perspective for Student Affairs*, National Student Personnel Association, Cincinnati, OH, 1978.

# CONCEPT BUILDING THROUGH ACTIVE LEARNING EXPERIENCES WITH THE CALCULATOR BASED LABORATORY (CBL)

---

N. MOTTA

*Dept. of Chemistry, University of Puerto Rico, Rio Piedras*  
nmotta@upracd.upr.clu.edu

## Introduction

The graphing calculator coupled with physical or chemical sensors is known as the Calculator Based Laboratory (CBL) and has proven to be an excellent tool for developing concrete experiences in science and math courses [1,2,3]. The CBL offers several benefits:

- Fast data acquisition and robust statistical tools for data processing;
- Flexible implementation—that is, measurements do not need to be restricted to a conventional laboratory; it can be used in a classroom, in the field, or even at home;
- A good motivation factor—students' attitudes are often positively influenced by the fact that they can handle the relatively sophisticated measurements that are possible with the available sensors.

With the CBL, it is possible to generate and process data in a convenient time frame within the laboratory or even the classroom set-up. The design of activities can be focused on understanding relationships between variables, building empirical models derived from those relationships, and bringing together generalizations. In this sense, the proper use of the CBL is consonant with active learning environments: student-centered activities whereby the use of incisive inquiry by the teacher replaces plain lecturing, and ideally, conceptual understanding takes the place of algorithmic thinking [4].

During recent years, we have been working with the design of active learning activities using the CBL for various groups such as high school teachers, pre-service science education students, and natural science students. The format of a typical CBL activity integrates the following stages:

- **Background**—Give the students the necessary information to make the most of the pedagogical objectives. It also helps in laying a minimum common knowledge base to facilitate an effective use of questions during the course of the activity.

- **Data Acquisition/Processing**—Provide a set of instructions as to how to operate the CBL to perform a given task. This is the stage where students follow directions to acquire familiarity with the procedures. Processing of the data may follow immediately or can be done after the discussion of initial results.
- **Analysis of Results/Synthesis**—At this stage, a set of questions is used to guide a discussion with the objective of extracting meaningful information from the results. This is the center of gravity of the whole activity, thus its design requires the greatest care and attention to every detail. Every single question represents a deliberate effort to stimulate students to think analytically—recognizing and interpreting patterns, relating factual information to observed data, and integrating results in the form of generalizations [5,6].
- **Application**—At this stage, students are faced with a hypothetical situation where the acquired knowledge can be applied. This stage is multifold: it helps the teacher to evaluate student level of understanding, and also helps students to self-evaluate the conceptual insight gained from the activity.

Variations from the suggested format are conceivable considering that the activity's objective will define the relative emphasis of each stage [7].

Among several chemistry activities we have developed, including the use of sensors for measurements such as pH, absorbance, and conductivity, a description of one of those activities is presented here to illustrate the implementation of the four-stage format.

### **An Example of a CBL Activity – “Acid and Bases: Beyond Chemical Antonyms”**

The purpose of this activity is to discover an empirical relationship between solution pH and solute concentration. From such a relationship, an operational definition of a weak and strong acid and base is obtained.

#### 1. Background Stage

At the beginning, the *general* objective of the activity is presented; that is, to study the relationship between the pH and the concentration of a given solute in solution ( $C_s$ ). The following concepts are reviewed:



- Logarithms
- pH
- Concentration
- Solution/solute/solvent
- Dilute/Concentrated Solution
- Hydrogen ion concentration ( $[H^+]$ ) in water
- Neutral/acid/alkaline solutions

It should be pointed out that a critical distinction must be made between the objective of the study (pH as a function of  $C_s$ ) and the general definition of  $pH = -\log[H^+]$ , where  $[H^+]$  stands for  $H^+$  concentration.

## 2. Data Acquisition and Processing Stage

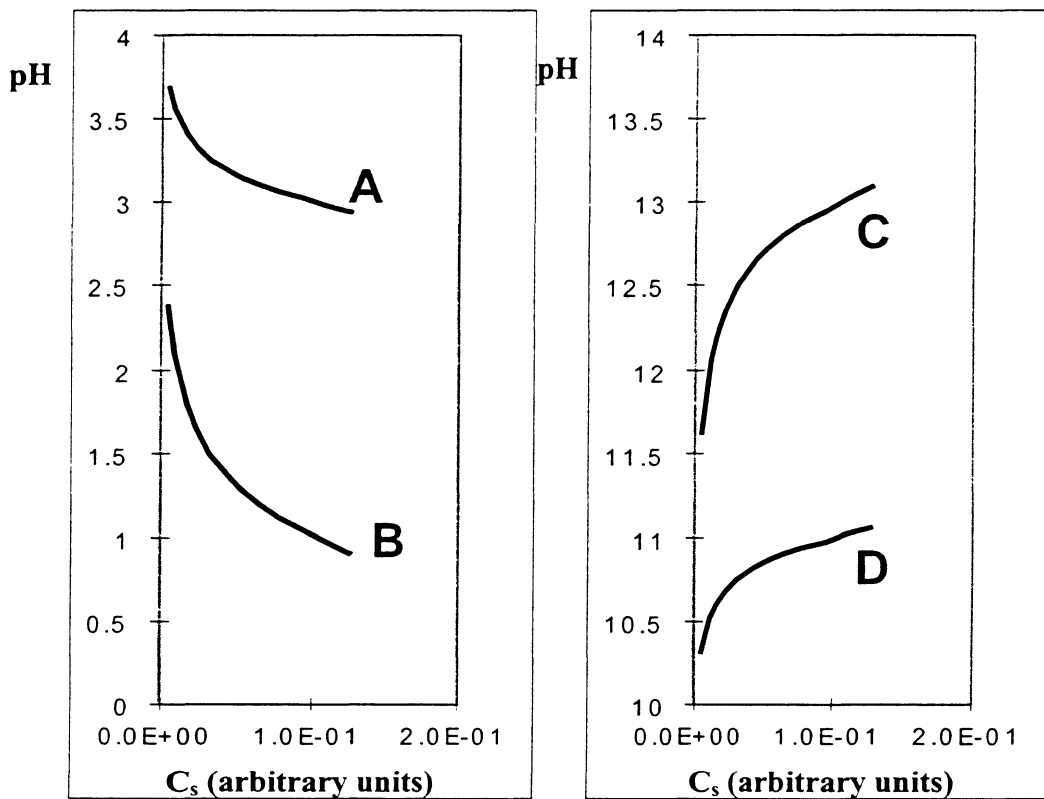
Several groups of students do measurements of pH of four solutions. We propose that the substances used in the activity be among those found in household products. See Table 1.

**Table 1.** Solutions used in the Study of pH as function of solute concentration.

Substance	Chemical Nature	Source
Ammonia	Weak Base	Glass Cleaner (Windex®)
Acetic Acid	Weak Acid	White Vinegar
Sodium Hydroxide	Strong Base	Sink Cleaner (Drano®)
Hydrochloric Acid	Strong Acid	Muriatic Acid (pool acid)

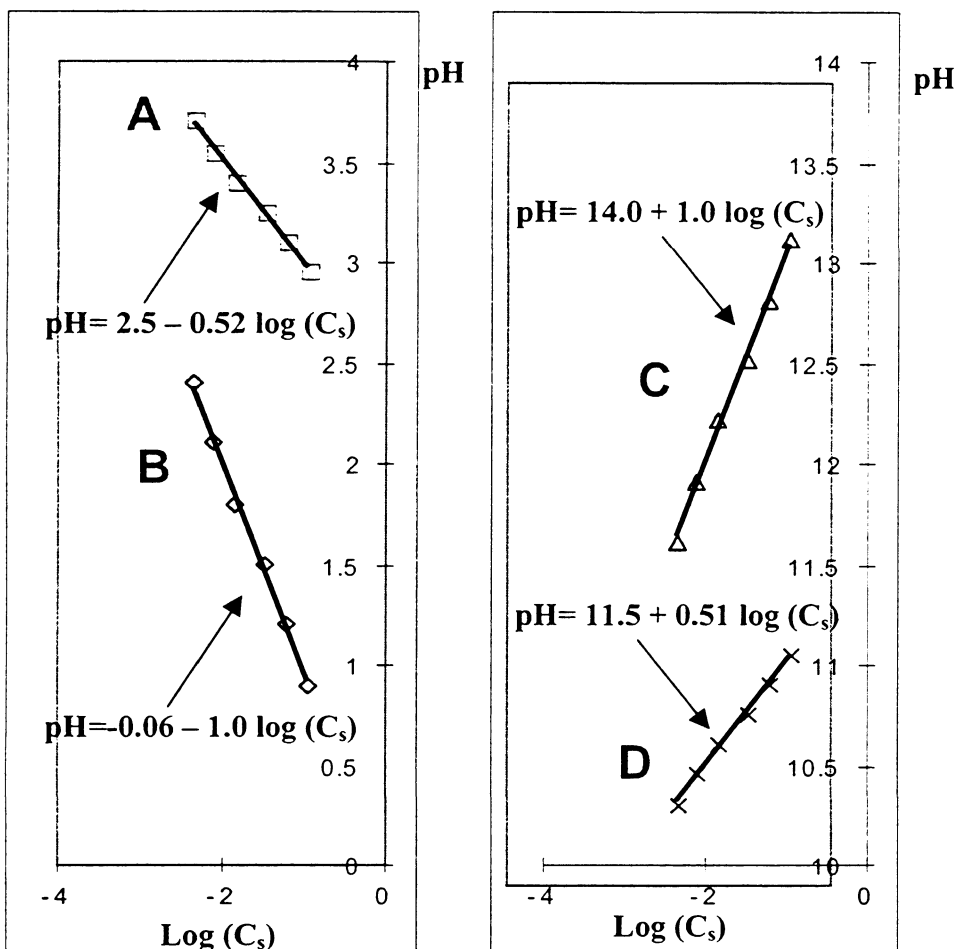
Each group of students does at least one pH measurement on each of the six solutions of a given substance of varying concentration (a total of six measurements). Students do not know the identity of the solutions, just their concentrations. The time needed is about thirty minutes.

Typical results obtained on the graphing calculator are shown in Figure 1.



**Figure 1.** Plots of pH as a function of solute concentration. A: Vinegar; B: Hydrochloric Acid; C: Sodium Hydroxide; D: Glass Cleaner (Windex®).

The observed trends of pH vs. concentration are discussed, and students compare them with graphical representations of known functions such as the logarithmic, linear, and exponential functions. Further discussions lead to the validity of data processing for its linear transformation as shown in Figure 2.



**Figure 2.** Plots of pH as a function of common logarithm of solute concentration. A: Vinegar; B: Hydrochloric Acid; C: Sodium Hydroxide; D: Glass Cleaner (Windex®).

Linear regression of the data points confirm the correlation between variables (with correlation coefficients greater than 0.98).

### 3. Data Analysis/ Synthesis Stage

The processed data present four straight lines suggesting a general model of the form:

$$\text{pH} = b + m \log C_s \quad (1)$$

where  $b$  and  $m$  represent parameters commonly known as the  $y$ -intercept and slope of the regression line (here the independent variable =  $\log C_s$ ).

By looking at the slopes of the lines, an interesting pattern is observed: the slope can take on the following values close to either  $\pm 0.5$  or  $\pm 1$ . In other words, the rate of change of pH as a function of the logarithm of solute concentration is either positive or negative and may either be close to 0.5 or 1.

At this point, students are asked to relate this finding to the chemistry of the system. Some students figure out that the observed trends have something to do with the acid/base properties of the solutions. For others, the distinct trends suggest that two interrelated properties define the behavior of the system. From this basis, we can come up with an operational definition of an acid and a base: the two apparent properties are the acid/base *behavior* of the solution and its acid-base *strength*. The slope sign indicates if the substance is an acid (-) or a base (+), while the slope magnitude is related to strength: 0.5 for a weak, 1 for a strong acid or base.

Notice how this simple experiment helps to characterize acid/base behavior as a result of the relationship between two variables; so that, knowledge of how pH varies with concentration leads to a decision about whether a substance is acidic or basic, and whether it is strong or weak.

Another important corollary of this activity is its integration to some math concepts. Part of the activity's discussion is devoted to finding a direct relationship between  $[H^+]$  and  $C_s$ . Knowing that  $pH = -\log [H^+]$ , the mathematical interpretation of the slope of the pH vs.  $\log C_s$  graph is given by the third column in Table 2:

**Table 2.** Mathematical Interpretation of the Slope in Equation 2 in terms of  $[H^+]$  vs  $C_s$

Chemical Nature	Slope	Relationship between $C_{H^+}$ and $C_s$
Strong Acid	-1	$[H^+]$ is directly proportional to $C_s$
Strong Base	+1	$[H^+]$ is inversely proportional to $C_s$
Weak Acid	-0.5	$[H^+]$ is directly proportional to the square root of $C_s$
Weak Base	+0.5	$[H^+]$ is inversely proportional to the square root of $C_s$

#### 4. Application Stage

After studying and understanding how the nature of a given acid or base solute affects the pH of its solution, the student is faced with a hypothetical situation where the acquired knowledge needs to be applied. An example of such an exercise is:

On the bench, there are two solutions (A and B) both exhibiting the same  $\text{pH} = 3.8$ . Both solutions are then diluted by the same factor, but the diluted solution A exhibits a  $\text{pH} = 4.3$  and the diluted solution B has a  $\text{pH} = 4.8$ .

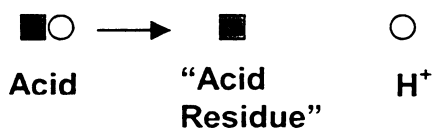
Questions:

Based on the acquired knowledge,

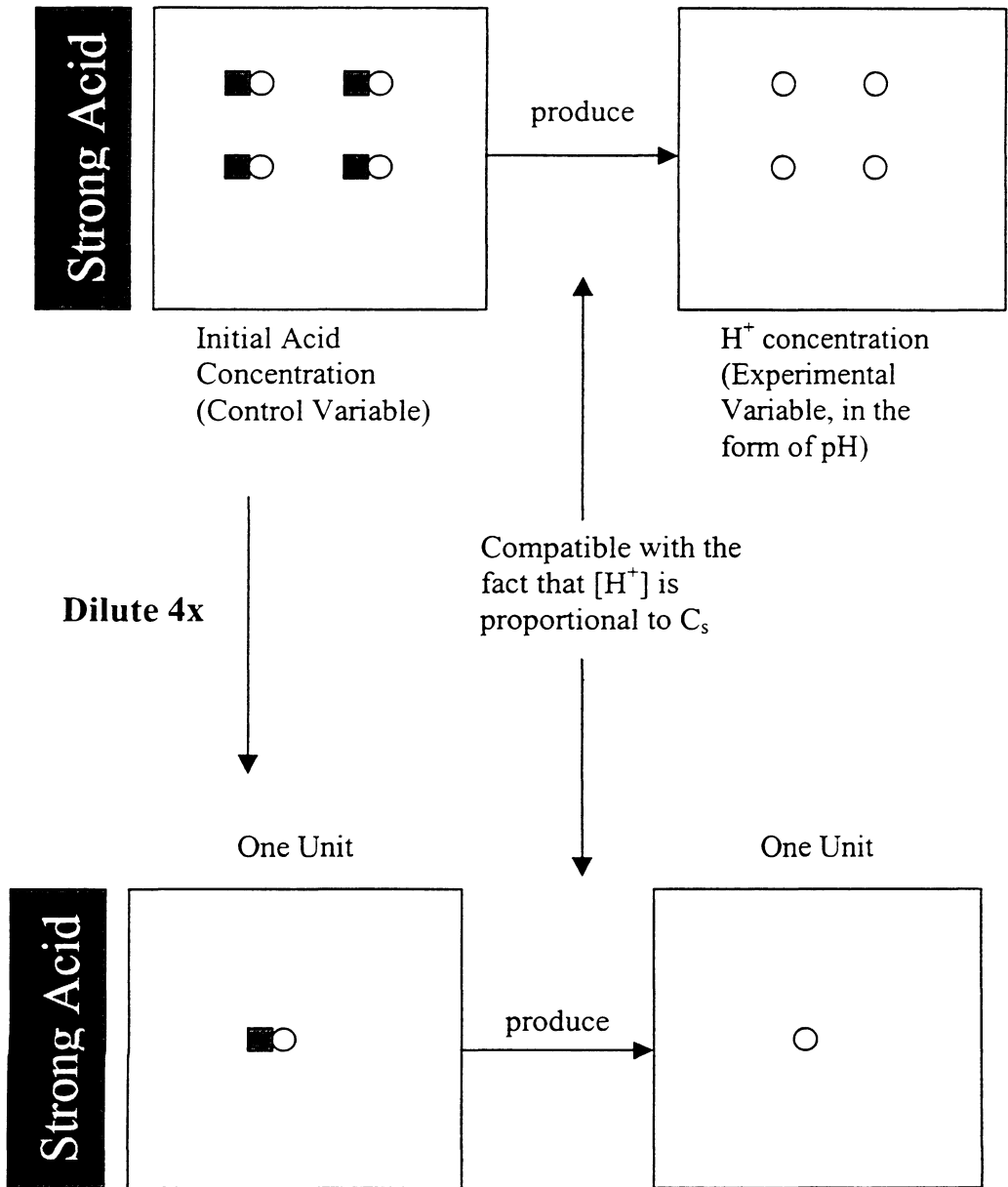
1. What is the nature and strength of solution A and B ?
2. How does the concentration of A and B compare?

Interestingly, students have trouble with those questions (specifically, determining the relative strength and concentration of both solutes). Even after going through this activity, some students (especially those with some background on the subject!) do not correctly identify the two solutions. One reason for the observed flaw is that students usually base their answer on the absolute value of pH at any given instance. They reason that the lower the pH of an acidic solution, the stronger the acid, obviously neglecting the effect of solute concentration. Solution B should be the strong acid because of its greater rate of pH change as the concentration of this solution is changed. On the other hand, solution A should be the more concentrated, since being a weak base it exhibits the same pH as the solution of a strong acid.

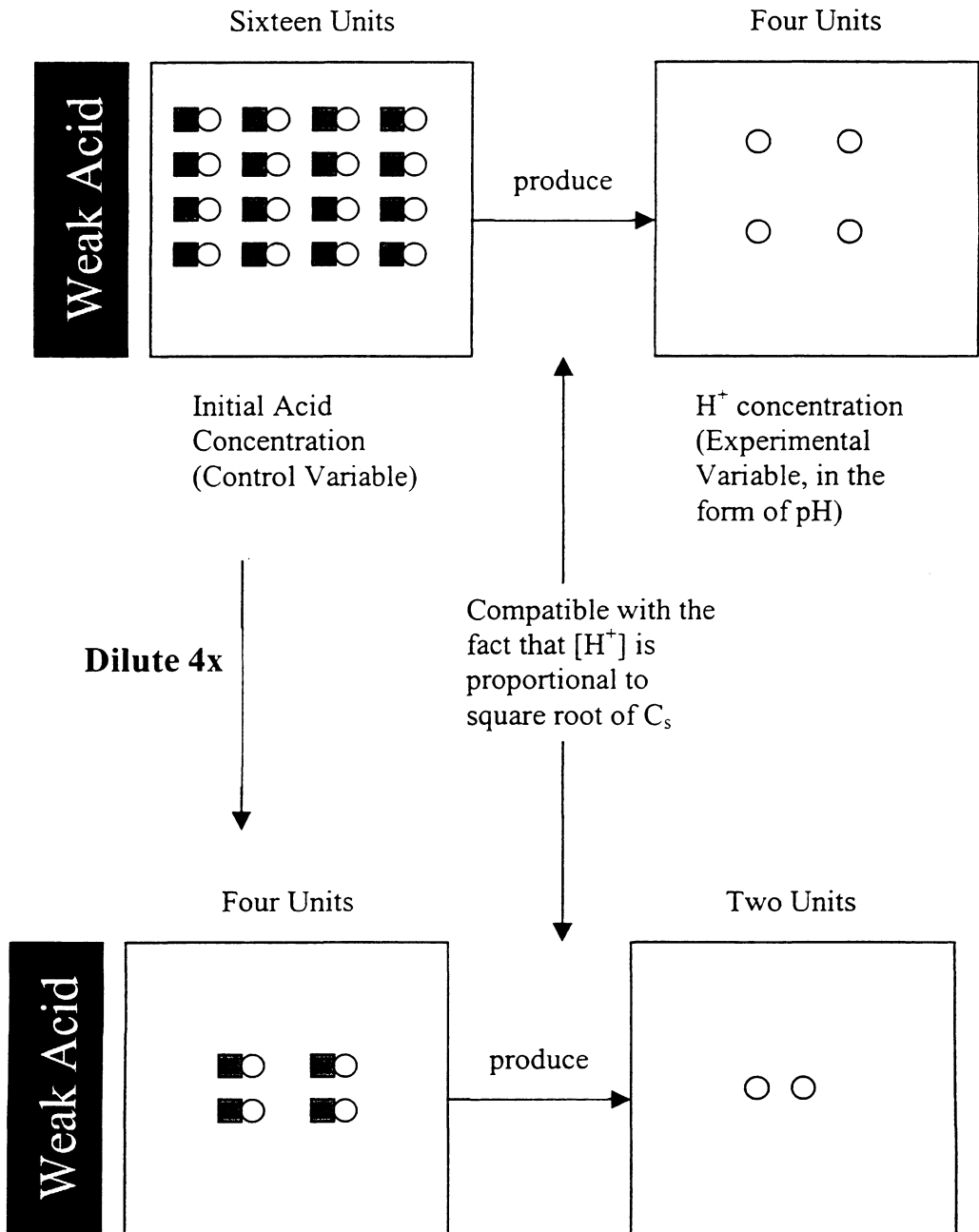
The discussion of this application provides the opportunity to clarify student understanding of acid/base solutions. It is possible to take advantage of the self-acquaintance the application produces and put the concepts in the right perspective. This application can be illustrated using an analogy that has elements of the student's previous knowledge. The most elementary definition of an acid is usually that it is a species capable of donating  $\text{H}^+$ . In that sense, an acid may be depicted as follows:



From the analysis of the results obtained in the activity, we concluded that  $[\text{H}^+]$  is proportional to the concentration of a **strong acid** (Table 2) while it is proportional to the square root of the concentration of a **weak acid**. The problem states that solutions A and B initially have the same pH (same  $\text{H}^+$  concentration) but after dilution, the pH of A is lower than the pH of B ( $\text{H}^+$  concentration in A is greater than  $\text{H}^+$  concentration in B). A pictorial presentation of those findings could be:



**Figure 3a.** Microscopic view of the dilution of a strong acid and its effect on H<sup>+</sup> concentration.



**Figure 3b.** Microscopic view of the dilution of a weak acid and its effect on  $H^+$  concentration.



Figure 3a illustrates the change in  $[H^+]$  when a strong acid is diluted. Considering a fixed volume at all times, the initial concentration of acid “produces” an equal concentration of  $H^+$  (four units). A solution of the same acid diluted by a factor of four is accompanied by a four-fold decrease in  $[H^+]$ . This is consistent with the finding establishing that  $[H^+]$  is directly proportional to  $C_s$  for a strong acid.

Figure 3b illustrates the change in  $[H^+]$  when a weak acid is diluted. Again, considering a fixed volume, this time the initial concentration of acid produces  $[H^+]$  equivalent to the square root of  $C_s$ . A solution of the same acid diluted by a factor of four is accompanied by a two-fold decrease in  $[H^+]$ . This is consistent with the finding establishing that  $C_{H^+}$  is directly proportional to the square root of  $C_s$  for a weak acid. Even though the original  $[H^+]$  in both solutions (Figs. 3a and 3b) were the same, both the difference in the nature and in the concentration of the acids involved, participate in generating the difference in  $H^+$  concentrations after dilution.

## Conclusion

Opponents of the implementation of inductive-thinking oriented activities in the classroom often claim that there is always a risk involved in carrying out an activity that consumes “valuable time” from covering course topics without assurance that this process translates into a deeper understanding of fundamental concepts. This article hopes to make the case that judicious use of the CBL facilitates the creation of effective learning environments for relating quantitative relationships with chemical concepts. The traditional classroom usually provides experiences in developing concepts from a deductive standpoint: general principles are presented, then they are applied to specific situations. The constructive classroom approach relies on an inductive thinking pattern: the study of phenomena in a particular context leads to generalizations and conceptualization. The convergence of both approaches should add a new dimension to the level of conceptual understanding.

Usually the relationships between pH and concentration are theoretically derived by defining the properties of those systems in the microscopic context. In the activity presented here, the relationship between variables is studied in a given chemical system and then a general interpretation is derived from recognizable patterns in the processed data. From this type of experience, the students realize the importance of mathematical models to describe physical or

chemical phenomena as well as understand that fixed numerical values in those models may have physical or chemical meaning.

With the wide variety of available sensors and the CBL fast acquisition and robust statistical capabilities for data processing, it is plausible to design activities focusing more on data analysis and its meaning. It must be pointed out, however, that neither the CBL by itself nor the results obtained with it equate to active learning. In designing a CBL activity, attention to the way in which questioning and inquiry will lead to genuine knowledge is the critical issue, since those elements establish the conditions of what an active learning environment is all about. ■

## Bio

Noel Motta is Associate Professor in the Department of Chemistry at the University of Puerto Rico, Río Piedras. His main interests are the use of computer-based modules for enhancing problem solving skills in general chemistry, and the development of evaluation instruments to assess scientific reasoning skills in the context of analytical chemistry.

## References

- [1] S. Arnold, P. Taylor, and J. Spencer, "The Use of Calculator Based Laboratory Equipment in Teaching Math, Chemistry and Biology," *Inquiry*, **3**(1) (1998) 6-8.
- [2] B. Albrecht and G. Firedrake, "Grabbing Data: What You Need to Log and Use Real-World Data." *Learning and Leading with Technology*, **26**(1) (1998) 36-40.
- [3] R. Farley and K. Wallo, "Student Discovery and Learning through Precalculus CBL Projects," *Journal of Mathematics and Science: Collaborative Explorations*, **2**(1) (Spring 1999) 29-36.
- [4] D.A. Lapp and V.F. Cyrus, "Using Data-Collection Devices to Enhance Students' Understanding," *The Mathematics Teacher*, **93**(6) (2000) 504-510.
- [5] L.M. Barden, "Effective Questioning & Ever-Elusive Higher-Order Questions," *The American Biology Teacher*, **57**(1) (1995) 423-426.
- [6] G. Marbach-Ad and P. Sokolov, "Good Science Begins with Good Questions," *Journal of College Science Teaching*, **30**(3) (2000) 192-195.
- [7] R.A. Huber and C.J. Moore, "A Model for Extending Hands-On Science to be Inquiry Based," *School Science and Mathematics*, **101**(1) (2001) 32-42.

# **APPLICATION OF BIOTECHNOLOGY TO SOLVE RELEVANT BIOLOGICAL PROBLEMS PROMOTES UNDERSTANDING OF UNDERLYING CONCEPTS**

P.A. BURROWES and G.M. NAZARIO

*University of Puerto Rico, Rio Piedras, San Juan, P.R. 0093*

pburrowe@upracd.upr.clu.edu, gnazario@upracd.upr.clu.edu

## **Abstract**

Although some efforts have been made to modify the curriculum of the *Introductory Biology* laboratories from a passive to a more experimental form, the use of modern biotechnology had not been implemented at our institution. The need to understand the applications of modern technology to real-life situations seems imperative at the turn of the century [1,2]. Because several studies have shown that the study of biotechnology by itself does not increase conceptual understanding, the objective of this research was to determine if the use of biotechnology to solve relevant biological problems increased conceptual understanding among our students. We designed two complex problems: one on the conservation of an endangered Puerto Rican frog, and the other on tropical plant evolution. Two students majoring in Biology-Education participated as research assistants in the design and implementation of the laboratory activities. Graduate biology students who worked as teaching assistants in the laboratories were trained to use equipment and teach the activities. Assessment evidence indicated that students exposed to these experiences: (1) increased biological literacy by understanding the use and application of cutting-edge biotechnology; (2) were able to make connections between organismal and molecular biology; (3) decreased levels of anxiety and insecurity associated with the use of laboratory equipment; and, (4) were motivated to conduct research within and beyond the classroom setting.

## **Introduction**

As the world becomes increasingly scientific and technological, our future grows more dependent on how wisely humans use science and technology. And that, in turn, depends on the effectiveness of the education we receive. With the exploding impact of science and technology on every aspect of our lives, especially on personal and political decisions that sustain our economy and democracy, we cannot afford an illiterate society [2].

Our participation in the 1999 National Association of Biology Teachers (NABT) Conference made us realize that many high school teachers are providing excellent hands-on biotechnology experiences in the classroom. The literature already presents examples of exercises involving biotechnology that have been implemented effectively at the high school level [1,2,3]. This came as a shock to us because the majority of students in Puerto Rico do not have this opportunity in their high schools, or even in first- and second-year biology courses at the

university level. Although biotechnology is undoubtedly promoting breakthroughs in the discipline, awareness of the significance of this relatively new branch of science remains limited [1]. A research group led by J.H. Wandersee from Louisiana State University (1996) found that instrumentation and methods drive research even more than theory does. Science laboratories strive to keep up with the latest instruments and methodologies, and their possibility of achieving funding rests in their competitiveness and productivity in applying these techniques [4]. The American Association for the Advancement of Science (AAAS), in *Benchmarks for Science Literacy*, emphasizes the importance of teaching technology to science students because it: encourages development of scientists; fosters development of new lines of research; and, inspires the design of new technology itself [5].

In the introductory biology laboratories (*General Biology*, *Botany*, and *Zoology* courses) at University of Puerto Rico, Río Piedras (UPR-RP), we have not used biotechnology for a variety of reasons; including, financial constraints, lack of experience among teaching assistants, and scarcity of laboratory exercises that deviate from simple “cookbook” recipes. One of the objectives of this research was to address these deficiencies. We designed two biological problems pertinent to Puerto Rico that required students to analyze scientific literature and apply biotechnology to obtain answers. The educational value of this experience was assessed with respect to its potential to increase conceptual understanding and trigger motivation toward scientific investigation. In the following pages, we describe the exercises emphasizing the skills that we aimed to develop among the students.

## Methodology

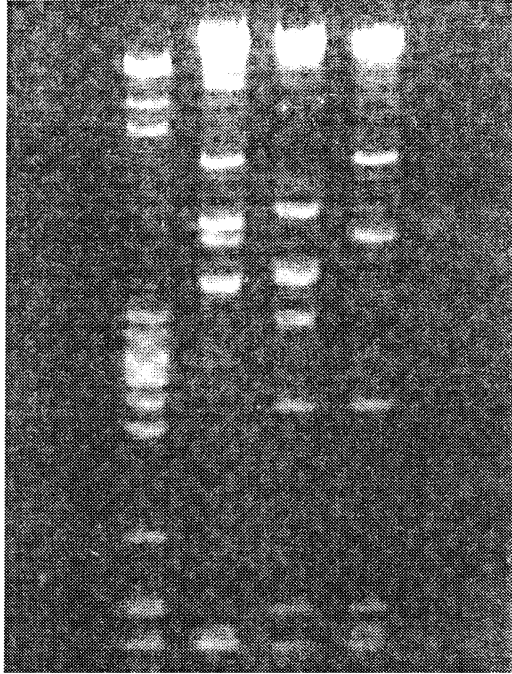
The Conservation of an Endemic Puerto Rican Frog *Bufo lemur* (“sapo concho”) - Target: Students in *Zoology* or *General Biology II* — The biological problem is one of conservation of a native species that is endangered. The laboratory exercise consists of a paternity analysis to identify the offspring sired by healthy parents, and thus, use that stock for re-introduction to the wild. *Bufo lemur*, known locally as the “sapo concho,” is unique to Puerto Rico, but it is declining drastically, and efforts to reintroduce individuals that have been bred in captivity at several zoos in the U.S.A. have been unsuccessful. Because zoo bred animals are kept in extreme sanitary conditions to prevent bacterial infections, it is likely that their immunity is weak and they succumb easily to natural pathogens in the wild.

A week in advance, students are given a reading assignment of an article authored by a local expert [6]. This article describes the natural history of the “sapo concho” and comments on

its conservation problems. At the beginning of the lab, students are divided into small groups to discuss the article. Then, the instructor tells them to suppose that a group of scientists were able to genetically engineer a stock of male frogs with strong immunity that could survive in the wild. At this point, students get very excited and generally remark that what needs to be done is to breed these frogs so that they pass on their “good” genes to their offspring, and then use this stock for reintroduction to the natural habitat. However, the instructor reminds them that it is expensive to engineer these “good” frogs and thus, that their number would not be abundant enough to create the great choruses needed to stimulate females to reproduce. Thus, it becomes apparent that they will have to use “good” and “bad” males to achieve mating, and that the problem will be to identify the offspring sired by the “good” males. Students are led through a series of questions on how biotechnology could contribute data that would be useful in identifying the father of the progeny, and with some guidance from their laboratory instructors, they participate in the design of the methodology to be used.

For the purpose of this lab, we could not extract DNA from the frogs because *Bufo lemur* is an endangered species; so we told the students that we would be using “pretend frog DNA” that had been obtained from bacteriophage lambda. Four different, but related bacteriophage DNA types were purchased from Fotodyne, Inc. (Cat. No. E1-2207/2208), and pre-cut with several restriction enzymes. This provided an opportunity for instructors to explain what restriction enzymes are, where they come from, and their importance in biotechnology. These enzymes have the ability to recognize particular DNA sequences and digest them at specific sites producing unique DNA fragments for an individual. Variation in the length of the DNA fragments (restriction fragment length polymorphisms – RFLP’s) are due to the differences in the genetic makeup of individuals, and can be viewed as stained bands when the DNA is separated by processes, such as electrophoresis. Individuals that are more closely related to each other will have more similarity among band patterns. Students were given four tubes with dry DNA, labeled: (1) offspring; (2) mother; (3) potential sire 1 = “bad” male; (4) potential sire 2 = “good” male. The laboratory procedure involved re-hydrating the DNA, centrifuging, loading it onto agarose gels, electrophoresing for 46 minutes, dyeing the gel with ethidium bromide, and viewing the fragments under a UV transilluminator to observe genetic differences among the samples (Fig. 1). After photographing the gels, students used rulers to help determine the number of shared bands (“fingerprints”) between the offspring and the potential sires. From their results, they were able to infer which was the most likely parent of the offspring, and decide whether this stock was appropriate for re-introduction to the wild. Although the DNA that we used was not really *Bufo lemur*, the students actually underwent all the steps of the scientific method and were able to

apply biotechnology in the same manner that it would have been applied if we had used the frog DNA. Thus, we do not feel that the use of virus DNA hinders the learning experience that this exercise offers. On the contrary, it made the laboratory simpler, shorter, and more cost effective for teaching purposes.

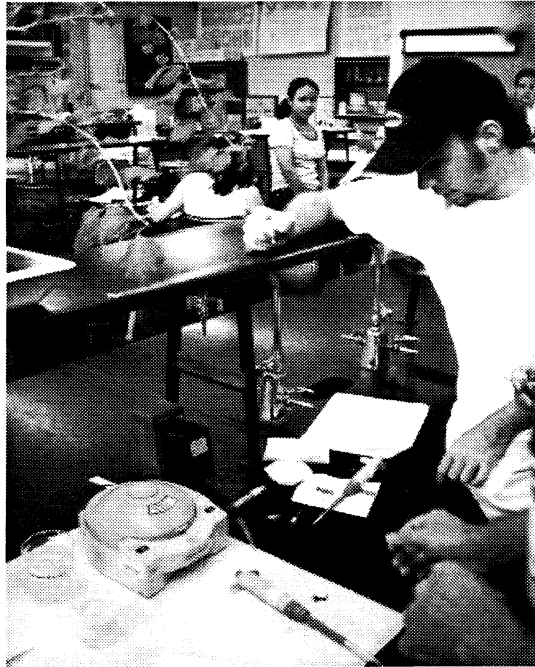


**Figure 1.** Results of a photograph taken by the students showing electrophoresis results of the frog (“sapo concho”) conservation case. From left to right, you can observe the banding pattern obtained for offspring (lane 1), mother (lane 2) and potential sires (lanes 3 and 4).

The Genetic Basis of the Observable Diversity in Tropical Plants - Target: Students in *Botany* or *General Biology II* — This problem makes reference to the fact that plants show anatomical and morphological differences that are based on the genes shared among close relatives. Plants include organisms that range in complexity from bryophytes to angiosperms. Their evolution includes processes, such as the development of vascular tissue, seeds, and flowers. In a laboratory organized in stations, students manipulate the roots, stems, leaves, and reproductive organs of live plants. They use the light and dissecting microscopes to make observations and to determine plant size, presence or absence of vascular tissue, morphology of reproductive structures, and arrangement of parts. Finally, they use their findings to identify and classify the plants in evolutionary sequence. In the next laboratory period, they get to investigate if these morphological differences have an underlying genetic basis.

Instructors take students around campus to collect tropical representatives of three plant groups: ferns (vascular, non-seed), gymnosperms (vascular, seeded, non-flower), and angiosperms (vascular, seeded, and flowering). They extract DNA from each plant group (Fig. 2) using Ward's Isolation and Purification of Plant DNA (Cat. No. 36W5902). DNA samples are amplified with random primers by Operon RAPD 10-mer kits containing 10-base oligonucleotide primers selected randomly from a group of sequences with a 60% to 70% (G + C) content and no self-complementary ends. Amplification reactions are performed in a thermal cycler programmed for 45 cycles of 1 minute at 94° C, 1 minute at 36° C, and 2 minutes 72° C. Amplified DNA fragments are electrophoresed in 1.4% agarose gels for 50 minutes, and detected by staining with ethidium bromide to observe differences in the DNA amplification patterns. Students compare results within and among plants from the different species of ferns, gymnosperms, and angiosperms. By quantifying differences in banding patterns among the groups, they infer evolutionary relationships and decide whether they do, or do not support the present classification.

For both the frog conservation and the plant evolution laboratory experiences, teaching assistants present the basic concepts related to molecular biological techniques, such as DNA extraction, amplification by the Polymerase Chain Reaction (PCR), digestion by restriction enzymes, random priming, electrophoresis, and analysis of DNA fingerprints. Their presentations are enriched by visual aids such as movies, and three-dimensional computer images. In addition, we provided an activity with paper manipulatives representing the DNA molecule and 3'—5' and 5'—3' primers, so that students could do hands-on what a PCR Thermocycler actually does (modified from Fotodyne workshop at NABT, TX, 1999).



**Figure 2.** Students working on the isolation of plant DNA.

## Results

The application of biotechnology to the two biological problems that we described above included several steps that aimed to develop the following skills:

- Analytical Reading of Scientific Literature – Readings from specific journals were assigned and discussed;
- Critical Thinking – At the end of each laboratory, students analyzed data from molecular markers, drew conclusions, and provided answers to specific questions regarding the problem (Fig. 1);
- Interdisciplinary Connections – Students had the opportunity to integrate concepts from molecular biology and genetics, to ecology, evolution, wildlife management, and conservation;
- Use of Technology – Students learned to use micro-centrifuges, micro-pipettes, PCR thermocycler, electrophoretic chambers, and UV transilluminators (Fig. 2).

The laboratory exercise on frog conservation was offered to 150 students in *General Zoology*, and the lab on tropical plant evolution was given to 156 students in *General Botany*. In order to do this, six graduate students from the Department of Biology, as well as a lab



technician, were trained to run the experiments successfully, and to conduct the entire laboratory activities with an inquiry-based teaching strategy. To investigate if this type of exercise promoted understanding, we designed a short test (ten items) that addressed the major concepts of the molecular biology involved in the biotechnology applied. This test was administered in a pre-test/post-test fashion. Student achievement in the post-test was significantly better than in the pre-test (In Zoology: student  $T = 4.11$ ,  $P = 0.000$ ,  $n = 95$ ; In Botany: student  $T = 4.78$ ,  $P = 0.000$ ,  $n = 128$ ), suggesting that conceptual understanding increased after performing the exercises. An assessment instrument (Table 1) to evaluate student attitude and perception with respect to this type of experience showed that they enjoyed these labs much more than the traditional descriptive type, and felt more confident about using biotechnology equipment.

**Table 1.** Percentages of student replies to specific questions that assessed their perception and evaluation of these laboratory exercises. Responses were from 1 to 4; where 1 = strongly disagree, 4 = totally agree.

Laboratory Exercises: Question	Sapo Concho				Plant Evolution			
	1	2	3	4	1	2	3	4
1. I enjoyed this problem-based lab more	0	3	10	87	0	2	7	91
2. I had time to learn to use the equipment	0	12	9	79	0	13	10	77
3. This exercise has helped me understand	0	0	3	97	0	0	4	96
4. I would recommend my professor	0	0	4	96	0	0	0	100
5. This exercise has encouraged me	4	6	7	83	3	9	11	77

## Conclusions

This research aimed to design exciting biological problems that students would resolve, using cutting-edge biotechnology as a tool to increasing conceptual understanding. Other scientists have suggested this practice as a means to develop research skills [7,8]. Our findings showed that both objectives were accomplished, and student evaluations served to motivate us to continue our efforts in this direction (Table 1). Our efforts served not only to contribute to the education of the undergraduate students enrolled in the courses, but also to train graduate students who served as teaching assistants to the labs. These students benefited from learning two aspects essential to their future careers: the application of a research tool; and, constructivist teaching methods. At present, the University of Puerto Rico holds a grant (NSF grant to J. Arce - PR K-12 Graduate Fellowships) that provides our graduate students the opportunity to work closely with cooperating teachers supervising in their classrooms. Our work complements this proposal by

providing professional development to graduate students in research and educational strategies.

The three courses (*General Biology*, *Zoology*, and *Botany*) that are enriched by these lab activities serve a heterogeneous group of students, which include Science-Mathematics-Education (SME), and all Natural Science majors. We expect that students exposed to the use of biotechnology in the laboratories will develop a positive attitude toward experimental biology. In addition, we anticipate that the opportunity to use sophisticated biotechnology in a pertinent setting will motivate students to become involved in research, study more, and generally perform better in science courses. ■

### **Acknowledgments**

This research was partially funded by a Collaborative for Excellence in Teacher Preparation (CETP) grant to Josefina Arce, University of Puerto Rico; and, by NASA - Puerto Rico Space Grant Consortium (NASA-PRSGC). We thank the Department of Biology at the University of Puerto Rico, Río Piedras for providing administrative support and several undergraduate students, Miley Oliveras, Daniel Gonzalez, and Carlos Galeano, who served as research assistants.

### **Bios**

Patricia A. Burrowes completed her Ph.D. in Ecology and Evolutionary Biology at the University of Kansas, and Gladys M. Nazario completed her Ph.D. in Plant Physiology and Biochemistry at the University of California, Riverside. They are presently Associate Professors of Biology on the Faculty of Natural Sciences at the University of Puerto Rico, Río Piedras. Their main research interest in the area of education is methods for promoting conceptual understanding in biology.

### **References**

- [1] M. Ahmed, "Biotechnology in the High School Classroom," *The American Biology Teacher*, **58**(3) (1996) 178-180.
- [2] G.D. Nelson, "Science Literacy for all in the 21<sup>st</sup> century," *Educational Leadership*, **57**(2) (1999) 14-17.
- [3] D. Bowlus and S. Grether, "A Polymerase Chain Reaction Laboratory for Introductory Biology Classes," *The American Biology Teacher*, **58**(3) (1996) 172-174.
- [4] J.D. Wandersee, "Preface," in J.D. Wandersee, D.R. Wissing, and C.T. Lange (eds.), *Bioinstrumentation Tools for Understanding Life*, National Association of Biology Teachers, White Plains, MD, 1996.

- [5] *Benchmarks for Science Literacy*, American Association for the Advancement of Science (AAAS), Oxford University Press, New York, 1993.
- [6] R.L. Joglar, "Se nos extingue el Sapo Concho," in R. L. Joglar (ed.), *Que Cante el Coqui! Proyecto Coqui*, San Juan, PR, 1999.
- [7] K.A. Parson, "Recombinant DNA technology: A topics course for undergraduates," *Journal of Chemical Education*, **65**(4) (1998) 325-326.
- [8] J. Wagner, "Recombinant DNA paper model simulation: The genetic engineer," *The American Biology Teacher*, **60**(7) (1998) 531-534.



# HELPING STUDENTS MASTER CONCEPTS IN MECHANICS BY GRAPHING WITH SPREADSHEETS

---

G. F. RESTREPO

*Colegio Universitario del Este, Carolina, Puerto Rico*

*Gersonf22@hotmail.com*

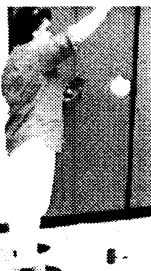
## Abstract

An example of a curricular activity to help students master concepts in mechanics is presented. Students measure positions and times of movements using calculators, and construct graphs using spreadsheets. Students learn to connect concepts in mechanics and reinforce them following a spiral approach of increasing complexity. Comments from students about the activity are also presented.

## Introduction

At the Colegio Universitario del Este (CUE), in Carolina, Puerto Rico, the physics course has been strongly influenced by the efforts of the Puerto Rico Collaborative for Excellence in Teacher Preparation (PR-CETP) through its Faculty Development Component. Developed through a Minority Science and Engineering Improvement Program (MSEIP) project, this new physics course has benefited from many seminars, workshops, and personal talks where the PR-CETP educational philosophy has been disseminated. The new course, *General Physics I*, was designed for students from the Applied Microbiology Program, who take it mainly during their fourth year in the School of Sciences, Health, and Technology, but it has also been used to teach physics concepts to students from other programs. The course was piloted in 1999 and it has been offered since then. A total of 49 students have benefited from this course. Among the changes made to the teaching format of this course as a result of the PR-CETP project, is the design of the curricular activities based on constructivism in an active learning environment [1,2]. More than ten activities have been used for the first part of the course, which has four units. Improvements in the assessment of the learning/teaching process have also been incorporated. An example of how the students reinforced their understanding of the relation between force and acceleration is presented, as well as the interconnection of related concepts in mechanics. To reinforce their conceptual understanding, the students were guided by means of student activities and the instructor, to make experiments and to collect data. From this data, the students used the basic concept of rate of change to construct position, velocity, acceleration, total force, potential energy, kinetic energy, and total mechanical energy versus time graphs.

### The Experiment: Free Fall Motion



The students use the interface Calculator Based Laboratory (CBL, from Texas Instruments) connected to a calculator and to a motion sensor to collect data on the upward pull of a ball. The picture shows an easy setting for this experiment. A similar setting is used by Sokoloff, Thornton and Laws, but with different interfaces [3]. A rope is attached to a ball, and a motion sensor (bottom right of picture) is placed on the floor below the ball. A sudden pull from the rope makes the ball experience free fall motion. The simplicity of this setup allows repetition of the experiment until good data points are obtained (repetition rates vary from one to four times). Due to the sensitivity of the system to nearby obstacles, the calculator can acquire “noisy” data points that do not correspond to the experiment. Once students learn to remove obstacles that prevent obtaining good results, the data are stored in lists in the calculator's memory and used to construct the position ( $x$ ) versus time ( $t$ ) graph. The calculator also contains programs for automatic graphing of the data from the experiment, but in this course students are taught to construct the graphs by themselves, which is an important part of the learning experience.

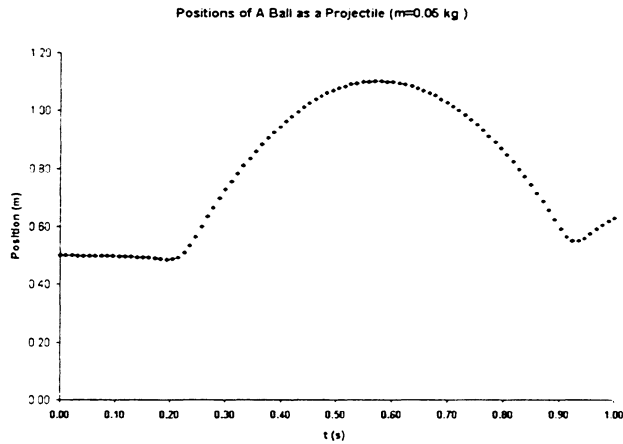
Before making the graphs, students are asked to predict the form of these graphs.

### Manipulating the Data

The students are trained on how to manage data from the lists in the calculator and from a spreadsheet. This training is offered in workshops and activities during class. The students can also download this activity from a web page designed for the course [4]. The spreadsheet is useful to give students templates to help them construct the graphs if the emphasis is to be made on the analysis of the graph itself rather than on the construction of the graph. This depends on the particular interests of the instructor according to the curricular sequence of the course. This article focuses on manipulation of data to construct graphs from a spreadsheet.

### Construction of Position vs. Time Graphs

Students construct the  $x$  vs.  $t$  graph on a spreadsheet. This graph is used to calculate the rate of change relative to corresponding changes in time, which helps students reinforce the concept of velocity.

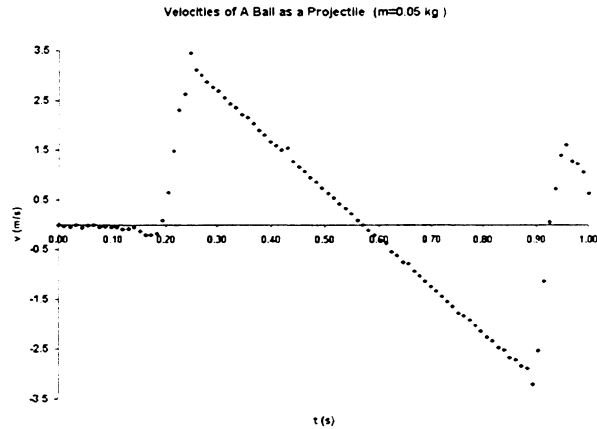


**Figure 1.** Position as a function of time for a ball in free fall.

The  $x$  vs.  $t$  graph for a typical experiment of a ball in free fall is shown in Figure 1. Students are taught to calculate velocity data through different activities. They learn to write formulas in the cells of a spreadsheet using  $x$  and  $t$  data; e.g., if the positions of the ball are placed starting from the 3<sup>rd</sup> row of column B [see Appendix] and the corresponding times start from the 3<sup>rd</sup> row of column A, then the formula for velocity to be entered at the beginning of the column of the velocities should be  $(B4-B3)/(A4-A3)$ . This is how the first velocity is calculated and the remaining velocities can be easily obtained likewise for the remaining  $x$  and  $t$  values.

### Construction of Velocity Graphs

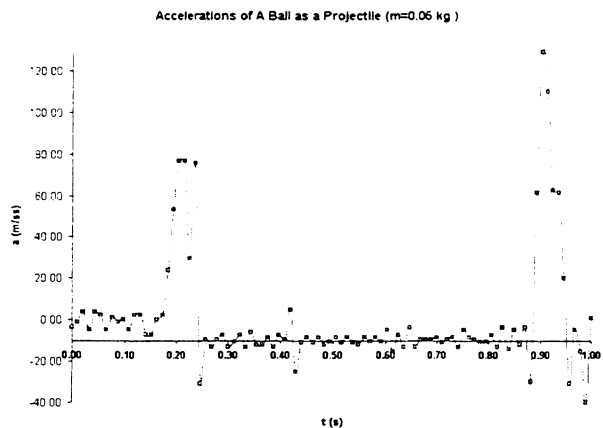
When the students compare the actual graphs with the ones they predicted, they understand the need to replace their previous knowledge with the new knowledge they construct by themselves from a concrete experience such as this. By graphing the velocity of the ball (see Figure 2), students realize the vectorial nature of the velocity. When making velocity and acceleration calculations, students are guided to recognize the cumulative error that is introduced, but no treatment is performed in order to preserve simplicity and emphasize conceptual understanding.



**Figure 2.** Velocity as a function of time for a ball in free fall.

However, correct manipulation of these graphs does not mean conceptual understanding, as revealed through assessment questions made to students. For example, when asked to interpret graphs in paper and pencil exercises, students sometimes failed to give correct interpretations, although they were guided to interpret and describe the movement from these graphs. However, making and interpreting graphs are among the deficiencies exhibited by students in this course. These difficulties have also been reported by Beichner [5]. Resistance to change prior conceptual structures by students has been reported by physics professors such as McDermott and others from the University of Washington [6], and Redish and Steinberg from the University of Maryland [7].

### Construction of Acceleration Graphs



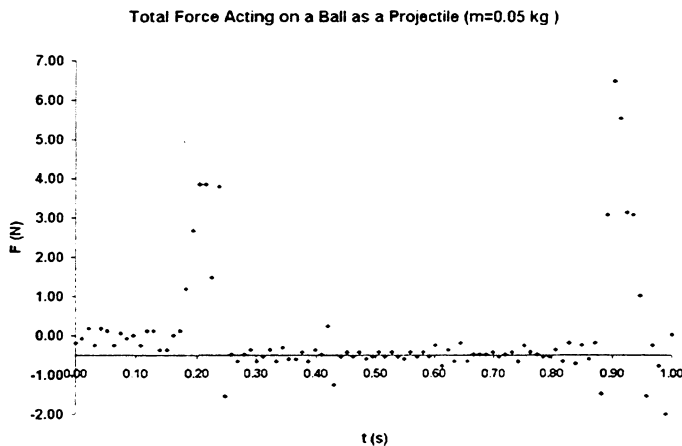
**Figure 3.** Acceleration as a function of time for a ball in free fall.



When students construct the acceleration graph on the rise and fall of the ball, they are aware of the constancy of its acceleration and that the acceleration is not the velocity of the ball, a common misconception held by students in this course as noticed from their assignments, diagnostic questions, and tests; similar errors were also reported by McDermott [6], Arons [8], and Thornton [9]. Students also compared their predictions on the acceleration of the ball at its highest point: the acceleration vs. time graph allowed them to visualize that the acceleration of the ball remained the same during the time it is in free fall, even at the time the ball is momentarily at rest at the highest point of its trajectory.

### Construction of Force Graphs

From acceleration and force data from other experiments, students learned the relation between force and acceleration (Newton's Second law).



**Figure 4.** Total force as a function of time for a ball in free ball.

Students enter this relation as an equation in another cell of the spreadsheet and generate total force data for the experiment. From this graph, students reinforce their understanding of the relation between force and acceleration when they observe both graphs having the same shape, differing only in scale by a factor equal to the mass of the ball. Students also studied the impulse given to the ball from these graphs.

### Construction of Kinetic Energy Graphs

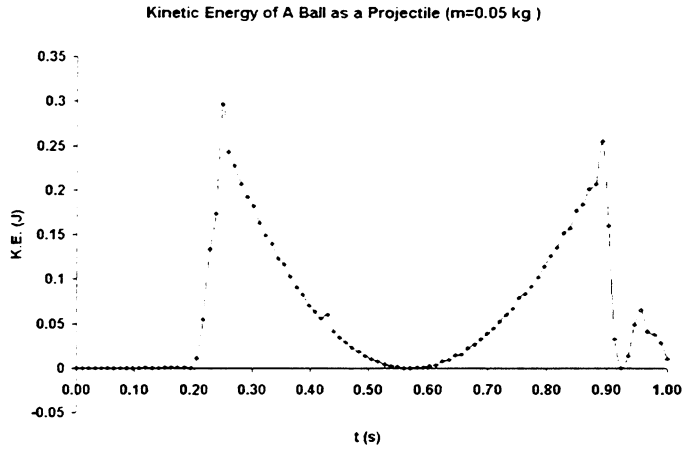


Figure 5. Kinetic energy as a function of time for a ball in free fall.

Students were motivated to use the relation between energy and Newton's Second law with other curricular activities, in order to generate data tables for the potential and kinetic energies as a way to guide them to conservation of energy. They used the same procedure of entering the equation in a cell of the spreadsheet.

After reinforcing their mathematical skills of squaring functions, students finally constructed the kinetic energy graph (see Figure 5).

### Construction of Potential Energy Graphs

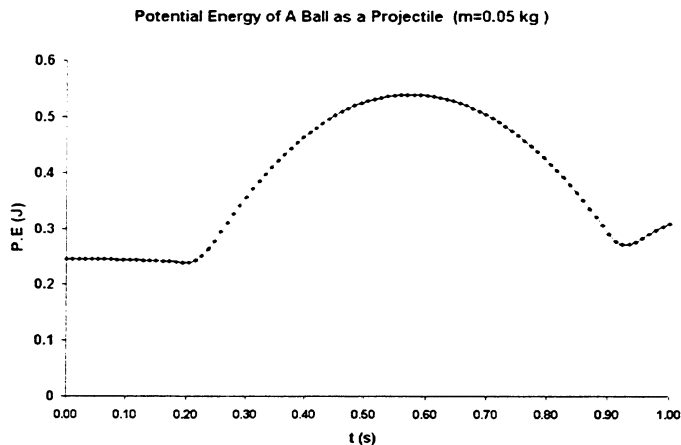
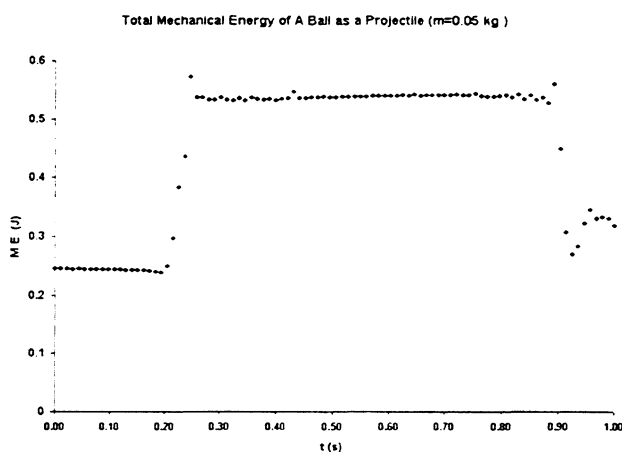


Figure 6. Potential energy as a function of time for a ball in free fall.

Following the same procedure explained above, the students construct a graph on the potential energy of the ball. They obtain a graph similar to an inverted version of the kinetic energy graph for the time the ball is in free fall.

### The Total Mechanical Energy of the Ball in Free Fall



**Figure 7.** Total mechanical energy as a function of time for a ball in free fall.

When students compare the two energies for the free fall of the ball, they visualize the relation between them. Having visualized this, they add the two energies in a separate cell of the spreadsheet and graph the total energy vs. time. The students discover that this sum is constant while the ball is in free fall. This way, they were guided to the concept of conservation of energy. They have never been told about conservation until this moment. And, they do this by being actively involved in an experiment and trying out the calculations by themselves.

### Assessing Conceptual Understanding

Conceptual understanding of students in this activity was assessed by means of pre- and post-tests, diagnostic and follow-up questions designed by the instructor. These tests were based on strategies modeled mainly by CETP and FIPSE workshops on preparing items for exams and on the format used by the Puerto Rico College Board. No use of standardized tests (Force Concept Inventory, etc.) was made, but elements from these tests were incorporated (i.e., selection of topics and format). Since this is a new course, there is no previous history on students' grades that allows adequate comparison with the results drawn from this course (to date,

this course has been offered three times, once as a pilot course). Preliminary results are published on the course website [10] and show that the students have increased an average of 75% in the total earned points for selected concepts from the post-test as compared to the pre-test (the test contained questions on nineteen concepts, the concepts selected were five). Results on the complete test also revealed that the increment in points earned was 84% higher for post-test than for pre-test. Students also expressed their feelings about the experiments, activities, and the methodology used in class. In general, the students felt comfortable with the methodology, and expressed being pleased with the activities used in the class through which they could discover concepts in an interesting way. A collection of student perceptions before and after the class, as well as general comments, can be read from the course website and are summarized below. Although the selected concepts inventory increased learning, the total test revealed that students did not progress on nearly ten concepts. These results are being used to redesign the activities and to evaluate the methodology used.

### **Summary of Student Comments**

Students were asked about their experience with the activities and the strategy used in class. Some comments from students are presented below, while a complete list of comments appear on the course website. Students wrote their responses to the following questions: 1. Indicate what you liked or disliked about this course; 2. What would you recommend about this course to students coming to the course next year?; 3. What would you change about this course?

- “The course is very good and the professor is very dynamic and enthusiastic.”
- “This course is good since you offer many activities and demonstrations, and you are not at the blackboard but with us, i.e., it is interactive.”
- “The good part about the course is that I have learned a lot since the class is dynamic, the bad part is that I am not familiar with computers.”
- “This course is very good, but sometimes you get excited and go so fast that I get lost. Besides that it is very good, the way the concepts are explored is the most interesting way because we see the concepts and then we discover what is in there. That is really fun, and so we learn.”
- “The good part of this course is that everything is done on the basis of exploration of the concepts. For example, we do experiments first to discover Newton's laws, and then we do different applications.”

- “I would tell the students that the class is very interactive. I love the class and we learn everything in a different manner. Is one of the best classes I have had.”
- “They [the activities] are very good and clarify doubts in what you need to learn or improve, however sometimes some of these activities have concepts that are a little hard or complicated.”

### **Recommendations**

Although the students showed good performance in manipulating graphs from spreadsheets, this does not guarantee that they improved their conceptual understanding dramatically. Reinforcement of the concepts should be promoted through repetition of similar activities in new contexts, as explained by McDermott [11]. Follow-up questions that assess transference of the concepts to new situations should be offered as much as possible. Workshops on how to use computers, calculators, etc. should also be incorporated into the curricular design from the very beginning to help students with these technological skills. Continual guidance from instructor and improvement on teaching strategies should be used to overcome these difficulties.

The students from the Middle Sciences Education Program at CUE will be taking this course in the year 2001. This academic program is also a new offering and no history is available about student performance on physics courses, but a hope is maintained for producing a positive impact on these future science teachers.

### **Conclusions**

Inclusion of the constructivist vision and philosophy of PR-CETP has been incorporated into the design of a new course in physics. Activities that incorporate technological applications should be offered to students with adequate support through additional activities such as seminars, workshops, related readings and others, to avoid technological anxiety. Also, continual intervention and guidance from the instructor is needed due to the complexity of the technological setting that sometimes overshadow the conceptual understanding. However, the active environment used in this course generally increased their motivation and interest toward the course. The use of spreadsheets is very convenient for studying concepts in dynamics and serves to assess the whole picture of students' understanding. Due to the fact that the graphs are strongly correlated, this strategy provides students with visual images of the interconnections of the concepts studied. Although the results drawn from this course are not comparable with previous year results due to the absence of history, this course has shown some improvement in conceptual

understanding in physics concepts and also will be impacting students from the Middle Sciences Education Program at CUE. ■

## Appendix

The table appearing below shows an example of the formulas used to calculate velocity in *Excel*. Results are shown up to the eighth  $x$ ,  $t$  data pair. Formulas appear at the right of the table. Once the formula for calculating the first velocity ( $v$ ) is entered in the corresponding cell of column C of the spreadsheet, the remaining velocities can be easily calculated by pressing over the right down corner of this cell (this command works when the column located at left of column C of the spreadsheet is complete). This formula can be entered in this cell by writing the following command:  $= (B4-B3)/(A4-A3)$ . Here B is the cell for positions  $x$ , A is the cell for times  $t$ , and C is the cell for velocities  $v$ . The acceleration, force, potential energy, etc., are entered similarly as shown in the table.

### Positions and times for a free fall

t (s)	x (m)	v (m/s)	a (m/ss)	Ft (N)	x(m)	EP (J)	EC (J)	EP+EC (J)	m (kg):	Equations for:
0.00	0.50	0.00	-3.56	-0.18	0.01	0.25	0.00	0.25	0.05	$v = (b4-b3)/(a4-a3)$
0.01	0.50	-0.04	-1.19	-0.06	0.01	0.25	0.00	0.25	a (m/ss)	$a = (c4-c3)/(a4-a3)$
0.02	0.50	-0.05	3.56	0.18	0.01	0.25	0.00	0.25	9.8	$F = 0.05*a$
0.03	0.50	-0.01	-4.76	-0.24	0.01	0.25	0.00	0.25		$EP = 0.05*a*(a3:a96)$
0.04	0.50	-0.06	3.56	0.18	0.01	0.24	0.00	0.25		$EC = 0.5*0.05*(c3)^2$
0.05	0.50	-0.03	2.38	0.12	0.01	0.24	0.00	0.24		$EMT = EC+EP$
0.06	0.50	0.00	-4.75	-0.24	0.01	0.24	0.00	0.24		
0.08	0.50	-0.05	1.19	0.06	0.01	0.24	0.00	0.24		

## References

- [1] G.M. Bodner, "Constructivism: A theory of knowledge," *J. Chem. Educ.*, **63** (1986) 873.
- [2] J. Stepan, B.W. Saigo, and C. Ebert, "Changing the Classroom from Within," *Partnership, Collegiality, Constructivism*, Saiwood Publications, Montgomery, AL, 1999.
- [3] D.R. Sokoloff, R.K. Thornton, and P.W. Laws, *Real Time Physics*, John Wiley and Sons, New York, 1999.
- [4] Fisica Website, Internet: <http://fisiger.50mcgs.com>.
- [5] R.J. Beichner, "The Impact of Video Motion Analysis on Kinematics Graph Interpretation Skills," *Am. J. Phys.*, **64** (October 1996) 1272.
- [6] L.C. McDermott, "Research on conceptual understanding of mechanics," *Physics Today*, (1984) 24.

- [7] E.F. Redish and R.N. Steinberg, "Teaching Physics: Figuring Out What Works," *Physics Today*, (1999) 24.
- [8] A.B. Arons. *Teaching Introductory Physics*, John Wiley and Sons, New York, 1997.
- [9] R.K. Thornton. "Learning Physics Concepts in the Introductory Course," in J. Wilson (ed.), *Conference on the Introductory Physics Course, on the retirement of Robert Resnick*, John Wiley and Sons, New York, 1997.
- [10] Fisica Website, Internet: <http://fisiger.50megs.com/fisica.htm>
- [11] L.C. McDermott. "How Research Can Guide Us in Improving the Introductory Course," in J. Wilson (ed.), *Conference on the Introductory Physics Course, on the retirement of Robert Resnick*, John Wiley and Sons, New York, 1997





## AN INNOVATIVE UNIVERSITY COURSE FOR COOPERATING TEACHERS

M. AGUIRRE ORTÍZ and L. GASPAR

*University of Puerto Rico, Bayamón*

aguirrem@coqui.net. l\_gaspar@upr1.upr.clu.edu

### **Abstract**

The transformation of a course for certifying cooperating teachers in Puerto Rico is described. The course was transformed to strengthen the teaching of science and mathematics and to make the course more congruent with the educational principles of constructivism promoted by the CETP projects at the national level, including Puerto Rico. The 45-hour requirement was distributed over nine days. The Open Space strategy was modified to include multiple active teaching-learning and assessment techniques, which promoted a learning environment based on trust, dedication, and the commitment of all participants to learn and help each other learn. Even more relevant was the fact that more content was covered and in more depth. The modified version of the course was offered to secondary level science and mathematics teachers, especially to teachers who work at the practicum centers that are part of the PR-CETP.

### **Introduction**

The Puerto Rico Collaborative for Excellence in Teacher Preparation (PR-CETP) is committed to establishing collaboration among institutions of higher education to enhance teacher preparation, especially in science and mathematics. Given its goal, the PR-CETP, in collaboration with the Faculty of Programs and Teaching of the University of Puerto Rico at Río Piedras, modified the course entitled, *The Purposes of the Teaching Practicum and the Role of the Cooperating Teacher*, to align it with the constructivist education principles that guide the major national reform movements [1].

The original course, which consists of 45 hours per semester, has been offered for the past few years at most of the higher education institutions with teacher preparation programs. This course is a requirement of the Puerto Rico Department of Education for those K-12 grade teachers who wish to become cooperating teachers.

The modified version of the course was offered to secondary mathematics and science teachers, particularly those who teach at the university practicum centers that are part of the PR-CETP. To fulfill the required 45 contact hours, the course was scheduled for five hours per day for nine days.

The modifications to the course encompassed the revision of content to update it and make it more pertinent, as well as the teaching strategies and methods, while focusing on active learning. Among the most important modifications to the course are:

- The content is focused on teaching science and mathematics at the intermediate and high school level;
- Constructivist educational practices are modeled, including: the creation of effective learning environments; the use of different cooperative learning modalities; and, the teaching-learning-assessment techniques that promote conceptual understanding;
- Innovative aspects that are relevant to the role of the supervisor carried out by cooperating teachers;
- Structured workshops, mainly in cooperative learning, with opportunities for reflection and self-evaluation to enhance self-learning abilities [2].

To develop the modified course, the strategy of Open Space was selected. In the field of education, the Open Space strategy represents a powerful tool to conduct meetings or courses, among others [3]. The strategy enables learners and communities of learners to become more effective in professional roles that are rapidly and constantly changing, by developing their skills as lifelong learners and collaborative problem solvers. It creates the conditions so that the maximum potential of the individual and the group of learners can be realized. The Open Space strategy captures the knowledge, experience, and innovation in the project, classroom, school or institution that is not captured through less open processes (adapted from [4] and [5]).

The strategy also focuses on the inquiry method. Within this educational structure, various constructivist teaching-learning-assessment techniques have been integrated, such as: interactive demonstrations; hands-on/minds-on workshops; exhibits; conferences; and, self-directed studies on themes related to cooperative learning. This broad range of educational techniques facilitated the design of diverse learning activities, which promoted active learning within effective communities of learners.

### **Description of the Development of the Course**

First Week: One of the techniques to create the optimal learning environment, that is, the community of learners, was the “self-portrait.” This self-portrait consisted of a creative

representation of the educational philosophy that guides the educational practices of the teacher. From the first day, and throughout the first week, five to fifteen minutes were designated for each member of the group to present their self-portrait to the rest. This allowed participants to learn about the unique characteristics of their colleagues, hence promoting a sense of belonging among the participants.

As a preamble to the development of the course, participants learned about, analyzed, and approved the five principles or fundamental ways of thinking for the effective implementation of the Open Space strategy. These principles included aspects such as, positive interdependence, individual responsibility, self-direction, self-evaluation, and development of positive attitudes and mental habits.

The five principles are:

- 1) Those of us who are here are the ones who had to be here. Therefore, this event is for ourselves, since we are the best ones to do what we want to do within what we are expected to do.
- 2) Whatever we achieve is what we can achieve. What we achieve is part of our self-evaluation and is influenced by our expectations. Therefore, the sky is the limit. This is a unique opportunity to learn together. It is very probable that this occasion will not be repeated in the same way and with the same people. So we should take advantage of it.
- 3) Since the agenda is flexible, we will start the group sessions at whatever time is best. We should all be responsible for the time assigned to us for the small group discussions, for contributing with ideas and for making sure that the creativity and learning process of the members is not diminished.
- 4) We will assign time for small group discussions. When the time-up signal is given, it means we must finish. When we are working with people who are important to us, there will never seem to be enough time. As the creative processes of each group have their own rhythm, we should expect that some groups will finish before others.
- 5) The Law of the Two Feet: If someone is in a place and feels that s/he has nothing to contribute or learn, s/he has the responsibility of moving to another group that fulfills her/his expectations. If s/he does not find options, s/he should simply take a break and rest. Nevertheless, if s/he does not find something of interest in the Idea Marketplace, then s/he must blame her/his-self, since s/he probably lost the opportunity to propose a topic of interest and to direct the session of her/his preference.

Once the community of learners was established with the aforementioned rules of the game in mind, participants decided enthusiastically to become involved in a new learning experience full of challenges. With the objective of guiding all learning experiences toward the topic of the course, the title of the course itself became a meaningful question. It kept participants focused toward the achievement of the course's objectives throughout the two weeks.

During the first day of the first week, guided by the meaningful question based on the course title, the participants decided about the topics they wanted to study. They identified the topics they felt passionate about, and willingly volunteered to guide the discussion in small group sessions about the proposed topics. The staff members and other community resources, who were knowledgeable about the topics that needed to be included, requested space to incorporate these topics if they did not emerge from the group.

Once the topics were selected, they were distributed throughout the course schedule and were placed on the giant Idea Marketplace poster that included spaces for working sessions for each day of the first week. From then on, the poster became the center of the Marketplace activity. In this activity, those who proposed each topic made a presentation about it and, through a brief explanation of the content and the importance of its study, participants interested in studying the topic joined them, since at least two persons were required in each of the groups. This way, the work groups were formed throughout the first week.

Each small group work session programmed in the Marketplace poster lasted between sixty to seventy minutes. The most relevant topics selected by the participants were: the theoretical foundations of the constructivist paradigm; the characteristics of cooperative learning and how to implement it in the classroom; the responsibilities and duties of the practicum supervisors, of the cooperating teachers, and of the student-teachers; the regulations that rule the teaching practicum in Puerto Rico; action research and innovative teaching-learning methods; and, ways to create effective learning environments.

To facilitate the study of the topics and the preparation of the written summaries, participants had access to books, journals, and official documents, among other reference materials, as well as to computers and printers. Teachers shared experiences, knowledge, and materials in each study group and they learned together, becoming each other's resources. The

staff members in charge of the course moved among the groups to offer support and contribute ideas and materials, when these were requested.

In each study group, participants took notes to prepare written and oral reports. The written reports were handed in at the end of the day so that each participant had the information related to the topics that had been studied in all the groups.

After each study group session, large 60-minute group meetings were held to listen to the group reports, clarify ideas, suggest new topics to be studied and, when necessary, restructure the Idea Marketplace for the following day. As the groups reported what they were researching and learning in the large group session, participants identified the aspects that required further study and those that had not yet been considered. The main purpose of the Idea Marketplace activity was to give an open space for participants to learn how to learn through interactions with peers, materials, technology, and resources. This learning activity facilitated reflection on the learning process in which the participants discovered the basic knowledge they already had and areas in which they needed improvement. Based on this discovery process, the Open Space strategy was modified by the group to include workshops, conferences, demonstrations, and exhibits of assessment techniques. This information was used to add study group work sessions in the Idea Marketplace.

Second Week: With the same cooperative spirit and joy that prevailed during the first week, teachers participated throughout the second week in interactive conferences to study topics, such as: alternatives for the professional development of teachers; assessment of conceptual understanding; learning problems; aspects that guide the teaching practicum; and, how to comply with the requirements of the Practicum Program of the Puerto Rico Department of Education.

During this phase, participants were stimulated to serve as resources based on their expertise on special selected areas. In this way they discovered that, as part of the team, they can model their best practices. In other areas, the staff members and other community resources developed topics through interactive activities.

The logistics for developing the described activities consisted basically of the following: after each conference or workshop, large group reflection periods were provided to share experiences, clarify doubts, apply what was learned in new situations. Afterwards, the participants met in small groups according to the topic they were interested in pursuing in depth.

Later, in an open discussion, each group presented the most important aspects discussed and established through consensus what should be emphasized the following day.

As the second week came to a close, the participants organized an exhibit about the assessment techniques that were being used in the classroom. In a free, individual, and spontaneous way, all participants presented the instruments to other colleagues, explaining how to create them, and narrating their experiences. Learning from one another, they shared information obtained through assessment instruments and how to use gathered data in the process of student learning.

### **Assessment**

Participants self-evaluated the quality of their own learning through a general rubric. The objectives of the course were written with the following criteria:

- Ability to guide my own learning;
- Ability to reflect on my teaching practices;
- Assessment of my strengths and limitations, and discovery of how to improve them;
- Capacity to check divergent ideas;
- Development of responsibility for my own learning and the learning of others;
- Understanding of the standards of excellence to become an effective cooperating teacher.

The previously described criteria were arranged in a rubric based on a Likert scale.

The evaluation of the course, in general, was carried out through focus groups. This activity provoked an additional learning experience since participants had to remember and talk about the concepts studied, thus broadening their learning.

Recognizing the importance of the affective dimension in learning [6], the course closed with an activity in which participants received a rose from the professors. The rose was a symbol of the commitment to work with dedication to help student teachers and other colleagues to achieve excellence.

### **Follow-up with Participants**

A follow-up component was incorporated into the design of the course as part of the assessment of the course, and to provide additional support to participants, to be carried out during the second semester of 2001-02. Focus group interviews, as well as visits to teachers in the classroom to explore what elements and strategies of the course they are incorporating into their practice will be carried out. Cooperating teachers will be interviewed to determine whether the new educational strategies, particularly the hands-on and assessment methods, are being used in the classroom.

### **Conclusions**

As can be seen through the description of the course experience, the learning environment developed through the Open Space strategy allowed participants to defend their points of view and self-direct their learning process in diverse settings. On the other hand, the learning environment allowed the development of general abilities: problem solving, decision-making, and the development of positive mental habits. It also facilitated the practice of important social skills such as listening, and consideration and respect for another person's ideas. Above all, the learning environment was characterized by trust, commitment, and the dedication of all participants toward learning and helping others to learn. Also very important, this strategy allowed more content to be covered in more depth through the course. PR-CETP hopes that other institutions adopt or adapt this model to offer courses leading to the certification of cooperating teachers. The central staff of the PR-CETP is available to offer guidance and technical assistance to institutions interested in developing this course model. ■

### **Bios**

María Aguirre is Associate Professor of Education at the University of Puerto Rico, Bayamón Campus. Her interests are assessment in the classroom and modeling teaching-learning-assessment techniques to promote conceptual understanding.

Lucy Gaspar is a retired associate professor, and Director of the PR-CETP project. Her interest is to facilitate collaboration between K-12 teachers and science and mathematics professors, and to improve the teaching of science and mathematics through the Science and Mathematics Teacher Preparation Program.

### **References**

- [1] *Blueprint for the Reform of Science and Mathematics Teacher Preparation Programs in Puerto Rico*, Puerto Rico Collaborative for Excellence in Teacher Preparation, Puerto Rico, 1997.

- [2] B.J. Zimmerman, "Self-regulated learning and academic achievement: the emergence of a social cognitive perspective," *Educational Psychology Review*, 2 (1990) 173-201.
- [3] S. Bringham, *Open Space Technology: Examples from Higher Education*, Kaludis Consulting Group, Washington, DC, 1999.
- [4] Dalar International Consultancy Website, [http://www.openspacetechnology.com/tr\\_ost.html](http://www.openspacetechnology.com/tr_ost.html)
- [5] H. Owen, *Tales from Open Space*, Abbot Publishing, Potomac, MD, 1995.
- [6] E. Jensen, *Teaching with the Brain in Mind*, Virginia Association for Supervision and Curriculum Development, 1998.



# USING MANIPULATIVES IN UNDERGRADUATE MATHEMATICS COURSES

---

D. MOORE

*Dept. of Mathematics, University of Puerto Rico, Mayagüez*  
moore@shuttle.uprm.edu

## Abstract

Students in undergraduate mathematics classes not only benefit from the use of manipulatives in the classroom, but also enjoy them. This paper specifically outlines one successful activity that used manipulatives in a large section of a precalculus course and then explores possibilities in other courses. It also addresses the use of mathematics manipulatives as a platform to introduce both active and cooperative learning in a large lecture setting.

## Introduction

Learning requires reflection and occurs best in an atmosphere that provides enjoyable interaction [1]. In fact, student-student, as well as student-faculty, interactions can have a great impact on learning [2]. Leinhardt's work suggests that students must build on prior knowledge, and that the act of learning is a social act. Learning involves construction of knowledge, an active process. As students learn, their knowledge is produced and then transformed by themselves as well as by their interactions with others [3].

Active learning has been called learning in which students are doing things and then thinking about what they are doing [4]. Science professors have had success implementing active learning in their large lecture sections, often in conjunction with cooperative learning [5-7]. Cooperative learning has been examined in numerous studies as a teaching strategy to promote active learning. In fact, cooperative learning has been called the most researched of all instructional methods and its impact has been addressed at multiple levels of student achievement [8-10]. Although it initially influenced K-12 institutions, there is a definite growing interest in cooperative learning at the undergraduate level [11,12].

This article will relay how a specific activity was implemented in a large lecture section of a precalculus course in an effort to incorporate both cooperative and active learning.

## Targeted Course

One professor assigned to teach a section of *Precalculus I* at the University of Puerto Rico, Mayagüez (UPRM) with 84 students, decided to implement some cooperative learning activities and demonstrations, both of which used manipulatives, to improve student interest and

learning in her course. The professor was inspired to do this by Eric Mazur who has been implementing small-group activities in his large physics lectures [13].

The *Precalculus I* course is required of all UPRM students. It is the most basic three-credit mathematics course offered, although students entering with insufficient backgrounds in mathematics are directed to a zero-credit basic mathematics course. Passing rates tend to be low in the *Precalculus I* course, especially in the second semester when most of the students are repeating the course due to their unsuccessful attempts in the first semester.

### **Experimental Activity**

On the first day of class, the professor decided to adapt an exercise taken from Marilyn Burns [14]. The students were each given a sheet of centimeter-squared paper and asked to trace around their hand, then to find its area. The professor then circulated throughout the auditorium-style lecture hall looking at each student's work. Common questions that arose with the professor's responses are given below:

*Student:* Does it matter if I open or close my fingers when I trace around my hand?

*Professor:* (Showing her hand in both positions) What do you think? Is the area affected?

*Student:* How can I find the exact area?

*Professor:* You don't have to have an exact number, just estimate. How would you go about estimating? [Some students had no idea where to begin; in those cases, the professor encouraged them to ask their neighbors how to start.]

*Student:* What formula should I use to find the area?

*Professor:* What formulas do you know for area? How could you use them?

Students used many ways to calculate the area of their hands. Some counted the number of squares on the centimeter-squared paper for an answer. Others divided the hand into a combination of rectangles or rectangles and triangles, and summed the answers from formulas they knew. Others drew a small rectangle inside the tracing of the hand and another outside the tracing of the hand to determine a lower and upper bound, and then estimated an answer using them.

Once students had their answers, the professor asked them to compare their answers with their neighbors. Students often held their hands together palm-to-palm to compare and to see if the bigger palm did indeed have the bigger area. Others just overlaid their tracings and held them to the light to compare. Many realized after talking with other students that  $\text{cm}^2$  were the appropriate units. In more than one instance, a student with a much larger hand had calculated a smaller area than a student with a much smaller hand. In those cases, the students tended to check with others to see which area needed “to be fixed,” recalculated that area, and then compared answers again.

The professor concluded by demonstrating the exercise on an overhead projector with her hand, using many of the ways that students in the class had. For the second part of the activity, she asked the students to take a second sheet of centimeter-squared paper and to draw a square, not a rectangle, on it with the same area as they had found for their hands. She asked them to work on this individually. After two minutes, she told students they could discuss their ideas with their neighbors. During this activity, the professor walked up and down the partitioned aisles to see how students were doing. The student who finished first had an area of  $121 \text{ cm}^2$ . The professor let the activity continue for about five minutes. Then she asked the student with  $121 \text{ cm}^2$  hand area to give his results. She went around the room soliciting responses from other students. Some students had used rectangles even though instructed not to do so because they couldn't find a square with integer side lengths that would work. Another common way to solve the problem, for example with a hand of  $105 \text{ cm}^2$ , was to say that the square had to have sides longer than 10 cm but smaller than 11 cm, so 10.5 cm was used. Some students pulled out calculators and would find even better decimal answers using trial and error. A few even knew that the side of the square should be the square root of the area of the hand.

The above activity was described in detail because it is a very rich activity. First, it was appropriate to use on the first day of class. It involved mathematics but was still an icebreaker. The estimation of the hand area did take some time, but that allowed the professor to see each student individually face-to-face—at least for a few seconds. This is not often done in a large lecture section. Although the numbers were not calculated, the professor felt that a higher percentage of these students came to see her during office hours than usual. More specifically, the activity:

- helped students recognize the difference between area and perimeter;

- showed the power of estimation;
- helped teach the difference between units of measure in one-dimension and square units used to measure two-dimensions;
- introduced the concepts of upper and lower bounds;
- showed that mathematics problems are not always solved with a formula—but that known formulas can be adapted and applied in creative ways;
- showed that there is not one right way to find an answer;
- established the importance of checking to see if an answer is reasonable;
- emphasized that even though a square is a rectangle, a rectangle is not necessarily a square;
- pointed out the difference between an estimation (a little over 7) and an exact number (the square root of 51);
- confirmed that numbers are hardly ever integers in real-life situations;
- allowed students a deeper, more concrete understanding of square roots.

One activity has been outlined above in detail. The professor also used a spring with weights and increasing rows of similar pattern blocks in two different activities designed to teach the definition of a function and multiple representations of a function, respectively. The spring was a Slinky®. It was suspended from the classroom ceiling with a styrofoam cup attached to the bottom. The cup acted as a “basket” for the weights which were coins. An initial measurement was taken to see how far the bottom of the “basket” was from the floor. Additional measurements were then taken to determine the distance from the basket to the floor when one quarter was added to the basket, then two quarters, then three. The students were then asked to determine how many quarters would be needed in order for the basket to touch the floor. As long as the Slinky® is not stretched too far, this develops into a nice decreasing, linear relationship. The professor implemented only the three activities, but chose them to address topics that seemed most crucial in the *Precalculus I* course.

### **Another Course**

The same professor also taught the *College Geometry* course in the same semester. Rather than spending the first few class periods reviewing basic geometric concepts that students should bring from high school and prerequisite college courses, the instructor decided to assign two- and three-dimensional string art projects to cooperative groups of students whose instructions were written using the basic terminology that students should know. Two of the

construction projects included: a three-dimensional figure with concurrent lines on parallel edges of an icosahedron; and, a three-dimensional figure with eight raindrops on an octahedron. The instructor noticed that students enjoyed the cooperative projects, but that they also seemed to benefit from the construction of the models. It was unclear if they benefited more from the application rather than sheer memorization of the terms or more from the actual hands-on involvement of creating the models. Regardless of which was more beneficial, the students did master the terms much more quickly and enjoyably than they would have in the period of two to three lectures and a quiz.

### Observations

Table 1 shows relative grade distributions for the experimental section of *Precalculus I* which had 84 students in the spring of 2001. Even though most students typically enrolled in this course have either failed *Precalculus I* in the fall semester or have had to take the zero-credit basic mathematics course, 65% receiving a passing grade of “D” or better (60% received a grade of “C” or better). This passing rate for the experimental section is higher than passing rates have been in past years in either the fall or spring semester (*Precalculus I* passing rates have ranged between 45% and 63% over the past ten years at UPRM). So, students with weak mathematics backgrounds or students who were unsuccessful in their first attempt at precalculus are now doing just as well in a large lecture section as students in smaller sections who entered the university with much stronger mathematics backgrounds. The author acknowledges that these results are being compared against other precalculus sections taught largely by less-experienced teaching assistants and is careful not to draw strong conclusions; however, departmental regulations at UPRM dictate that 90% of all student grades for *Precalculus I* do come from common departmental examinations.

**Table 1.** Grade distributions for 84 *Precalculus I* students in the spring of 2001.

GRADE	STUDENTS (%)
A	13
B	23
C	24
D	6
F	18
W	17

## Conclusion

Professors, including mathematics professors, should rise to the challenge of better meeting the needs of all their students. Teaching strategies that allow for more active learning on the part of the student should be implemented [15]. The professor in this study tried to incorporate only three new activities. However, these activities were all connected to crucial or prerequisite topics in precalculus that could be used to span multiple ideas.

Besides implementing different kinds of activities to teach mathematical concepts, the professor tried to present material in such a way that it would capture the interest of the students. She also tried to ensure that students understood that student-student and student-professor interactions were encouraged. The curriculum can easily be enhanced with experiences that provide students opportunities to strengthen communication skills, while supplying a more active learning environment. Although it calls for more creativity on the part of the instructor, more active, cooperative work should be implemented and tested for its effectiveness in undergraduate mathematics classrooms. ■

## Bio

Deborah Moore is Associate Professor of Mathematics at the University of Puerto Rico, Mayagüez. Her interests are the integration of mathematics and science, the role of mathematics in the sciences, and the use of manipulatives to promote conceptual understanding of mathematics.

## References

- [1] P.T. Ewell, "Organizing for learning a new imperative," *AAHE Bulletin*, **50**(4) (1997) 3-6.
- [2] A.W. Astin, *What Matters in College: Four Critical Years Revisited*, Jossey-Bass, San Francisco, CA, 1993.
- [3] G. Leinhardt, "What Research on Learning Tells us about Teaching," *Educational Leadership*, (April 1992) 20-25.
- [4] C.C. Bonwell, and J. Edison, "Active Learning: Creating Excitement in the Classroom," *ASHE-ERIC Higher Education Report No. 1*, George Washington University School of Education and Human Development, Washington, DC, 1991.
- [5] R.C. Dougherty, et al., "Cooperative Learning and Enhanced Communication," *Journal of Chemical Education*, **72** (1995) 793-797.

- [6] E.A. Hoffman, "Successful application of active learning techniques to introductory microbiology," *Microbiology Education*, 2(1) (2001) 5-11.
- [7] D.R. Paulson, "Active learning and cooperative learning in the organic chemistry lecture class," *Journal of Chemical Education*, 76 (1999) 1136-1140.
- [8] D.W. Johnson and R.T. Johnson, "What we know about cooperative learning at the college level," *Cooperative Learning: The Magazine for Cooperation in Higher Education*, 13(30) (1993) 17-18.
- [9] R.E. Slavin, "Synthesis of research on cooperative learning," *Educational Research*, (4)1 (1991) 67-77.
- [10] D.W. Johnson, R.T. Johnson, and K.A. Smith, "Cooperative Learning: Increasing College Faculty Instructional Productivity," *ASHE-ERIC Higher Education Report No.4*, The George Washington University School of Education, Washington, DC, 1991.
- [11] R.E. Slavin, "What post secondary cooperative learning learns from elementary and secondary research," *Cooperative Learning and College Teaching*, 4(11) (1993) 2-3.
- [12] K.A. Smith, D.W. Johnson, and R.T. Johnson, "Cooperative learning and positive change in higher education," in A. Goodsell, M. Mahler, V. Tinto, B.L. Smith, and J. MacGregor (eds.), *Collaborative Learning: A Sourcebook for Higher Education*, National Center on Post Secondary Teaching, Learning and Assessment, University Park, PA, 1992.
- [13] E. Mazur, *Peer Instruction: A User's Manual*, Prentice-Hall, Englewood Cliffs, NJ, 1997.
- [14] M. Burns, *About Teaching Mathematics: A K-8 Resource*, Math Solutions, Sausalito, CA, 1992.
- [15] W. McKeachie, "Improving lectures by understanding students' information processing: Learning, cognition and college teaching," *New Directions for Teaching and Learning*, No. 2, Jossey-Bass, San Francisco, CA, 1980.





# **UNDERSTANDING OF THE MOLE CONCEPT ACHIEVED BY STUDENTS IN A CONSTRUCTIVIST GENERAL CHEMISTRY COURSE**

---

C. UTRIA-ECHEVARRIA and M. BRAVO

*University of Puerto Rico, Rio Piedras*

mlbravo@caribe.net

## **Abstract**

The purpose of this research project was to study the conceptual understanding achieved in a general chemistry course based on a constructivist approach. A group of 28 students participated in repeated measures obtained by means of conceptual maps about the mole concept prepared three times during the course: at the beginning the course, immediately after the concept was studied, and after studying other related concepts. In addition, eight students selected from the group of 28 were interviewed. The interviews were carried out focusing on their conceptual maps. The analysis of the repeated measures indicated significant differences among the three times, especially between the first two. It was evidenced, therefore, that these students obtained a significantly higher level of understanding of the mole concept. The qualitative analysis carried out with students identified a broad range of responses that represent different levels of hierarchical organization, of progressive differentiation, and of formation of significant relations of the mole concept. Some recommendations offered are to develop and implement teaching methods that promote understanding of scientific concepts, and to prepare science professors and teachers to emphasize teaching for conceptual understanding.

## **Introduction**

According to the American Association for the Advancement of Science (AAAS), a fundamental assumption for changes in the classroom is that schools do not need to teach more and more content, but instead should focus on the essence of scientific knowledge and teach this more effectively [1-2]. In the area of science, these reforms in teaching methods become imperative in order to achieve higher levels of effectiveness. The National Science Foundation (NSF) supports initiatives that experiment with ways to change teaching practices [3].

The teaching of science requires clear goals and non-traditional models that use the *inquiry processes*—exploration, based on the natural curiosity of human beings—to promote the development of skills associated with scientific culture [4]. Through these active learning strategies, the objective is to promote the understanding of basic concepts by students, as an indispensable requirement to understand the fundamental theories of science. Conceptual understanding is defined as the student's ability to adequately recognize, interpret, explain, and illustrate the connections among the subordinate concepts of a macroconcept and among these with other related concepts [5].

In chemistry, for example, the teaching of the core courses should promote students' capability to design their own scientific experiments [6]. That capability requires a higher order understanding of the concepts that make up accepted theories. Consequently, any instructional process that fails to achieve understanding of concepts should be considered ineffective.

There are a considerable number of studies that illustrate the problems students face in developing understanding of concepts and principles of chemistry [7-12]. The problems underscored by this literature are: (1) student learning is predominantly through repetition or memorization, rather than through the active construction of knowledge; (2) students do not know the most important attributes of the concepts nor can they establish the necessary relations among the concepts to understand a macroconcept or a chemistry idea; (3) teaching could fail if it does not offer enough experiences in which the learner can reflect and express the ways in which they are establishing connections.

There is much controversy about what promotes conceptual understanding in a discipline. In chemistry, the relation between solving numeric problems and understanding the concepts has been studied [13]. It is also important to point out the research related to the alternative concepts presented by the students on some chemistry concepts. The studies by Gabel [13], Gabel, Sherwood, and Enochs [14], Anamuah-Mensah [15], and Bunce, Gabel and Samuel [16] indicate that the depth of conceptual understanding usually attained by students is inadequate to solve chemistry problems that require transfer—in other words, chemistry problems in which students must use and relate concepts in a different context to be able to solve them. Likewise, the studies demonstrate that students frequently solve numerical problems only by using an algorithmic approach.

Other studies have shown that traditional instruction in chemistry modifies students' concepts, but not to a great extent [17,18]. Occasionally, instruction creates errors in scientific conceptions or misconceptions. Based on these findings, the need has been identified to explore the effectiveness of instructional strategies designed to promote depth of conceptual understanding. For this purpose, professors and educational and scientific researchers on the secondary and university levels in Puerto Rico carry out educational innovations that seek to promote conceptual understanding. For example, the Puerto Rico Statewide Systemic Initiative (PR-SSI) and the Puerto Rico Collaborative for Excellence in Teacher Preparation (PR-CETP) focus their efforts toward the transformation of science and mathematics education through the

development of innovative curricula, and the use of innovative teaching and assessment strategies.

One of the transformed courses through these efforts is the *General Chemistry* course of the University of Puerto Rico, Rio Piedras, which serves as a basis for this study. The study is part of a larger research project that constitutes the master's thesis of the first author of this paper [19]. In this thesis, besides what is presented here, the effectiveness of the constructivist approach adopted through this course in promoting conceptual understanding of the core concepts of *General Chemistry* was evidenced, in comparison with another course taught with traditional teaching methods. The group studied evidenced a significantly higher level of conceptual understanding, compared with another group with comparable sociodemographic and educational characteristics, on a test developed by William Robinson from Purdue University, translated and adapted in Puerto Rico.

The study presented here intends to delve into this finding through a detailed study of the understanding of the mole concept with students taking the *General Chemistry* course based on a constructivist perspective. The professor for this course uses extensive active learning activities. Within these teaching and learning strategies are tasks in cooperative learning groups inside and outside the classroom. Interactive demonstrations based on the process of predicting-observing-explaining, and based on experiments done in the classroom, are also widely used. The professor guides students through a process in which they all predict what could happen in a given situation and which they later research, to clarify their ideas. For example, she introduces the mole concept using an interactive demonstration based on an analogy described by Arce [20]. The professor brings an electronic balance and various matchboxes, each filled with the same number of paperclips, but with different kinds of clips. The thinking process is guided by means of the handout shown in Figure 1. With this interactive demonstration, students "discover" or construct their own understanding of the origin of Avogadro's number before the actual number is known. Later on, another activity carried out in the classroom is the critical analysis of a letter to the editor published in a local newspaper (excerpt shown in Figure 2). In these activities, students work in groups to discuss the problems and agree on an answer. In the letter to the editor activity, students must apply their newly acquired knowledge of stoichiometry and balancing equations to a real life situation in order to understand the important piece of information omitted by the writer.

### Interactive Demonstration

Avogadro said:            Equal volumes of gases contain the same number of particles.

As an analogy to equal volumes, we have four match boxes, each one containing the same number of paper clips, but with different kinds of clips inside each box.

<u>Box label</u>	A	B	C	D
------------------	---	---	---	---

<u>Mass of box and content</u>				
--------------------------------	--	--	--	--

<u>Mass of box</u>				
--------------------	--	--	--	--

<u>Mass of content</u>				
------------------------	--	--	--	--

How can we express the ratio of the masses of the clips contained inside each one of the boxes?

How can we define a *clipol*?

Let's weight the mass of a *clipol* of each kind of clip and count the number of clips in each.

	A	B	C	D
--	---	---	---	---

<u>Clips in box</u>				
---------------------	--	--	--	--

<u>Mass of <i>clipol</i> to be weighted</u>				
---	--	--	--	--

<u>Number of clips in a <i>clipol</i></u>				
---	--	--	--	--

**Figure 1.** Handout of the interactive demonstration used to study the mole concept.

**Can't release more weight than it burns**

In my quest for information regarding the coal-fueled Cogentrix® plant in Mayaguez, I read with interest the article titled "Can't Trust Regulations on Cogentrix®" by professor JB, a fine article that exposes the principal reason to oppose the establishment of this electricity generating plant at its current location.

The main reason used by most against the plant and expressed clearly by JB, is the lack of confidence in the regulatory agencies ability to establish appropriate standards and much less enforce them.

We must require that the appropriate standards are established and must insist that they are the same all over the world.

JB's article, as usual in the printed matter by Cogentrix® oppositionists, has some figures that are grossly exaggerated and cannot be true. In the third paragraph of the article JB states "These discharges include.....15.3 million pounds per day of the "greenhouse" gas carbon dioxide.

As a professor in chemical engineering, JB should not believe this. The little chemistry that I took in college always taught that the molecular weight in a chemical reaction had to remain equal. How about the true weights? Is Cogentrix® going to exhaust more weight than the coal it consumes? How about a free Chemistry class, Prof. JB?

Signed                      H.L.F, Jr.  
Mayaguez

**Figure 2.** Transcript (only names omitted) of the Letter to the Editor used in the *General Chemistry* course.

To guide the study reported here, the following research questions were posed: Does students' understanding of the mole concept increase after participating in constructivist learning activities in a *General Chemistry* course? What are the characteristics of the conceptual understanding achieved by students in relation to the mole concept?

## Method

A mixed method approach was used to achieve a better understanding of the problem studied. The qualitative and quantitative methods were used independently, but simultaneously [21].

The basic research technique used was the concept map administered three times: once at the beginning of the course; again immediately after the mole concept was studied; and then after studying other related concepts. This technique, in conjunction with a rubric, enables the assignment of scores to students according to their performance, and it can be used to guide interviews to obtain qualitative information. A repeated measures statistical analysis of the scores obtained by all students in the concept maps they constructed was carried out (n=28). On the

other hand, an individual interview was carried out with eight students selected from among the 28, to inquire about their conceptual work in the three concept maps they elaborated during the course.

Participants – Students who took the constructivist course during the first semester of the academic year were the participants in the study. There were twenty females and eight males with an average age of 19.2 years and an average college entrance GPA of 3.43 (from a maximum of 4.0). The eight students interviewed were selected from among the 28 students. To select them, students were placed in descending order based on the scores they obtained in the second concept map. The students were divided into four equal groups. The highest quarter (highest scores) and the lowest quarter (lowest scores) were selected. In each of these groups, four students were randomly selected. This selection justifies the interest in describing the understanding developed by students who are outstanding in terms of the conceptual understanding they achieve, in contrast with students who manifest difficulty or limitations in their conceptual understanding. In this way, the power to observe a broad range of characteristics related to conceptual understanding is optimized.

Data Collection – The concept map is a procedure developed by Novak [22], based on a theory developed by Ausubel [23] and used in several studies to evaluate conceptual understanding in chemistry [22, 24]. Concept maps are made by establishing a hierarchy and relating concepts through propositions. They are used to allow students to express their knowledge about a concept through their own construction and learning styles.

To collect information, 28 students were asked to construct a concept map of the mole concept three times during the course. Students had 45 minutes to elaborate the conceptual map each time. At time 1, at the beginning of the course (August 2000), each of the students was asked to elaborate a concept map to explore the prior knowledge students brought to the course about the mole concept. At time 2, after the concept of mole was taught in class (October 2000), students were handed the concept maps they had elaborated in time 1, to correct, add, eliminate or re-elaborate according to what they deemed most appropriate. At time 3, a little before the end of the course (November, 2000), after related concepts had been taught, the concept maps created during the two previous times were handed to the students again. They were instructed to make corrections, to add concepts, to eliminate concepts or to establish new relations with other concepts they had studied.

Through the in-depth interviews, the understanding achieved by students was determined. They were asked to explain their thought processes and the ways in which they evidenced changes in conceptual understanding. Questions such as the following were asked: What reasons did you have to establish this hierarchy? Why do you think this relation is important in this part of the map? How do you justify the changes in hierarchy between the first and second maps? Why did you make these changes in the second and third maps? Why do you present a larger number of connections in this map? What examples can you add to these concepts?

Data Analysis – The scoring of the maps was done through the use of a rubric applying the criteria developed by Novak [22]. The score is distributed according to the characteristics of the map, including: hierarchy, propositions, ramifications, intercrossing, and examples. The fundamental base of the scoring scheme is the cognitive learning theory of Ausubel [23].

The researcher scored all students' conceptual maps using the rubric; the final score given to each of the maps for the three times was cumulative. Also, a doctoral student in education with experience in the conceptual map technique independently evaluated all of the maps, using the same rubric. Reliability between the two judges who evaluated the maps was determined through Spearman's statistical *rho* test. Results showed high reliability between the judges for the independently derived scores the three times (Spearman  $r=0.980, 0.989, 0.995$ , respectively). In case of discrepancy between scores, the two judges sought agreement regarding the score of the maps, and the scores that were assigned by consensus were the ones used in the analysis.

The scores attained by the students in the conceptual maps the three times were statistically analyzed calculating the mean and standard deviation for each administration. To evaluate differences among the three measures, the statistical test MANOVA (SSPS) was used.

For the qualitative analysis of the data gathered through the interviews, the constant comparative method was used. Through this method, the coding of information in deductive and inductive categories is combined at the same time that all the units of meaning are compared among themselves [25]. The use of a computer program for the qualitative analysis, *The Ethnograph* version 5.0, facilitated the grouping of the fragments corresponding to each category in thematic files.

## Results

The first question that guided this study focused on the increment in conceptual understanding attained through the course. The inspection of the means of the repeated measures obtained through the maps suggests that there was an increase between scores for times 1 and 2, and they continued to increase, although to a lesser degree, in time 3 (see Table 1). The MANOVA test for repeated measures identified significant statistical differences among the concept maps of the three times ( $F=57.24$ ,  $g_l=2$ ,  $p=0.000$ ). Differences between times 1 and 3 were identified in the same way ( $F=80.09$ ,  $g_l=1.27$ ,  $p=0.000$ ) and between time 2 and the mean of times 1 and 3 ( $F=14.16$ ,  $g_l=1.27$ ,  $p=0.001$ ). From these results, it is concluded that students evidenced a progressive improvement, and a statistically significant one, throughout the different times of measurement, which indicates that their conceptual understanding of the mole concept increased considerably as the learning process advanced in the constructivist course.

**Table 1.** Mean and Standard Deviation of the Repeated Measures.

<b>Times</b>	<b>Means</b>	<b>Standard Deviations</b>
Time 1	1.536	1.934
Time 2	12.250	7.511
Time 3	15.536	8.500

Regarding the characteristics of the conceptual understanding achieved by students of the mole concept, the second research question of this study, data was analyzed through coding in categories based on the cognitive learning theory of Ausubel [23] and the studies by Novak and Gowin [26]. The selected categories are processes described by Ausubel that characterize the achievement of conceptual understanding, including hierarchical organization, progressive differentiation, and integrative conciliation. These categories were divided into subcategories that allowed the discovery of gradations or levels within each of the processes.

Results are illustrated below with examples of the answers given by the students interviewed. Examples included evidence of the different characteristics of conceptual understanding that were observed. The answers correspond to the participants from the two groups of students in the sample—that is, students with high scores and those with low scores at time 2.



Hierarchical Organization – According to Ausubel [23], the cognitive structure is organized hierarchically. A sound hierarchical structure for the understanding of a concept begins with broad, inclusive concepts and later follows with more specific and less inclusive concepts. The characteristics associated with hierarchical organization that characterize conceptual understanding attained by students are the following: (1) general or concrete conceptual relations; (2) conceptual relations without a clear distinction between general and concrete concepts; (3) simple high or low level conceptual relations; and, (4) complex high and low level conceptual relations. These characteristics denote progress in the conceptual understanding achieved by students.

In the analysis of the information from the interviews, it was observed that students with low scores in the maps had a tendency to form only general or concrete conceptual relations (45%). In an equal proportion, students formed conceptual relations without clearly distinguishing between general and specific concepts (45%). In the group with high scores in the maps, a tendency to form high and low level conceptual relations, simple as well as complex, was observed, although the latter occurred to a lesser extent (64.7% and 17.64%, respectively).

An example of a general conceptual relation is a statement by Beatriz (the names used are pseudonyms, those beginning with an “A” are used to identify students from the group with high scores and those with “B” to identify those from the group with low scores). She establishes a hierarchy with very general concepts. Although she also mentions specific concepts, Beatriz does not express a coherent relation in her conceptual hierarchy. She also explains the reasons that led her to establish the hierarchy shown in the map:

When I thought about a mole I thought that it could be about elements as compounds, ... and in fact I am thinking that in a mole of an element there is the same amount as there is in a compound... and ..... that what this tells me about a mole.... In a mole of a certain amount, there are certain grams or 6.02 by 10 to the 23 units of a mole.

In these expressions, it can be observed that the relationships between concepts do not incorporate hierarchy. At first instance, she relates the mole concept with elements and compounds without reaching a greater degree of specificity of these concepts. Later, she relates the mole concept with grams and with the Avogadro number, evidencing a leap between the first level (elements and compounds) and the second level (grams, Avogadro number). This is to say, the general concepts on one hand and the specific or concrete concepts on the other.

Alfred establishes a simple hierarchical organization. He defined the mole concept in first instance. From this definition, he starts to relate concepts, keeping in mind the general and inclusive ones, as well as the specific and non-inclusive one. He commented:

Well, from the mole to the most explicit, defining the mole as the quantity of substance and from there each concept leads to the other... it became normal in other words...it was pretty easy for me to go from the lower definition to compound, and from compound to element, and from there to molar mass... the definitions take us there... the higher one, I really guide myself by the higher one.

These expressions evidence a logical way of organizing the compounds. Defining the mole concept allowed the student to acquire a broader view about the relationships he established. This shows a better understanding of the set of relations between the mole concept and the ones that are subordinate to it. On the other hand, it is important to keep in mind that the creative students are capable of finding new ways to represent relationships and conceptual hierarchies [26].

Alice establishes hierarchies with conceptual relationships considered complex. Her hierarchical organization begins with the definition of the concept, and later establishes relations with broad and inclusive concepts and continues with less inclusive and more specific concepts. In the hierarchical organization of the maps of the second and third times, a greater degree of specificity of the mole concept is observed. About this she comments:

Mole is a unit that represents a quantity of a substance whether of a compound or of an element. .. because the elements are the simplest and the compounds are beyond. The compounds and the elements are represented by the chemical formulas and from here you reach the stoichiometric calculations to determine atomic mass, molar mass.. atomic mass is expressed in u.m.a. ... molar mass is in grams by mole of molar mass I can reach the Avogadro number which is equal to  $6.02 \times 10^{23}$  molecules, ions and other things.

From the findings, it can be said that students with lower scores in general present an insufficient understanding of the concepts related to the mole concept which is clearly manifested in the lack of hierarchical organization that is evident in their answers. This is consistent with

studies by Herron [27] and Abraham [28]. These researchers point out that the students present difficulties of understanding the mole concept due to limitations in their understanding of the related concepts and the use of rules and memorized algorithms. On the other hand, students with high scores presented definitions of the mole concept based on other concepts that are consistent with the findings from previous studies [29-32]. These researchers point out that a clear indicator of sound understanding of the mole concept in students is that they express a clear definition of the concept. Also, they can relate it with other concepts such as stoichiometry, molar mass, and solution concentration, among others.

Progressive Differentiation – The Ausbelian principle of progressive differentiation establishes that significant learning is a continuous process, during which new concepts reach higher significance as they acquire new relations [26]. Therefore, concepts are “never totally learned,” but are always being developed, modified or becoming more explicit and inclusive as they continue to differentiate progressively.

Among the identified characteristics associated with progressive differentiations that characterize students' conceptual understanding, are the following: (1) assimilation of the meaning of concepts; (2) recognition of new conceptual relationships; and, (3) reorganization of the cognitive structure.

The observed tendency in students with low scores is mostly in the assimilation of the meaning of the concepts (64.28%). In the group with high scores in their concept maps, we found the tendency toward differentiation of the mole concept is to recognize new concepts (40%) and to change or reorganize their cognitive structure (52%). The following is an example of assimilation of the meaning of concepts expressed by Beto:

Mole is the quantity of something... it is the quantity of substance, molecules, atoms... it's very confusing to relate it because it is so abstract, the stoichiometry, all that... it confuses and one has to understand it well.

From these expressions, it can be said that although Beto has internalized the meanings of the given definitions of the mole concept, he is not able to relate new concepts to those already existing in his cognitive structure. The differentiation he makes of the concept is limited. To a great extent, it could be because he did not establish specific new conceptual links. These

conceptual links are relatively precise indicators of the degree of differentiation of a concept that can be attained [26].

An example that evidences the recognition of new concepts is Alfred's explanations:

I can not say that they are a conversion measure at the start if I don't give the definition of mole to understand it more... because that helps to understand what a mole is, all the definitions and relations of the mole are important to point out in the map... it is important to know for what it is used... how it relates, for example to atomic mass, molar mass, grams of a compound.. it is important to know that there is a basic number that is called Avogadro because he was the scientist who knew that there was an exact number, although he didn't know exactly which, but he knew.

In Alfred's answers, we observe the importance he gives to the definition of mole. He also makes reference to its use and how it relates to other concepts. Alfred's differentiation level of the concept is in evidence. On the other hand, his expression of a preference to understand the concept better, serves as an indicator to affirm that his level of differentiation is in continuous development.

Alba, for her part, in explaining the relations that she establishes in her maps, makes a differentiation between the atoms and molecules of a compound. She also differentiates that the molar mass is defined as the quantity of grams per mole. An example of the conceptual links and differentiation Alba makes is:

When I look at the periodic table and I see hydrogen and it says that it is 1.008 I have to be aware that it is a quantity that I have of hydrogen in a mole...when you analyze the composition of hydrogen you find that it is the atoms that form a molecule and the Avogadro number lets you know that a mole of any substance is 6.02 by 10 to the 23 atoms of that specific substance... and that molar mass is defined as grams per mole and that atomic mass is measured in u.m.a.

From Alba's explanations, it can be observed that one of the characteristics of conceptual understanding of the mole is to be able to differentiate it. This means to be able to reach higher levels of specificity through which the student internalizes the meaning of the concepts. Also, to be able to establish more differentiated relations of the mole. Alba's explanations are consistent

with Novak and Gowin's study in which they showed that high differentiation in concepts in the cognitive structure of individuals is an indication of sound conceptual understanding [26].

Integrative Conciliation – Novak and Gowin establish that there is a sound understanding of a concept if the learner recognizes new relations (illustrated through the interconnections in a conceptual map) among related sets of concepts in hierarchical levels [26]. They also sustain that when understanding of a concept is achieved by the student, he/she is capable of solving conceptual conflicts in meaning.

Among the characteristics associated with the integrative conciliation related to conceptual understanding attained by students about the mole are the following: (1) relationships with non-appropriate concepts; (2) memory relationships; and, (3) significant relationships.

In analyzing the information from the interviews, a tendency to establish relations between non-appropriate concepts was observed in the group with low scores (54.5%). Another characteristic was the establishment of relations based on memory (40.9%). On the other hand, four students with high scores in their maps established mainly significant relations among concepts (87.5%).

Bernie explained erroneous or poor connections. He had difficulty in relating the subindex of chemical formulas with the appropriate number of atoms. An example of these relationships is the following:

Well, if you have an element then you can associate that such an element is equivalent to a mole..it is an association that you make that in this element there is a mole.. if you had an element such as hydrogen ( $H^2$ ) then you would have about two moles.

Bernie's explanations are consistent with the findings of Yaroch [12]. This researcher found that students do not make appropriate distinctions between the coefficient that precedes the formula in an equation and the subindexes of the formulas of either compounds or elements.

Belkis and Beatriz presented erroneous conceptions when they defined the mole. Belkis defines the mole as follows:

The mole is... it is like the atomic mass in which grams of the elements and compounds are found... that is the mole.

In this definition, it is clearly shown that the relationships established are not appropriate for the mole concept. This is consistent with the findings of Staver and Lumpe which show that one of the most frequent mistakes made by students is that they define mole as a mass expressed in grams [30].

Beto, for his part, establishes new relations among related sets of concepts, but does not explain how or why a determined conceptual link is important. The relations he establishes are based on memory. An example is:

I do not know the real importance of the relation (mole and u.m.a.) ... I placed what I understood about mole... I really didn't want to put it all together... one thing has nothing to do with the other... I know that the Avogadro number is equal to  $6.02 \times 10^{23}$  particles, I don't know what relation all this has, I just put them together, that's all.

The conceptual relationships (interconnections) that Beto establishes are essentially based on memory. This finding from this study coincides with Herron's [27] and Abraham's [28] statements that one of the barriers to successfully solve chemical problems that deal with the mole concept is the use of rules or memorized algorithms. An example of the significant relations is what Alicia expresses:

The atomic mass is the mass of an element but expressed in u.m.a.... it is the same as if I could use the example of the oxygen element which is 16 u.m.a. as it is the same for the molar mass but expressed in grams.

It is considered significant because the student explains adequately how and why a particular conceptual link (interconnection) is important in the map. This description provided by Alicia agrees with the studies by Staver and Lumpe [30] who point out that there is a connection among the students' definitions of mole, and their explanations of the numerical identity that exists between the atomic mass and the molar mass of a substance.

## Discussion

A progressive increment in the understanding of the mole concept throughout time, as evidenced in repeated measures on concept maps, was observed in students from the *General*

*Chemistry* course taught through a constructivist approach. The design of this study does not enable us to conclude that the changes were solely due to the constructivist approach. However, it evidenced that a significant increase in conceptual understanding was attained, thus suggesting that the teaching strategies used in this *General Chemistry* course might have been effective for this purpose. The understanding of concepts in chemistry is important for students to comprehend the scientific processes inherent in this discipline in a significant way. Moreover, good instruction in chemistry should modify students' comprehension of concepts [17-18]. Feasible and effective instructional models are needed for promoting the understanding of chemical concepts [24,33].

The study also evidenced the characteristics of the understanding of the mole concept achieved by students, as observed during in-depth interviews. We noticed that students, particularly those who obtained low scores in their conceptual maps, established general or specific conceptual relationships about the mole concept. For this reason, a hierarchical organization of the concept was not observed in their conceptual structure. This finding is consistent with the studies of Novak and Gowin [26]. These researchers determined that the meaning a student has of a particular concept depends on first instance on the hierarchical level of the conceptual relations they establish. On the other hand, it was identified that some students, specifically those who obtained high scores in their maps, established high-low level conceptual relationships, some simple and others more complex. These relationships reflect an organized hierarchical structure of the mole concept.

This research also evidenced that one of the characteristics of conceptual understanding achieved by students is that of relating new concepts with previously existing ones in their conceptual structure. This was illustrated in the continuous differentiation of the mole concept evidenced by students in their conceptual maps and in their explanations of the changes they made between the first map (before instruction) and the second one they developed (after instruction). This finding illustrates the statement by Osborne and Cosgrove who pointed out that each student has previous knowledge and that through the teaching and learning process, prior knowledge gradually progresses [34].

The establishment of significant relations of the mole concept by students is another characteristic, no less important, that was documented through this study. These relations evidence the knowledge structure acquired by students and are an indication of the sound understanding of a concept. This finding is consistent with the results of Novak [22]. This

researcher indicated that significant relationships show the mutual connections of the concepts as well as their hierarchical order for the transformation of knowledge by students.

Another important finding highlighted by this study is the persistence of inappropriate relations among concepts in some students, specifically those who obtained low scores in their maps. This was observed in the explanations they offered to the ideas included in their conceptual maps in the three different times, in spite of the instruction received. This means that even though the constructivist teaching-learning methods were effective for most of the students in changing their initial levels of conceptual understanding, the establishment of inappropriate relations persisted with some students. A study by Cros, Castrette, and Fayol points out that erroneous concepts are difficult to eradicate even through effective instruction [17]. This finding constitutes a challenge for faculty and researchers in the teaching of chemistry. It reinforces the need to continue seeking ways to modify these erroneous concepts in some students.

In view of the findings of the present study, the following conclusions can be reached: (1) The constructivist approach apparently contributed to promote an increase in the understanding of the mole concept in a *General Chemistry* course; (2) the understanding of the mole concept progressively increased in students who took the researched course, evidenced through the analysis of understanding before studying the concept in class, as they finished discussing it, and some time after the discussion; (3) a broad range of answers was identified which represent different hierarchical organization levels in the understanding of the mole concept—this encompassed the presentation of general or concrete conceptual relations alone, to the establishment of high level conceptual relations; (4) a progressive differentiation of the understanding of the mole concept developed by students was identified—this progressive understanding was evidenced in several forms, that is, including the assimilation of the meaning of concepts themselves, through the recognition of new relations about it, and through the reorganization of their cognitive structure; (5) the formation of meaningful relations using subordinate concepts of the mole concept, was characteristic of the integrative conciliation process among students; (6) even though most students increased the level of their conceptual understanding after participating in constructivist activities, the establishment of inappropriate relations among the concepts persisted with some students.

From the experiences and results of this study, the following recommendations are made: (1) the teaching of science should focus on the promotion of understanding of scientific concepts; (2) science professors and teachers should be prepared to implement teaching and learning



processes that promote improved conceptual understanding among students; (3) they should also be prepared to adequately assess conceptual understanding (concept maps and interviews are alternatives); (4) special attention should be given to the development and implementation of effective strategies to help students substitute erroneous or incomplete concepts; (5) courses in which teaching methods are being transformed should be studied to learn about the educational value of such efforts.

As in all research endeavors, the present study has strengths as well as limitations. The use of a multi-method approach allowed access to broad and precise information, as well as depth to the obtained findings. This is evidenced by the fact that the quantitative changes observed in the repeated measures could be described in more detail and understood in depth through the interviews carried out with the students. Because of this, one of the contributions made through this research for educational practice is to offer a multi-method approach that represents a useful option for the study of understanding of any concept in science. The mixed methods approach in this study was based on the use of concept maps, a technique used in multiple research projects by authors such as Easley [35] and Novak and Gowin [26] to study changes in cognitive structures. In the present study, the usefulness of concept maps to detect these changes was confirmed. The participation of an external evaluator, besides the principal researcher, to score the maps, the high reliability of their independent judgements and the calibration of their scores with each other was also a strength of this research. Moreover, the development of a rubric to score the maps, applying Novak's criteria but with a different population and scientific concept, and in conjunction with the high level of agreement among judges, adds evidence to the validity of the rubric. For this reason, the rubric might be used by other researchers interested in studying the conceptual understanding of students on different levels. Professors and teachers could also use it to assess the conceptual understanding achieved by their students at different times in their learning process.

On the other hand, a limitation of the study was that the principal researcher was the only person who carried out the categorization of data obtained in the interviews. Nevertheless, the elaboration of the categories integrated the input of three professors from the University of Puerto Rico and of a doctoral student of the Program of Curriculum and Teaching of Science, who participated as an external evaluator in the scoring of the concept maps. A more important limitation of this study is the absence of a comparison group and appropriate controls to be able to conclude that the observed changes in the understanding of the mole concept were due to the constructivist teaching strategies and that the levels of change observed were higher than would

have been observed using more traditional teaching approaches. Studies of this kind are needed to convincingly reach these conclusions. However, results from another part of the larger research, on which this study is based, suggest that that could be the case. It involved a quasi-experimental design in which students from the constructivist course targeted in this study were compared to a group taught through traditional teaching methods: the groups were similar in sociodemographic and educational characteristics and did not differ in their pre-test scores. The experimental group showed a significantly higher level of conceptual understanding than the comparison group on a test, developed by William Robinson from Purdue University, that assesses concepts covered in a general chemistry course, including the mole concept. ■

### Acknowledgments

We are grateful to Dr. Maria Aguirre and Dr. Maria Medina for their recommendations as members of the Thesis Committee of the first author. We also acknowledge the contribution of Elena Maldonado who willingly assisted as evaluator for the concept maps. Finally, we wish to express special thanks to Dr. Josefina Arce and to the students of her *General Chemistry* course for allowing us to carry out this research and bring it to a happy conclusion.

### Bio

Carlos Utria-Echevarria is Professor of Chemistry at the INEM University Miguel Antonio Caro, at Baranquilla, Colombia, and Advisor to the Research Centre of the Universidad Autónoma del Caribe, in Baranquilla, Colombia.

Milagros Bravo-Vick is Professor in the College of Education at the University of Puerto Rico, Río Piedras, and Coordinator of the Evaluation Component of the Puerto Rico Collaborative for Excellence in Teacher Preparation (PR-CETP).

### References

- [1] *Science for all Americans*, American Association for the Advancement of Science, Washington, DC, 1989.
- [2] J. Wandersee, J. Mintzes, and J. Novak, "Research on Alternative Conceptions in Science," in D. Gabel (ed.), *Handbook of Research on Science Teaching and Learning*, Macmillan, New York, 1994.
- [3] M. Nakhleh, K. Lowrey, and R. Mitchell, "Narrowing the Gap Between Concepts and Algorithms in Freshman Chemistry," *Journal of Chemical Education*, 73(8) (1996) 758–762.

- [4] A. Rivas, "La importancia de la naturaleza de las ciencias en el desarrollo de una cultura científica" ("The Importance of the Nature of Science in the Development of a Scientific Culture"), *El Gran Educador*, **1**(2) (1999) 7–8.
- [5] M. Aguirre, Open-ended questions: An alternative mode to assess the students' performance in concept development and use of scientific vocabulary. Unpublished dissertation. State University of New York at Buffalo, 1998.
- [6] J. Arce, "Student-designed Experiments in Scientific Lab Instruction," *Journal of College Teaching*, (1997) 114–118.
- [7] S. Novick and J. Nussbaum, "Junior High School Pupils' Understanding of the Particulate Nature of Matter: An Interview Study," *Science Education*, **62**(3) (1978) 273–281.
- [8] S. Nurrenbern and M. Pickering, "Concept Learning versus Problem Solving: Is There a Difference?" *Journal of Chemical Education*, **64**(6) (1987) 508–510.
- [9] M. Pickering, "Further Studies on Concept Learning versus Problem Solving," *Journal of Chemical Education*, **67**(3) (1990) 254–255.
- [10] R. Peterson and D. Treagust, "Grade 12 Students' Misconceptions of Covalent Bonding and Structure," *Journal of Chemical Education*, **66**(6) (1989) 459–460.
- [11] B. Sawrey, "Concept Learning versus Problem Solving: Revisited," *Journal of Chemical Education*, **67**(3) (1990) 253–254.
- [12] W. Yarroch, "Student Understanding of Chemical Equation Balancing," *Journal of Research in Science Teaching*, **22**(5) (1974) 499–459.
- [13] D. Gabel, "Use of the Particle Nature of Matter in Developing Conceptual Understanding," *Journal of Chemical Education*, **70**(3) (1993) 193–194.
- [14] D. Gabel, R. Sherwood, and L. Enochs, "Problem-solving Skills of High School Chemistry Students," *Journal of Research in Science Teaching*, **21**(2) (1984) 221–233.
- [15] J. Anamuah-Mensah, "Cognitive Strategies Used by Chemistry Students to Solve Volumetric Analysis Problems," *Journal of Research in Science Teaching*, **23**(9) (1986) 759–769.
- [16] D. Bunce, D. Gabel, and K. Samuel, "Enhancing Chemistry Problem-solving Achievement using Problem Categorization," *Journal of Research in Science Teaching*, **28**(6) (1991) 505–521.

- [17] D. Cros, M. Chastrette, and M. Fayol, "Conceptions of Second Year University Students of Some Fundamental Notions of Chemistry," *International Journal of Science Education*, **10**(3) (1988) 331–36.
- [18] J. Rowell, C. Dawson, and H. Lyndon, "Changing Misconceptions: A Challenge to Science Educators," *International Journal Science Education*, **12**(2) (1990) 167-75.
- [19] C. Utria, "Entendimiento conceptual logrado por estudiantes en un curso de química general de corte constructivista" ("Conceptual Understanding Achieved by Students in a Constructivist Course"), Tesis de grado (Masters' thesis). Universidad de Puerto Rico, 2000.
- [20] J. Arce, "Relative Atomic Mass and the Mole: A Concrete Analogy," *Journal of Chemistry Education*, **70** (1993) 233.
- [21] M. Bravo, "El enfoque multimetodológico en la investigación intercultural: Bases conceptuales y epistemológicas" ("The Multi-method Approach in Intercultural Research: Conceptual and Epistemological Foundations"), *Pedagogía*, **28** (1992) 42–49.
- [22] J. Novak, "Application of Advances in Learning Theory and Philosophy of Science to the Improvement of Chemistry Teaching," *Journal of Chemical Education*, **61**(7) (1984) 607–612.
- [23] D. Ausubel, *Educational Psychology: A Cognitive View*, Holt, Rinehart, & Winston, New York, 1968.
- [24] M. Nakhleh, "How Can Research Uncover What Students are Learning?" *Journal of Chemical Education*, **71**(3) (1994) 201–203.
- [25] B. Glaser and A. Strauss, "The Discovery of Grounded Theory," in R. Strauss and J. Corbin, *Basics of Qualitative Research: Grounded Theory Procedures and Techniques*, Sage Publications, Newbury Park, CA, 1990.
- [26] J. Novak and D. Gowin, *Aprendiendo a aprender (Learning to learn)*, Traducción por (Translation by) J.M. Campanario y E. Campanario, Ediciones Martínez Roca, 1988.
- [27] J. Herron, "The Role of Reasoning in Problem Solving," in J. Staver and A. Lumpe (eds.), *Problem solving and conceptual understanding*, Symposium conducted at the Midwest regional meeting of the American Chemical Society, Kansas State University, Manhattan, KS, 1990.
- [28] M. Abraham, "Sources of Alternative Conceptions in Chemistry," in J. Staver and A. Lumpe (eds.), *Problem solving and conceptual understanding*, Symposium conducted at the Midwest regional meeting of the American Chemical Society, Kansas State University, Manhattan, KS, 1990.
- [29] J. Staver and A. Lumpe, "A Content Analysis of the Presentation of the Mole Concept in Chemistry Textbooks," *Journal of Research in Science Teaching*, **30**(4) (1993) 321–337.

- [30] J. Staver and A. Lumpe, "Two Investigations of Students' Understanding of the Mole Concept and its Use in Problem Solving," *Journal of Research in Science Teaching*, **32**(2) (1995) 177–193.
- [31] R. Cervellati, A. Montuschi, D. Perugini, N. Grimellini-Tomasini, and P. Balandi, "Investigation of Secondary School Students' Understanding of the Mole Concept in Italy," *Journal of Chemical Education*, **10** (1982) 852–856.
- [32] S. Novick and J. Menis, "A Study of Student Perceptions of the Mole Concept," *Journal of Chemical Education*, **53**(11) (1976) 171–173.
- [33] M. Freedman, "Relationship Among Laboratory Instruction, Attitude toward Science, and Achievement in Science Knowledge," *Journal of Research in Science Teaching*, **34**(4) (1997) 343–357.
- [34] R. Osborne and M. Cosgrove, "Children's Conceptions of the Changes of State of Water," *Journal of Research in Science Teaching*, **20**(9) (1983) 825–838.
- [35] J. Easley, "The Structural Paradigm in Protocol Analysis," *Journal of Research in Science Teaching*, **11** (1974) 281–290.



# THE LEARNING OF MATHEMATICAL CONCEPTS AND PRINCIPLES THROUGH THE INTEGRATION OF TECHNOLOGY IN LABORATORY ACTIVITIES

---

E. MORERA GONZÁLEZ  
*University of Puerto Rico, Cayey*  
edwinmorera@yahoo.com

## Introduction

The role of educational technology—computers, calculators (scientific, graphing, programmable, and others) Calculator Based Laboratory (CBL), sensors, videodiscs, CD-ROMs, and telecommunication networks through which real data can be accessed—are instruments that aid the learning process in mathematics, and have given teaching an innovative quality, capable of greatly influencing mathematical knowledge and reasoning. Although it is not the solution to teaching and learning problems in mathematics, there is evidence that technology will slowly become a catalyst agent of change in mathematics education [1].

Thanks to the possibilities offered through the dynamic manipulation of mathematical objects in multiple systems of representation within interactive structures, technology opens spaces that allow students to have new mathematical experiences which are hard to achieve in a traditional medium; in which they can manipulate directly mathematical objects within an exploration setting. In considering solutions to problems, such as the approach to the teaching of mathematics and the construction of knowledge as a learning model, some authors [1,2,3] have established that the pedagogical principles that serve as the foundation for the constructivist paradigm may contribute to the integration of new technologies in education. Through this approach, qualitative changes in the nature of learning and teaching in mathematics may be promoted.

## Laboratory Activities as an Option for the Learning of Concepts

The results found in mathematics courses that follow traditional teaching methods, such as the exposition of content as a finished body of knowledge, the theoretical administration of results, and the mechanical solution of problems point toward changes that lead to the consideration of more active methods. Using these methods, students explore, make conjectures and deductions, elaborate justification, test arguments, and understand that the primary responsibility of learning lies within themselves [4]. These ideas are not new, as Polya wrote in

1975, “if learning mathematics is reflected to some degree in the invention of this science, there must be a place in it for intuition, for the plausible inference.” [5]

Through well-designed laboratory activities that integrate technology, students participate actively in the process and construct their mathematical knowledge. In this setting, the students’ task is not to use the technology to make calculations mechanically (this may be done in other settings), but rather to analyze and reason about the results obtained through this technology. To achieve this reflection and reasoning, we must seize the pedagogical advantages it offers. For example, the graphing calculator promotes: speed in computation, visualization, interaction, and learning from mistakes. Besides properties such as its graphing, numerical, symbolic, and programming capabilities, and its ease of use, it allows students to construct processes and mathematical objects which are complemented by the graph to attain higher levels of learning, compatible with a quasi-experimental mathematical presentation [6].

In these laboratory activities, the important element is the active construction process that links new knowledge with prior knowledge, observation, reflection, analysis, argumentation, proof of results, and others, but not the result. Instead of receiving the information in a passive manner, or simply copying the information from the professor or the textbook, students analyze the information in an active way from the start, trying to make sense of it and to relate it with what they already know about the subject. This constructive process is important because unless students construct representations of the new knowledge, making it their own as they paraphrase it and consider its meanings and implications, the learning will be retained only as mechanical and inert memories relatively void of meaning [7]. In this process, the exposition of recipes that are memorized for a brief period is out of place. Learning will be more meaningful through discoveries that occur during explorations motivated by curiosity [8].

In consequence, these laboratory activities should be designed within the framework of guided discovery, through which students are provided the opportunity to manipulate mathematical objects actively and transform them through direct actions. Also, they are designed in such a way that they stimulate students to seek, explore, analyze or process, in one way or another, the information they receive instead of only responding to it. These laboratory activities will be fruitful whenever the following is taken into consideration:

- The complexity of the mathematical content to be taught;



- The complexity of the cognitive processes involved in the learning of mathematics;
- The fundamental role that curriculum designers and faculty should play in the design and implementation of teaching situations which address students' difficulties and needs, and take advantage of technology to create spaces in which students can construct broader and more powerful mathematical knowledge.

A radical change is proposed, from a passive method based on receiving information toward an active method in which mathematical knowledge is constructed. In a setting such as this, the cooperative participation of students is fundamental [9-12]. This setting allows students to interact regularly with many of their peers, to discuss interesting questions about the course and to learn from each other. This is why it is necessary to provide an adequate physical environment where students can carry out these laboratory activities that will lead toward higher levels of learning mathematical concepts and principles.

### **Implementation of Laboratory Activities**

The need of an adequate physical environment for the implementation of laboratory activities refers to more than a room full of the necessary equipment; it is a place where there is an environment in which students can explore the objects they study. It should be a place where students have the freedom to comment, ask questions, and make conjectures about the course matter. In this environment, the professor is available to serve as a facilitator who offers students the opportunity to verify their analysis, so that they may identify mistakes in their reasoning for themselves and generate feedback on their own knowledge. This is the way that they construct and reconstruct the object of the learning process.

The physical environment must fulfill the conditions that allow students to carry out their work, *without unnecessary* distractions, and promote the interaction of ideas among peers, the professor, and teaching assistants. As the students set the process of the scientific method in practice through the laboratory activity, they construct high level mathematical knowledge.

### **Considerations for Writing a Laboratory Activity**

The preparation of a laboratory activity requires more elaboration time to achieve the exploration and discovery of a concept. The following are some general considerations that provide guidance for writing a laboratory activity [13].

1. According to the proposed objectives, the laboratory activity should fall into one of the following categories:
  - Developed before the presentation of a topic: the activity should be initiated with a problem that stimulates discussion. The discovery of concepts belongs to this type.
  - Those that include interesting applications with data that have not been manipulated because of the extent of the calculations. Questions about analysis and interpretation of the obtained results are suggested so that the experience is not reduced to a simple numerical calculation. An example of this is the laboratory in which a phenomenon is modeled and the characteristics and properties are explored.
  - Those in which the content presented is broadened or reinforced in class. The professor can provide questions to motivate the analysis of the situation and help students to observe and predict or make conjectures about the results, according to the topic previously explained.
2. It is imperative that professors master the content of the class very well, even more than if it were an expository class, so that they can provide adequate answers to questions that emerge during experimentation.
3. The problems to be studied should be carefully selected so that they are not too easily solved, but require analysis of the situation, besides being interesting and pertinent for students.

Example: Representation systems<sup>1</sup>

The use of technology allows the dynamic handling of multiple representation systems of mathematical objects. This is one of their relevant characteristics from the perspective of learning mathematics. Representation systems are a central aspect of the students' understanding of mathematical objects and their relations, as well as the mathematical activities that they perform when they carry out tasks that have to do with these objects [8,9,10]. External representations allow the student to organize mathematical experiences and to organize the information internally. From this perspective, a representation system is composed of a set of symbols that are manipulated according to rules that identify or create characters, operate within them, and

---

<sup>1</sup> The complete laboratory is very long, so only a brief description is included.

determine relations among them. The same mathematical object can be represented by different representation systems.

We have developed a laboratory where the student manipulates the symbolic representation, the graph, and the table of values of a quadratic function. The function  $f(x)=x^2+5x-6$  is represented by students in the symbolic representation system, in the graphic representation system, and in the value table representation system (see Figure 1), among others.

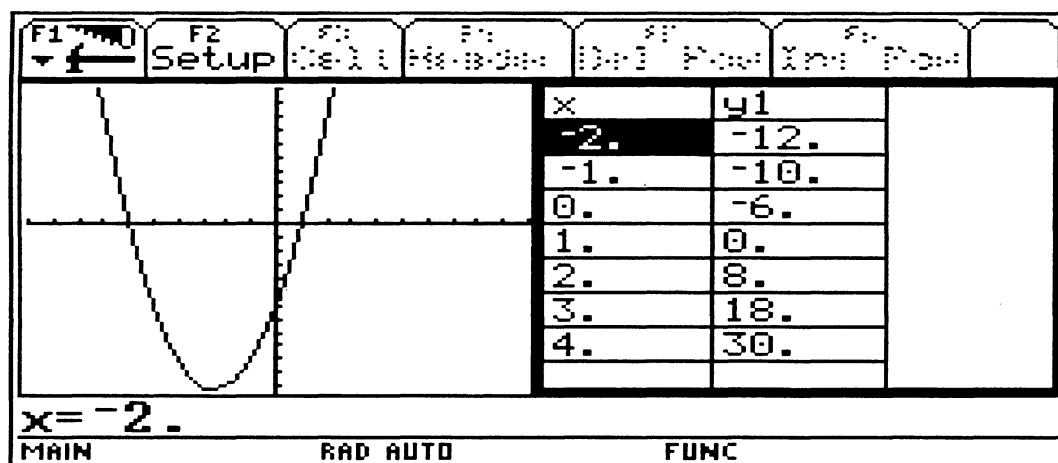


Figure 1.

The idea of representation makes it possible to characterize the students' activities as they carry out the task. The laboratory is designed so that students do syntactic transformations within the same representation system. They transform  $f(x)=x^2+5x-6$  into  $f(x)=(x-1)(x+6)$  or into  $f(x)=(x+2.5)^2-12.25$  in the symbolic representation system; they also transfer the graph horizontally or vertically or when the dilation in the graphic representation system varies. The second type of mathematical activity that students perform in the laboratory is the translation between representation systems. That is, the relation of the function on the graphic as it goes from the base symbolic representation  $f(x)=x^2$  to the expression  $f(x)=(x+2.5)^2-12.25$  (in which it is possible to identify the localization of the vertex) or to the expression  $f(x)=(x-1)(x+6)$  (in which the roots may be located).

In this way, students handle procedurally the representation systems and this action serves as a base for evolving into a conceptual understanding of the mathematical object and the

mathematical relations. Student understanding evolves along two axes: one axis is horizontal along which the management of the representation systems advances from a mathematical concept; along the second axis advancement is made in the materialization process (from procedural to conceptual) of the same concept [14].

### **Final Comments**

During the past few years, several groups have recommended the use of new educational technologies for the learning of mathematics. Some authors have pointed out that the sustained use of technology in the classroom will convert it into a setting where the student discovers, formulates conjectures, justifies and tests arguments. Our experience has been to use these laboratory activities as an additional experience to the traditional classroom.

The development of these activities takes up more time and effort, since the needs of the students must be considered. From this viewpoint, the textbook becomes one more reference and the professor becomes less dependent on it.

The results with future teachers found in the integration of these laboratory experiences in their mathematics classes are heartening. The level of the type of questions they pose is higher than the traditional ones. The students become familiar with the way in which mathematical knowledge is constructed, promoting the compression of the epistemology of the knowledge area they will teach. The evaluations of these activities by students have been positive. In focus groups carried out with students, they have expressed that: “when I’m in the classroom as a teacher I will follow this methodology”; “I like the laboratory activities because they are more active than in the traditional class”; “the use of the graphing calculator allows us to do the analysis faster and I have more time to understand the material.”

Technology is obviously not the solution to teaching and learning problems in mathematics, but it is making us think about it. It is possible that the major contribution of technology to the teaching and learning process of mathematics consists of the interaction between it, the professor, and the student and this is changing the vision that students have of mathematical content and the educational process. ■

**Bio**

Edwin Morera González is a professor in the Department of Mathematics-Physics at the University of Puerto Rico, Cayey. His topic of interest is the integration of technology to the learning of mathematics, in particular the graphing calculator.

**References**

- [1] P. Gómez, *Tecnología y Educación Matemática: una empresa docente*, Grupo Editorial Iberoamérica, Mexico, 1998.
- [2] R. Oliveros, "El efecto de la calculadora en la enseñanza de matemáticas," *Memorias Décima Reunión Centroamericana y del Caribe*, Puerto Rico, 1996.
- [3] M. Solís, "Profesores, matemática, enseñanza y tecnología: estudio sobre la aceptabilidad de la supercalculadora como recurso didáctico," *Memorias Octava Reunión Centroamericana y del Caribe*, Costa Rica, 1994.
- [4] E. Morera, "Cambio de Paradigma en el Proceso de Enseñanza-Aprendizaje de las Matemáticas: Del Conductismo al Constructivismo," Conferencia presentada en la Semana de las Matemática del Colegio Universitario de Cayey, Cayey, PR, 1998.
- [5] G. Polya, *Matemáticas y razonamiento plausible*, Editorial Tecnos, Madrid, 1975.
- [6] I. Lakatos, *Pruebas y Refutaciones. La lógica del descubrimiento matemático*, Alianza Editorial, Madrid, 1982.
- [7] T. Good, and J. Brophy, *Psicología Educativa Contemporánea*, Longman Publishing Group, New York, 1996.
- [8] F.A. Hitt, "Representaciones Mentales y Visuales en el Aprendizaje de Conceptos Matemáticos," Conferencia dictada en el Colegio Universitario de Cayey, Puerto Rico, 1998.
- [9] C. Janvier, *Problems of Representation in the Teaching and Learning of Mathematics*, Lawrence Erlbaum Associates, Hillsdale, 1987.
- [10] J.J. Kaput, "Technology and Mathematics Education," in D.A. Grouws (ed.), *Handbook of Research on Mathematics Teaching and Learning*, Macmillan, New York, 1992.
- [11] J. Bruner, *School for Thought: A Science of Learning in the Classroom*, MIT Press, Cambridge, MA, 1993.
- [12] E. Cohen, *Designing Group Work: Strategies for a Heterogeneous Classroom*, Teachers College Press, New York, 1986.
- [13] T. Good, M. McCastlin, and B. Reys, "Investigating work groups to promote problem solving in mathematics," in J. Brophy (ed.), *Advances in Research on Teaching: Vol. 3, Planning and managing learning tasks and activities*, JAI Press, Greenwich, CT, 1992.
- [14] D. Tall, "Computer Environments for the Learning of Mathematics," in R. Biehler, et al. (eds.), *Didactics of Mathematics as a Scientific Discipline*, Kluwer, Dordrecht, 1994.



# **THE DESIGN, IMPLEMENTATION, AND ASSESSMENT OF A NEW CAPSTONE COURSE AIMED AT SCIENCE EDUCATION MAJORS**

---

R. BETANCOURT and J. ARCE

*Dept. of Chemistry, University of Puerto Rico, Rio Piedras*  
rbetanc@upracd.upr.clu.edu, j\_arce@upr1.upr.clu.edu

## **Abstract**

This paper rationalizes the selection of the concept of energy as the central theme of a new capstone course aimed at science education majors. It describes the goals of the course and the activities that preceded the course design and led to the selection of the topics, of the educational materials, and of the teaching methodologies. It presents a sequential description of the manner in which the conceptual knowledge of energy was to be developed. The specific experiments, interactive demonstrations and other educational materials utilized for the conceptual development of the concept of energy in context are described and referenced. The course objectives are described, as well as the instruments utilized to assess student learning. It also presents the activities utilized to assess the course, in addition to the modifications made to the course syllabus based on this assessment.

## **Introduction**

The reform of teacher preparation programs must be harmonized with the reforms being carried out at the K-12 level. The communication among all the sectors involved in the science and mathematics reform is mandatory in order to ensure the same vision and clear and complementary objectives. For this reason, we started the reform of our teacher preparation programs, by first looking at the K-12 science and mathematics reform that had been going on for several years. We found that important documents have been developed; one of which, the Science Content Standards, was of particular interest. These local science content standards are based on macro concepts that cut across all the scientific disciplines, thus giving a more integrative and interdisciplinary approach to the teaching of science. The seven local Science Content Standards are: (1) The Nature of Science, (2) The Structure and Organizational levels of Matter, (3) Systems and Models, (4) Energy, (5) Interactions, (6) Conservation and Change, and (7) Science, Technology, and Society. Of these standards, we selected Energy as the main theme of a capstone course because it is a fundamental and important concept that teachers find difficult to teach [1-3]. Furthermore, examples of the concept of energy are very familiar and relevant to our students in the areas of chemistry, physics, biology, and earth sciences. While Energy was the concept selected for development in this course, Energy is not the only Science Content Standard we wanted to address. The course aimed to cover some aspects of all the Standards,

especially The Nature of Science, Systems and Models, Interactions, Conservation and Change, and Science, Technology, and Society.

In the design of the capstone course, we took into consideration that it would be taught at an advanced level where students could bring together the knowledge and skills developed during the courses of the core curriculum in a coherent, meaningful, relevant, and applicable way. Students would have prior knowledge of the fundamental concepts of energy in the different areas of science.

We considered that the capstone course could help students develop their ability to transfer knowledge from one science discipline to another. It could also give them the opportunity to apply different teaching methodologies and strategies in a teaching situation in which they will receive constructive criticism from peers and faculty. In addition, a capstone course could give them the opportunity to assess their level of understanding of fundamental concepts, help them identify their misconceptions, and motivate them to work on improving their knowledge and ability to develop conceptual understanding with their students, once they become teachers.

### **Designing the Course**

The first step in the conceptualization of the capstone course was the selection of energy as the central theme. The second step was to select the topics to be studied. These had to be relevant and already discussed in the introductory chemistry, physics and biology courses; major topics that encompass elements from the different disciplines. We understood that this topic selection would be conducive to an increase in students' motivation to gain a more in-depth and meaningful understanding of the concept of energy. Before making the final selection, we consulted professors in introductory science courses to identify the context in which they covered the forms, manifestations, and transformations of energy. Small, informal meetings were held with physics, biology, chemistry, and earth science professors. We asked them to identify the sections in the textbooks where energy concepts were discussed. We studied these materials to gain an understanding of students' previous knowledge of energy. Research in an extensive library and on the Internet was also conducted to identify websites of energy-related sources. The following topics were selected to be covered in the course: the development of a high-energy sports drink; human metabolism; energy saving light bulbs; photosynthesis; cellular respiration; alternatives to fuel energy; the occurrence of earthquakes; and, global warming and the formation



of hurricanes. These topics are relevant to daily life, fundamental to the scientific understanding of our world, and discussed in previous courses.

The third step was to select the course's curricular materials. Chemistry, biology and physics professors that teach the introductory courses recommended curricular materials that could be used to explore, experiment with, or apply the fundamental concepts. Some of these professors designed new experiments and activities. Again, we researched the Internet and the library for books, videos, CDs, case studies, articles, and laboratory experiments related to the selected topics, and made a selection of these materials. We also developed interactive demonstrations and identified short investigations for students to perform.

Another very important activity was the selection of the teaching methodologies and strategies that would be used in the course. We decided to use the inquiry and constructivist approach and to model scientific research. We felt that by doing so we would be promoting active learning, critical analysis, and in-depth understanding of the underlying concepts, as well as addressing the other content standards. The course was conducted as a workshop to promote student participation and continuous self-assessment of knowledge. The professor introduced the fundamental concepts by modeling the best content-specific teaching methodologies and the proper use of educational technology. Group presentations, based on the application of conceptual knowledge to the solution or interpretation of problems encountered in real life situations, were an integral part of the course. These presentations gave students the opportunity to use new technology and to apply different teaching strategies to a class composed of peers and professors, who provided immediate feedback on their teaching strategy and selection of materials.

Another very important aspect was to decide on the previous science courses that students should have taken. We felt that in order to develop an understanding at the microscopic level of the macroscopic manifestations of energy, students needed to know the principles that govern the physical and chemical aspects of matter and the role of plants and animals in ecological systems. At our university, this knowledge is gained in the following two-semester courses: *General Chemistry*, *General Physics*, and *General Biology*. In addition to requiring these basic science courses, we also decided to require the first semester of *Organic Chemistry*, specifically because it introduces infrared spectroscopy and the oxidation/reduction reactions that occur in the metabolism of organic molecules in nature.

### The Course Sequence

The sequence of the topics discussed in the course and how they are interrelated is presented in Figure 1 and Table 1, respectively. Initially, the basic principles of kinetic and potential energy were introduced. They were elaborated by means of semi-Socratic discussions and hands-on group activities where students needed to delve into their conceptual understanding instead of the mathematical algorithmic manipulation of equations. Familiar and simple examples were extracted from everyday life and then analyzed and studied in depth, from the macroscopic to the molecular level. Using this same teaching methodology, we developed more complex aspects of energy, such as heat transfer, absorption and emission of electro-magnetic radiation, and conservation and transformation of energy. As the course progressed, topics from biology, physics, chemistry, and earth sciences were discussed and analyzed building on the deep conceptual understanding developed early in the course. The principle activities utilized to introduce and develop the concepts related to energy to a very deep level of conceptual understanding are included in the table. As part of this process, groups of students were assigned special projects that required small investigations. Students presented the results of their investigations, emphasizing the energy principles relevant to their project. The topics of some of these investigations are included in Table 1.

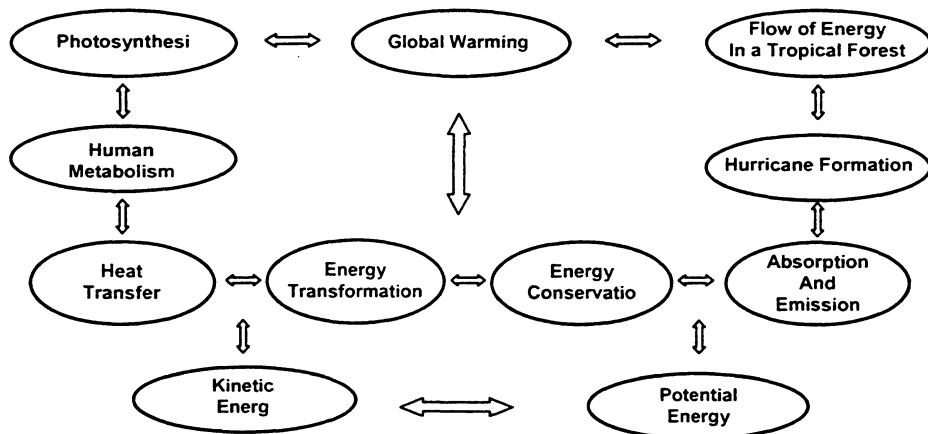


Figure 1. How are topics interrelated?

**Table 1.** The sequence of topics and examples of activities carried out to develop the concepts.

Topic	Emphasis	Activities
Potential and Kinetic Energy	Types of Energy  Interchangeability and conservation	Demos: Bouncing ball; free fall of a piece of paper in flat and crumpled forms; storing and releasing energy in a mousetrap. Videos: Free fall of a vault jumper; a person in weight training; and, the free fall on the Moon of two objects with same mass but different shapes [4]. Student Investigation: Should we use high efficiency bulbs? Why are they more efficient than conventional bulbs? Student Investigation: Based on your weekly caloric intake and exercise, will you gain weight eventually?
Heat and Heat Transfer	Difference between heat and temperature  Conduction of heat  Specific heat	Joule's experiment of the mechanical equivalent of heat [5]. Demo: Heating of naphthalene to its melting point. Experiment: Determination of the Heat of Fusion of ice [6]. Experiment: Determination of the specific heat of two objects (metal and rubber) with the same mass.  Experiment: The determination of the temperature of water heated above 50° C with a thermometer that reads from 0-50° C [7].
Heat Transfer	Conduction, convection, and radiation	Demo: The burning candle [8] experiment: Selection of the most efficient cooking pot amongst three of different metal compositions [9].
Capture of Radiant Energy from the Sun	Absorption of ultraviolet, visible, and infrared light  Why is photosynthesis a spontaneous process?  Storage of energy in chemical bonds	Experiments: Absorption of visible and infrared light by various atmospheric gases [10]. Experiments: Identification of compounds that absorb radiation in the processes of photosynthesis, hurricane formation, and global warming. Field Study: Flow of Energy in a Tropical Ecosystem <sup>1</sup> . Student Debate: According to Scientific Research - Is Global Warming Real?
Human Metabolism of Fats, Proteins, and Carbohydrates	Transformation of energy  Chemical bonds as a source of energy	Student Investigation: Why are carbohydrates a faster source of energy than proteins or fats? [11]  Student Investigation: What is the role of each of the components of the sports drink Gatorade®? [12]

<sup>1</sup>Unpublished exercise by Patricia Burrowes, Ph.D., Assistant Professor in the Dept. of Biology, University of Puerto Rico, Rio Piedras.

### **What are the Course's Objectives?**

We are aware that upon graduation these students will teach their students the fundamental ideas of the Energy standard. In order to do so, they have to develop an in-depth conceptual understanding of these ideas and they must be able to carry out activities that are conducive to that understanding. With this in mind, the following objectives were developed. After completing the course, students should be able to:

- Base their understanding of energy on the few universal laws that describe and explain the manifestations of energy;
- Distinguish between the forms of energy: potential (gravitational, chemical, elastic, electromagnetic, and mass) and kinetic (heat, moving objects, sound, and waves) in various complex contexts;
- Identify the modes in which the forms of energy are manifest in chemical bonds, electromagnetic waves, photosynthesis, and atmospheric phenomena;
- Determine whether on-line information is valid;
- Lead a discussion on a scientific topic utilizing critical thinking skills, valid data, respect for opponents' ideas, and ethical principles;
- Describe at an atomic and molecular level, the physical, chemical, and biological changes that occur during the transformation of energy;
- Predict the spontaneity of the transformations of energy;
- Estimate and compare the magnitude of the forms of kinetic and potential energy;
- Describe the combinations of the forms and transformations of energy that occur in complex processes such as photosynthesis and hurricane formation;
- Apply conceptual knowledge of energy to the solution or interpretation of problems encountered in real life situations.

### **How Did We Assess Student Learning?**

We developed a strategy to assess the impact of the course based on students' progress. The grade was skewed to give more weight to students' progress in the mastery of the fundamental concepts as they were developed in an ascending spiral. Weekly quizzes, laboratory reports, presentations, and a debate were used in the assessment process. Pre- and post-concept maps served the same purpose of assessing depth of conceptual understanding and student ability to establish interconnections among disciplines. A final exam that required in-depth analyses of all the energy transformations involved in familiar complex situations—for example, the

generation of electrical energy from flowing water—was part of the assessment. When we analyzed students' answers, we found that their conceptual understanding had improved considerably. To our disappointment, we also found that some basic misconceptions still lingered, in agreement with other results reported in the literature on conceptual change [13-16].

### **How Was the Course Assessed?**

We developed various instruments to assess the impact of the course in the development of students' conceptual understanding of energy principles. Initially, we probed the knowledge students brought from other courses and their attitude toward the study of science. The assessment of conceptual understanding was carried out with a concept map, and the attitude toward science with a modified version of the Maryland Collaborative for Teacher Preparation's questionnaire: *Attitudes and Beliefs about the Nature of and the Teaching of Mathematics and Science* [17]. The initial concept map revealed very poor connections between basic concepts and their relationship to macro concepts in the areas of photosynthesis and the greenhouse effect. Quizzes were carefully prepared to assess the progress of conceptual understanding throughout the course. These quizzes were targeted to measure the level of attainment of specific objectives that we developed in the course in a spiral-ascending mode. Students were actively involved in the assessment process since they were well aware that this was a pilot course. After every three-hour session, we reflected as a group on the class experiences. In these reflections, students identified areas where they still had difficulty, topics that they found irrelevant, and areas that were not covered in the course but that they thought should be included. The teaching methodologies used were assessed in a similar manner. At the end of the semester, a post-conceptual map was administered and it revealed significant improvement in the comprehension of the interrelationship of the basic principles and the macro concepts studied in the course. A significant improvement was also observed in students' attitude toward learning science. The details of how we conducted this thorough assessment is the object of another article soon to be published.

### **Modifications**

The information gathered led us to modify the course for the future in a variety of ways. We will not use a textbook and will refer students to selected chapters in books on physics [13], biology [18], biochemistry of metabolism [10], physiology [19], meteorology [20], and physical sciences [5]. We will supplement this material with articles from journals and websites [12, 21-30]. The sequence of topics will also change: radiation will be studied before photosynthesis; metabolism before the composition of Gatorade; and heat transfer on earth before hurricanes. In

addition, we plan to eliminate topics such as alternative sources of fuel energy, earthquakes, and cellular respiration [31-33]. Based on the finding that some misconceptions on energy transformations persisted, we will include more hands-on activities. Although students were given guiding questions on which to base a debate on global warming, we found that this topic is so complex, and there is so much information, that it was difficult for students to focus on the main issues. We have made a selection of articles and have identified specific topics that students should address in their debate. Students will have this information to help them prepare for the debate. ■

### Bios

Rosa Betancourt-Pérez is a professor in the Department of Chemistry at the University of Puerto Rico, Río Piedras. She teaches the organic chemistry course that the future science teachers must take and the capstone course which is the subject of this paper.

Josefina Arce is a professor in the Department of Chemistry at the University of Puerto Rico, Río Piedras and is Principal Investigator of the Puerto Rico Collaborative for Excellence in Teacher Preparation. She teaches general chemistry and co-teaches the described capstone course.

### References

- [1] R. Trumper, "Being constructive: an alternative approach to the teaching of the energy concept," *International Journal of Science Education*, **12**(4) (1990) 343-354.
- [2] K.S. Taber, "Energy—By Many Other Names," *School Science Review*, **70**(252) (1989) 57-62.
- [3] D.M. Watts, "Some Alternative Views of Energy," *Physics Education*, **18**(5) (1983) 213-217.
- [4] R. Hoffman, "The Conservation of Energy" [Videotape], *The Mechanical Universe and Beyond Series*, Annenburg CPB Collection, 1987.
- [5] R.M. Hazen and J. Trefil, *The Physical Sciences - An Integrated Approach*, John Wiley and Sons, New York, 1996.
- [6] J. Arce and R. Betancourt, "Student-Designed Experiments in Scientific Lab Instruction," *Journal of Research in Science Teaching*, **27**(2) (1997) 114.
- [7] J. Trefil and R.M. Hazen, "Measuring Temperature With Only Limited Means," *Laboratory Manual, The Sciences-An Integrated Approach*, John Wiley and Sons, New York, 1998.
- [8] M. Faraday and J. Wong, *The Chemical History of a Candle*, Cherokee Publishing Company, 1993.

- [9] J.I. Selco, "Cooking Efficiencies of Pots and Pans (EQE)," *J.Chem. Educ.*, **71** (1994) 1046.
- [10] S. Anthony, T. Brauch, and E. Longley, "What Should We Do About Global Warming?" *Chem Connections*, John Wiley and Sons, New York, 1998.
- [11] M.C. Linder, "Energy Metabolism, Intake and Expenditure," *Nutritional Biochemistry and Expenditure*, Elsevier, New York, 1991.
- [12] M.E. Hermes, *Case Study: The Development of Gatorade*, Internet: <http://science.kennesaw.edu/~mhermes/concept.htm>
- [13] G.J. Posner, et al., "Accommodation of a Scientific Conception: Toward a Theory of Conceptual Change," *Science Education*, **66** (1982) 211-227.
- [14] A. Lightman and P. Sadler, "Teacher predictions versus actual student gains," *The Physics Teacher* **31** (1993) 162-167.
- [15] M. Nissani, "Phases of the moon: a guided discovery activity for clarifying the nature of science," *Science Activities* **31** (1994) 26-29.
- [16] E.P. Solomon, "Photosynthesis," *Biology*, Saunders, USA, 1999.
- [17] J.R. McGinnis, G. Shama, A. Graeber, and T. Watanabe, *Development of an instrument to measure teacher candidates' attitudes and beliefs about the nature of and the teaching of mathematics and science*, Paper presented at the Annual Meeting of the NARST, Oak Brook, IL, 1997.
- [18] P.P. Urone, "Work, Energy and Power," *College Physics*, Brooks/Cole, USA, 1998.
- [19] F.H. Martini, "Metabolism and Energetics," *Fundamentals of Anatomy and Physiology*, Prentice Hall, USA, 2001.
- [20] C.D. Ahrens, "Energy: Warming the Earth and the Atmosphere," *Meteorology Today*, USA, 1994.
- [21] R. Kerr, "Warming's Unpleasant Surprise: Shivering in the Greenhouse?" *Science*, **281** (1998) 156-158.
- [22] T.L. Delworth and T.R. Knutson, "Simulation of Early 20th Century Global Warming," *Science*, **287** (2000) 2246-2250.
- [23] J. Hansen, "A Common-Sense Climate Index: Is Climate Changing Noticeably?" *Proc. Natl. Sci. USA*, **95** (1998) 4113-4120.
- [24] C. Suplee, "Unlocking the Climate Puzzle" *National Geographic*, **193**(5) (1998) 38-71.

- [25] F. Joos, et al., "Global Warming and Marine Carbon Cycle Feedbacks on Future Atmospheric CO<sub>2</sub>," *Science*, **284** (1999) 464-467.
- [26] P.D. Jones and T.M.L. Wigley, "Global Warming Trends," *Scientific American*, (1990) 84-9.
- [27] J.D. Mahlman, "Uncertainties in Projections of Human-Caused Climate Warming," *Science*, **278** (1997) 1416-1417.
- [28] J.L. Daly, *Still Waiting for Greenhouse*, Internet: <http://www.john-daly.com>
- [29] *Top 10 Global Warming Myths*, Internet: <http://www.coaleducation.org/issues.top10.htm>
- [30] *Global Warming: Fact vs. Myth*, Internet: [http://www.environmentaldefense.org/pubs/FactSheets/e\\_GWFact2.html](http://www.environmentaldefense.org/pubs/FactSheets/e_GWFact2.html)
- [31] D.P. Reagan and R.B. Waide, *The Food Web of a Tropical Forest*, The University of Chicago Press, Chicago, IL, 1996.
- [32] T.D. Schowalter, "Invertebrate Community Structure and Herbivory in a Tropical Rain Forest Canopy in Puerto Rico Following Hurricane Hugo," *Biotropica*, **26** (1994) 312-319.
- [33] M.E. Power, "Top-down and Bottom-up Forces in Food Webs: Do Plants have Primacy?" *Ecology* **73** (1992) 733-746.



# CREATIVITY VS. STRUCTURE: A CHALLENGE IN DISCOVERY CHEMISTRY

---

R.S. LAMBA

*University of Puerto Rico, Cayey*

*I would do away with introductory chemistry lectures completely and build a first year (chemistry) course entirely around experiments*

Harry B. Gray

ACS Priestley Medalist (1990)

## Introduction

Traditionally in most institutions of higher education, chemistry is considered to be a very structured and vertical subject matter. In addition, practitioners of science have been preaching that creativity has been bestowed on only a few selected minds. Instruction is still characterized by a model in which the teacher discusses the material, tests the students on this material, and then turns to the next topic. To combat this situation, innovations and proposals soar, sweeping reforms are adopted, yet ultimately, most teachers return to textbook-based instruction, or the "talk-and-chalk" method.

During the last decade or so, hundreds of published studies and reports have come to the same conclusion: *The educational foundations of our society are presently being eroded by a rising tide of mediocrity that threatens our very future as a people.*

As chemists, we agree that the laboratory component is crucial and an essential part of the curriculum. However, in most situations we find that:

- there is little coordination between the laboratory and other aspects of the course;
- in a typical experiment, neither students nor their instructor have any doubts about the outcome; the only question unanswered is the extent of agreement between the students and the "correct answer";
- in the laboratory, the students "mimic" or go through the physical movements of various techniques without involving thinking skills;
- the curriculum is "a random assortment of arcane facts."

Since we teach the way in which we were taught, we should not be surprised that the faculty repeats the same process with their students. Effective science teaching has proven to

center around laboratory experience where the students "discover" scientific concepts through experiments [1]. This curriculum reform using the discovery approach has been developed primarily for the future teachers, in which they become part of the process by participating first-hand in an investigation.

### **Science as the Process of Discovery**

The constructivist theory [2-5] predicts that hands-on activities can play an important role in learning because students are actively involved in the process of constructing science. To be successful, the hands-on activities should be characterized by a process in which the students discover something about their daily life, rather than merely confirming or verifying something they read in a textbook; in other words, activities that more accurately reflect the process by which students can practice and develop critical thinking skills used by research chemists while constructing chemical knowledge.

The design of these activities, however, must avoid the trap into which so many traditional laboratory courses have fallen—a trap characterized by experiments that tell the students what they are expected to learn, and implemented in an environment in which students come to the lab, read the appropriate section of the lab manual, make a series of observations or collect experimental data, record these observations or data, and then go home.

Science is a creative endeavor and, therefore, it is important to remove as much as possible the "recipes" that often appear in general chemistry experiments. The experiments should provide information and guidelines rather than "recipes" or procedures as appropriate.

Because the goal of these activities is to actively engage students in the pursuit of deep understanding, to be successful they must be developed within a framework that permits a proper balance between a structured laboratory activity and opportunities for students' creativity. Our curriculum for the basic chemistry courses prepared for the future teachers recognizes the fact that our students are not familiar with this approach. Furthermore, the integration of content with pedagogy using the discovery method is an integral part of our teaching learning process.

### **The Project**

Over about the last ten years, we have developed a project with grants from the National Science Foundation (Grant # DUE-9354432) and the U.S. Department of Education-MSEIP

(Grant #P120A30018). The instructional format utilizes hands-on activities and the discovery (inquiry) approach using locally available, low-cost materials and equipment, and integrates the content and the pedagogy. Instead of merely rearranging the order of presentation, adding new, presumably exciting topics, and eliminating subject matter that is deemed unnecessary or uninteresting, we decided to make the laboratory activity the centerpiece of the learning experience.

The laboratory-centered instruction utilizes experiences where the student discovers concepts which are designed to illustrate the experimental basis for science. These experiences do more than just introduce students to fundamental techniques and lab procedures; they also contain hypothesis formation, data gathering, analysis, and hypothesis testing stages. Concepts introduced through laboratory activities are then followed by classroom discussions building on the experimental nature of science.

### **The Motivation for Developing Discovery Labs**

Several years ago, the Committee on Professional Training of the American Chemical Society (ACS) came to the following conclusions:

The continued decline of student interest in science and mathematics is held by many to emanate from ills attributed to introductory courses. In chemistry, the introductory courses are often seen as needlessly dull and difficult, and more a barrier than an entrance to the subject.

Most institutions are not immune to this problem. Although overall enrollment in science courses is generally stable, only about 10% of science majors actually complete their chosen degree program. This can be understood by noting that introductory chemistry courses are required for all science and education majors, but almost 50% of the students in general chemistry either drop the course or receive grades of "D" or "F."

The students enrolled in general chemistry believe that the courses contain a series of abstract concepts for which they can find no applications outside of the classroom. A study of the faculty in the chemistry departments generally reveals that a great majority teach the way they have been taught: use traditional "talk-and-chalk" teaching styles, and use the laboratory to verify the concepts and principles covered in lectures.

After a quick study of the chemistry departments of most institutions in Puerto Rico, it was found that:

- the curriculum is traditional and taught in a classical manner; it relies heavily on lectures and textbooks to present material. The laboratory is being relegated to the role of verifying principles covered in lectures and, while this was an efficient way to cover concepts and facts, it didn't expose the student to the basic processes of chemistry;
- we must find a way to ensure a more active participation by every student.

We are convinced that the problems with the introductory courses cannot be solved by changing the order of presentation of topics, or by adding new, presumably more exciting topics. It requires a different perspective on teaching chemistry, in which **the laboratory should be the centerpiece of the students' learning experience**; whereby, concepts are introduced in the laboratory and then discussed after the laboratory activity is completed. This could only be achieved with an investigative approach, which involves the students in questioning, forming hypotheses, observing, testing, designing experiments, organizing and seeking patterns in data, developing qualitative and/or quantitative analysis of data, forming concepts, and communicating results in a scientific manner. In this approach, the instructor is no longer an authority figure who acts as the primary source, but as a guide in a situation where students discover concepts for themselves. In other words, the classroom should have a constructivist environment.

### **The Framework**

The basis of all the laboratory activities is the learning cycle. In each activity, the students have an opportunity to explore, and possibly with the help of the instructor, discover the concept in the context of their daily life. Emphasis is placed on the nature of science, the context, and the applications of science.

### **The Curriculum**

A series of student-tested laboratory activities have been developed for use in general chemistry courses. The experiments have the following characteristics:

- each experiment has a student manual and a teacher's guide;
- the students are given the information they need to carry out (and in some cases design) the experiment;

- they are given guided exposure to specific laboratory techniques and help to lead them to develop for themselves an understanding of significant chemical concepts;
- they are given questions for discussion that ask them to think about the analyses of the data and implications of the experiment they performed or the data they collected;
- a key objective is to learn how to approach a particular problem while gaining appreciation for the practical applications of chemistry. Relevant application questions are included as "Extensions and Applications."

### **The Philosophy of Discovery**

The goals of these experiments are to achieve a balance between the process and content of chemistry, to show chemistry as it is done by practicing chemists, within an environment in which students build conceptual knowledge.

The experiments are not linked to a particular textbook, or even style of text. The goal in developing these experiments is to link many instances, one laboratory experience to another. However, sufficient guided inquiry directives within every experiment for both safe and successful learning outcomes are provided. In this sense, the user can perform selected individual experiments in any order.

The nature of the discovery approach to chemistry might be best understood by examining the following series of experiments that begins with the discovery of differences between "copper" pennies minted before or after 1982. These provide the basis for discussions of stoichiometry and limiting reagents, builds a quantitative model of the relative activity of the different metals, and then uses the chemistry of these elements to introduce both corrosion and chemical kinetics. Each experiment starts with a question stated in a practical context. Examples are:

- Are All Pennies the Same?
- How Much is Enough?
- How Much is Too Much?
- Using Metals to Make Electricity.
- Which Metal is More Active?

- Why is a “Harley” Chrome Plated?
- Why Did My Watch Stop Suddenly?

### **The Format of Discovery Labs**

To sustain interest and foster curiosity, the student manual for these modules contains only the basic information needed to do the activity: an introduction, objectives, list of materials and procedures, explicit safety directives, observations, data analysis. This information guides the students through the process of organizing the data in a manner that is logical to them in the stages of hypothesis formation and hypothesis testing, and results and conditions.

The teacher’s guide is also a central feature of each experiment and contains the following sections: a detailed introduction, concepts developed through the experiments, skills used, materials and chemicals needed, safety, anticipated results and comments, extensions, and global time.

The experiments are designed in the spirit of team learning and collegiality to maximize the contributions peers can make in improving learning and chemical understanding. Ten topic units which are common to most general chemistry courses have been developed. Examples are: scientific method, stoichiometry, gases, and oxidation reduction. Each unit contains two to three experiments with the characteristics described earlier.

### **The Approach**

A curriculum reform through laboratory-driven instruction has been designed and developed for the teacher preparation program in order to give students a feeling of the reality of science by an encounter with phenomena. Regardless of the exact nature of the program, it is necessary to find a proper balance between a structured laboratory environment and opportunities for student learning and creativity.

The laboratory is used inductively—to introduce concepts, which are further developed in post-lab discussions. This is achieved through an investigative approach, which actively involves the students. In this process, the instructor acts as a facilitator who assists in the process in which the students discover concepts for themselves. In other words, the laboratory provides a constructivist environment.

The key feature of the laboratory-driven courses is the discussion that occurs when student-generated data are combined. This can be facilitated through the use of a low-cost computer interface which pools student data and projects these data on a television monitor [6].

Students create knowledge from experimental evidence in a post-lab discussion session. The role of the instructor is important in this process; for example, by suggesting graphical analysis or another experiment, thus breaking complex questions into a series of simpler steps and allowing student creativity to match their level of sophistication. In the discovery curriculum, the instructor remains a central figure, guiding and choreographing the activity.

The nature of the curriculum materials developed might best be understood through the following example.

### **Sample Experiment: How Long Can a Bubble Last?**

A typical experiment begins with a question. The objectives include an investigation in a scientific manner by studying the effect of varying conditions (soap concentration, its temperature, bubble size) on the time that a bubble lasts [7,8]. Further, students are asked to design an experiment for determining the effect of different surfaces on bubble longevity.

#### *The Effect of Concentration*

Students are provided with four soap solutions of different concentrations and asked to practice with one of the solutions to blow bubbles. They are asked to predict what should happen to the lifetime of the bubble as the concentration of the soap is increased. (Most students predict that as the concentration of the soap solution increases, the time taken for the bubble to burst [its lifetime] also increases.)

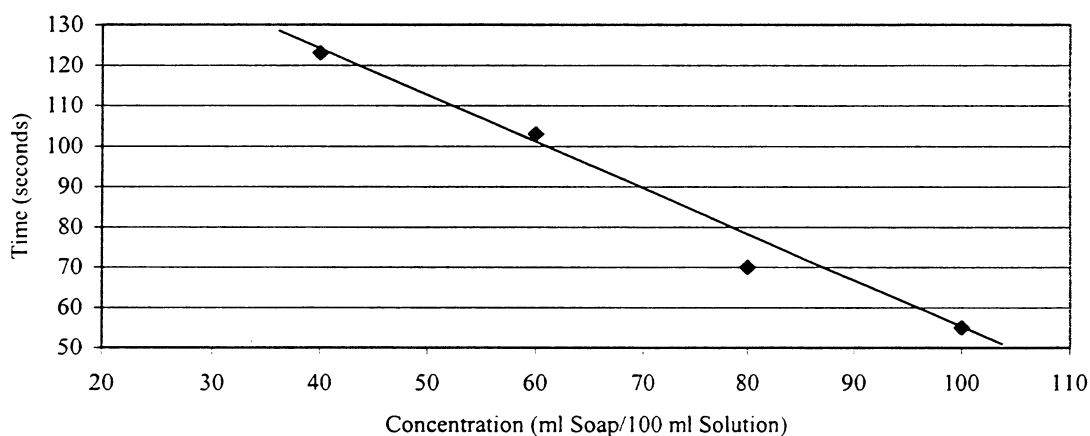
Then, instructions call for blowing bubbles of a known diameter on a flat laboratory surface using 1 ml of a liquid soap solution (Dawn® works best in our experience). They work in groups of two and record the instant the bubble bursts. They repeat their observations with all four concentrations until they get consistent results.

Each group collects its data and then all data are displayed for discussion. Each group's prediction is compared with the class data:

Concentration (ml soap/100ml solution)	40	60	80	100
Average time(s)	123	103	70	55

As part of the objectives, the students are asked to present data as a graph of the time of bubble bursting vs. concentration of the soap solution.

Effect of Concentration



The teacher leads the discussion as to why their prediction and their observations contradict. Factors on which the lifetime of the bubble depends, such as hydrogen bonding, cohesive and adhesive forces, are brought in through their discussion and observations.

### *The Effect of Temperature*

The students are asked to hypothesize what will happen to the lifetime of a bubble as the temperature varies. (Invariably, they hypothesize that as the temperature increases, the lifetime of the bubble decreases.)

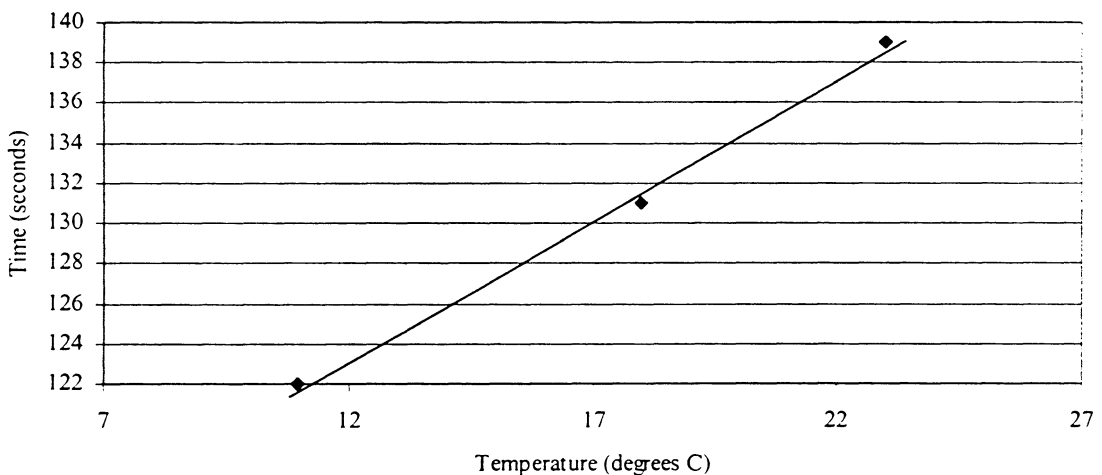
They are divided into groups and make their observations at three different temperatures such as, 10°C, 20°C and 25°C. That is, one group of students perform the experiment at 10°C, the other at 25 °C, and so on.



The students are asked to provide their own data table and plot a graph of the time of bubble bursting vs. temperature of the soap solution for a specific size of the bubble. Again, their observations are not consistent with their hypotheses. The class data are again displayed.

Temperature (°C)	11	18	23
Average Time (s)	122	131	139

Effect of Temperature



Finally, the students are asked to design an experiment(s) to study the “effect of the size of the bubble,” and the “effect of different surfaces” on the lifetime of the bubble. In each part, in the results and conclusion section, they are asked to summarize their findings and give a possible explanation for the problem under investigation. Through this activity, concepts that the students discover are: adhesion, cohesion, the wetting of a solid surface by a liquid and factors affecting reaction rates. Hydrogen bonding is reinforced and discussed further.

### Evaluation

Preliminary evaluation of these experiments at several institutions (University of Puerto Rico at Cayey, Inter American University of Puerto Rico and Purdue University, W. Lafayette) suggests that we have met our goal of transforming the traditional laboratory experience into one in which some of the motivation for learning has been shifted from the instructor to the students. Qualitative data was gathered with Reflective Diaries and interviews with students; and, quantitative measures included a comparison of the grades obtained by students taking this course

in the traditional and the discovery approaches. Students loved the approach, felt they were learning relevant chemistry and recommended this course to other fellow students. The chi-square comparison of traditional and discovery formats consistently revealed a higher percentage of “B”s and “C”s in the discovery format and a lower percentage of dropouts and “F”s. In our curriculum, students take an active role in the planning and carrying out of the activities, with emphasis on the processes, and not solely on the products of science.

### Conclusion

The discovery-based curriculum developed inculcates student learning using easily accessible materials available in their daily lives through direct experiences. During the process, students make their own observations, acquire their own data, and analyze and interpret their data with guidance from the instructor and in collaboration with their peers. Although our model is not completely open-ended, there are sufficient elements of creativity in this structured format to support the insights expected of the students in the process of discovery. Throughout the process, the instructor is behind the scenes, a guiding force, choreographing the activity, ensuring that student creativity is called for in small, manageable increments.

We have developed reform of a general chemistry course by addressing the pedagogical needs of the teacher preparation program. This reform has synchronization in its philosophy and style of teaching. Our approach to pedagogy at the college level reflects the style of instruction that is expected of teachers in school, since the laboratory-driven introductory course mirrors many aspects of instruction that future teachers are expected to employ. ■

### References

- [1] R.S. Lamba, et al., “Constructing Chemical Concepts Through a Study of Metals and Metal Ions,” *Journal of Chemical Education*, **74**(1095) (1997).
- [2] D.P. Ausubel, *Educational Psychology: A Cognitive View*, Holt, Rinehart, & Winston, New York, 1968.
- [3] G.M. Bodner, “Constructivism: a Theory of General Knowledge,” *Journal of Chemical Education*, **63** (1986) 873-878.
- [4] T. Kuhn, *The Structure of Scientific Revolutions*, Chicago University Press, Chicago, IL, 1962.
- [5] J. Piaget, *The Psychology of Intelligence*, Trans. M. Piercy and D.E. Berlyne, Routledge and Paul, London, 1950.

- [6] R.S. Lamba, "Laboratory Driven Instruction in Chemistry," *Journal of Chemical Education* **71** (1994) 1073-1074.
- [7] A.L. Kuehner, "New Tough Films and Bubbles," *Journal of Chemical Education*, **25**(211) (1948).
- [8] S. Sato, "Invitation to Chemistry through a Large Soap Bubble Chamber," *Journal of Chemical Education*, **65**(616) (1998).



## **PROGRAM EVALUATION IN THE CONTEXT OF DEBATES IN THE FIELD: THE EVALUATION OF PR-CETP**

---

M. BRAVO

*University of Puerto Rico, Rio Piedras*  
mlbravo@caribe.net

### **Abstract**

The purpose of this paper is to present some controversies in the field of evaluation that shape the way evaluation is currently carried out. Since evaluation uses methods developed in the social sciences, some of the controversies come from debates in this field (i.e., the quantitative vs. qualitative debate), but others derive from the nature of program evaluation as applied research (i.e., external vs. internal evaluations; independent vs. collaborative evaluations; role of evaluator regarding use of evaluative results). The article examines these controversies and proposes a multi-method or mixed methods approach as the most appropriate way to carry out program evaluations. It also describes the positions adopted in the evaluation of the Puerto Rico Collaborative for Excellence in Teacher Preparation (PR-CETP) project concerning other controversies in the field. Understanding these controversies might help math and science faculty to become more knowledgeable consumers of evaluation results, as well as more informed collaborators in evaluations of programs in their fields.

### **Introduction**

The evaluation of a program is a systematic study of its characteristics and merits. Evaluative research involves the systematic application of the methods of the social sciences to study programs [1]. Consequently, the currents and controversies present in the social sciences influence the evaluation field. One of the important debates in this field is the use of qualitative (data expressed in words or narrations) or quantitative (data expressed in numbers) methods in research in these disciplines. This debate is fundamental because it is the basis of the research activity and underlies other important issues. Additional controversies arise from the nature of program evaluation as applied research that is highly influenced by the social, political, and economic context in which it is carried out [2]. A debate regarding the working conditions of evaluators—that is whether evaluation should be carried out by people external to the program or by those that work for the program (external vs. internal evaluators)—has arisen. Another one concerns whether the responsibility for designing and carrying out the evaluation should fall on an independent person/entity or, if it should be a collaborative endeavor. The use of evaluative results has also been a matter of controversy; specifically, whether evaluators should have the responsibility for promoting the use of evaluation results and what kind of use should be sought. Understanding these controversies might help math and science faculty to become more knowledgeable consumers of evaluation results, as well as more informed collaborators in

evaluations of programs in their fields. The present article examines the above mentioned controversies and proposes a multi-methods or mixed methods approach as the most appropriate way to carry out program evaluations. It also describes the positions adopted in the evaluation of the Puerto Rico Collaborative for Excellence in Teacher Preparation (PR-CETP) project concerning other controversies in the field.

### **Debate Concerning Qualitative vs. Quantitative Methods**

One of the most important controversies in the realm of research in education and the social sciences, as well as in program evaluation, is the use of qualitative or quantitative methods. The strengths and weaknesses of these types of methods have been thoroughly debated [3-4]. Those that criticize the quantitative methods denounce the dehumanizing tendencies of numeric representations, claiming that a better understanding of causal processes could be obtained through the intimate knowledge of people and the resultant qualitative observations [4-6]. They adduce that it allows an understanding of the concrete manifestations of a program that produces valid knowledge about its effects. On the other hand, those that advocate the use of quantitative methods reply that qualitative data are very expensive if they are used extensively, they are highly subject to bad interpretations, and they usually contain information that is not uniformly gathered in all cases and situations. In the case of impact evaluations especially, it has been pointed out that, to obtain results scientifically acceptable which yield relatively precise estimates of the effects of a program, quantifiable information that is systematic and uniformly gathered is required [1].

### **Epistemological Pluralism**

This controversy arises from a clash of epistemological paradigms [3]. Researchers and scholars differ about the respective merits of the two approaches due to their different views about the nature of knowledge and how knowledge is acquired [7]. Qualitative researchers argue that there is no objective social reality, that all knowledge is “constructed” by observers who are the product of the cultural, social, and political environment in which they operate. On the other hand, while quantitative researchers no longer believe that their methods yield absolute and objective truth, they adhere to the scientific model and seek to develop sophisticated techniques and statistical tools to study social phenomena.

Until recent times, the positivistic and empiricist approach prevailed in science. This conception arises from the mechanic model based on the works of Galileo and Newton [8]. The clock was used as a model of the cosmos, and eventually was taken as the cosmos itself. The

world was conceived as a great machine whose operation could be discovered by breaking it down into their constituent parts: take the whole, divide it into parts, analyze it, and put everything together again. This conception involves a vision of the human reason as autonomous, as bequeathed to us by Descartes [9]. It establishes a separation between the knowing subject and the object of knowledge; it assumes the existence of a stable material reality that can be totally captured by the human mind.

However, the physics of Einstein and Plank opposes the mechanical conception of the world. On the microphysics level, constituent elements of that great machine are not found but, instead, relationships exist between abstract entities [8]. The essence of nature is not objects, but interconnections; matter is composed of interconnections. No intrinsic properties can be identified in these abstract entities; rather, they depend in good measure on the theoretical and methodological models used to study them. The resulting observation, consequently, is as much a function of the phenomenon itself as of the theoretical and methodological schemas used to study it [10]. The image of the universe that arises is that of a dynamic, indivisible whole, whose parts are essentially interconnected and could only be understood as patterns of a cosmic process.

This vision has important repercussions for research in the human sciences, and therefore, in program evaluation. It indicates that knowledge is not the direct result of experience, but rather is, in good measure, a human construction. It leads researchers to conclude that there is not a single theoretical perspective nor a single method that will lead us to approach human phenomena with more certainty [10]. One cannot talk about a single scientific method that is appropriate to capture reality as it is, since this is a futile objective, impossible to achieve. It is only possible to capture deformed approximations to that reality, that result from the interaction between the phenomenon and the theoretical and methodological models used to study it; hence, the importance of explicitly describing them. This conception entails an epistemological pluralism in which it is considered that the comparison and interaction of diverse systems of research permits a better understanding of the phenomena under study than is possible to achieve with a single system. A better understanding could arise from the syncretic interaction of several positions [10]. Since knowledge is not the direct result of experience, but mostly a human construction, the comparison of several constructions could lead to a deeper and more certain understanding of a studied phenomenon. Using more than one method can strengthen the validity of research results, an approach called triangulation [7].

### **Mixed Methods in Program Evaluation**

The field of research and evaluation in education, and other human sciences, has been moving toward the acceptance of this epistemological pluralism. Shadish, Cook and Leviton point out that no paradigm for the construction of knowledge is better than another since all the approaches are plagued with considerable difficulties [2]. A better theory of program evaluation is one that assumes this position, according to these authors. The use of both types of methods could strengthen the validity of results produced than by either one by itself [11]. Frechtling and Sharp have pointed out: "Experienced evaluators have found that most often the best results are achieved through the use of mixed method evaluations." [7] It is increasingly recognized that all data collection, qualitative as well as quantitative, operates within a socio-cultural context and is affected to some extent by the perceptions and beliefs of investigators and data collectors. This pluralistic position establishes that each approach has its utility and that all methods are not equally good for all purposes, so it is necessary to identify the strengths and weaknesses of the same for diverse situations [2].

The selection of methods depends on the purposes of the evaluation and the aspect of the program in focus, as well as the specific situation in which it is carried out. For example, Rossi, Freeman, and Leviton consider that qualitative methods could play a preponderant role in the evaluation of the conceptualization and design of programs, as well as in monitoring its implementation [1]. In contrast, quantitative approaches are considered to be more appropriate for the evaluation of their impact and efficiency. On the other hand, Fink considers that qualitative methods are useful for programs whose objectives are still in process of being defined and to explore the viability of the quantitative methods to be used in an evaluation [12]. Another use suggested by this author, is in cases in which there were no valid and reliable measures available to evaluate the impact of a program. In these situations, information on the processes is gathered as well as the participants' perceptions concerning the program impact. Qualitative methods could also be used to supplement more common quantitative data (e.g., surveys, standardized tests); because they are "personalized," they could add emotion and tone to purely statistical results [12]. This particular combination of methods provides concrete examples of the life of the studied people, many times in their own words, deepening and giving emphasis to the human experience suggested by the numeric discoveries [13].

The selection of the research approach to use in an evaluation is not only an epistemological, but also a strategic matter. Evaluations are carried out usually with the purpose of accountability, to promote program improvement, or contribute to the formulation of public



policy. These activities have a strong political dimension. Upon making decisions concerning methods, therefore, one should consider the type of information that the program stakeholders and audiences would accept as valid knowledge. A position that reflects this point emerges from the expression of Chelimsky indicating that it is rarely wise to enter a burning political debate armed only with a case study [14].

### **Mixed Methods in the Evaluation of PR-CETP**

The evaluation carried out in the PR-CETP project is an example of the use of the alluded mixed methods approach. As it is described in other articles in this special volume, the Puerto Rico Collaborative for Excellence in Teacher Preparation (PR-CETP) has as its basic goal the transformation of the main programs of science and mathematics teacher preparation in Puerto Rico. This transformation is geared to achieve that future teachers provide an education of excellence to all K-12 students. Seven higher education institutions, four public and three private, make up the collaborative. The project seeks to make changes in four elements of the programs, Curricula, Professional Development, Student Support, and Institutional Policies, through four interinstitutional components that coordinate the reform. The evaluation of the project is focused on the project goals and involves the use of diverse qualitative and quantitative methods to collect information with formative and summative purposes. Next, we present some specific examples that illustrate the sole or combined use of these methods.

### **Quantitative Methods**

The quantitative methods used in the evaluation have allowed us to obtain abundant information from a great number of participants from different institutions which, since it is quantifiable, can be easily coded and analyzed in a statistical context. The strategy used to examine the achievement of one of their basic goals, the development of future teachers' conceptual understanding of subjects that they will teach, could serve to illustrate the utility of the quantitative methods to evaluate the impact of an intervention. The quantitative strategy used is a set of tests of conceptual understanding developed to evaluate the understanding of the main science and math concepts that are covered in university gateway courses: pre-calculus, general biology, general chemistry, and general physics. A test was also developed to evaluate the understanding of basic concepts about human development, concepts on which educational methods are based and, are therefore pertinent for all future teachers. These tests were constructed by a team of professors of different disciplines, based on the content and professional standard that guide the education of K-12 students. They were subjected to a rigorous process of item analysis, modifications based on these results, and testing of their psychometric properties. The

tests were used to answer the following evaluation question: To what extent are the future teachers moving toward the goal of achieving conceptual understanding of the subject matter they will teach?

These tests are being used in two main ways. First, they are administered as pre- and post-tests in courses that are reformed according to the constructivist educational philosophy that sustains the transformations of PR-CETP. When comparable groups exist, these tests are also administered in order to contrast results obtained from reformed courses versus non-reformed courses. In this way, the value added in conceptual understanding by the reformed courses could be evaluated. Second, tests are administered to graduating future teachers of the corresponding disciplines in order to know the level of understanding achieved in basic concepts of the subject that they will teach. The use of the quantitative technique employed, given its ease of administration and analysis, has allowed its systematic use in numerous groups of students. These large numbers allow comparisons and generalizations about the targeted future teachers.

### **Qualitative Methods**

Qualitative methods are used in the PR-CETP evaluation to understand the experience of participants from their own frame of reference in the context of individual institutions. It allows an understanding of the concrete manifestations of the project that produces knowledge about its implementation and effects. For this purpose, information is gathered using varied qualitative methods.

Some of these methods are focus groups and interviews. Two focus groups are annually carried out in each institution, one of students and another of professors. These have allowed capturing the perceptions that they have about the implementation and achievements of the project. In the past year, a series of two interviews per institution were also begun, one with a dean or director of a science or math program, and another with a corresponding administrator of an education program. These techniques are basically used to answer the following evaluation questions: To what extent is the project moving toward its stated goals, according to participants' perceptions? Which activities or strategies are aiding the participants to move toward the project's anticipated goals? What barriers are encountered and how are they being overcome? In order to overcome the limitation that information might not be uniformly gathered in all situations, guidelines for collecting and analyzing the resultant qualitative data have been developed. The obtained results are used to adjust the activities of the project to the needs and

preferences of participants and to the advancement of the project in the achievement of its goals and objectives.

### **Combination of Methods**

Another goal of the project is the institutionalization of the practices and transformations carried out in the teacher preparation programs. One of the practices to institutionalize is the collaboration between the faculty of sciences/mathematics and the faculty of education in the preparation of future science and math teachers. To study the achievement of this goal, we have combined qualitative and quantitative methods. On one hand, a survey is carried out annually in which the faculty is requested to judge the level of the existent collaboration on a scale that measures ten levels of collaboration, from “none,” all the way up to “considerable” collaboration. By means of open questions, they are also asked to describe the collaboration in their institution, and to provide suggestions on how to improve it. In the professors’ focus groups and in the deans/directors’ interviews, they are also asked about their perception of existent collaboration, and the role that PR-CETP has played to promote it. This combination of methods provides concrete examples of the situations studied in the participants’ own words, deepening and giving emphasis to the human experience suggested by the numeric results. Upon examining results coming from diverse sources and methods, by means of a process of triangulation, many instances in which the qualitative and quantitative results converge or supplement each other have been identified. Even in cases in which they diverge, both types of information have allowed a better understanding of the studied matter.

### **Debates that Arise from the Nature of Program Evaluation**

Besides the epistemological debate, other debates have emerged in the evaluation field that are more directly related to the basic nature of program evaluation. Evaluation is an applied research that is carried out in a social, political, and economic context.

### **Evaluators’ Working Arrangements**

There exist several controversies in the field that focus on the people that carry out evaluations. One concerns their working arrangements, what has been called the insider-outsider debate [1]. That is, if the evaluators are external to the evaluated program or if they work in the program and, therefore, are internal evaluators [15]. One position is that evaluators could work better when their positions are as secure and independent as possible of the influences of the staff and management of the project. It is adduced that external evaluators could exercise more objectivity, have less conflict of interest with the internal stakeholders of the program, and could

be more attuned to the needs of external stakeholders, especially those providing its funding. The contrary position posits that the frequent contact with the personnel of the program and those that make decisions improves the evaluators' work. They can obtain a better knowledge of the objectives and activities of the program than is possible to achieve by external evaluators. They also inspire more trust so they could get more truthful information, and could be in better harmony with the necessities of internal stakeholders.

The most prevalent position at the present time in the field maintains that there are few reasons to categorically prefer external or internal evaluations [1]. The existent evidence is far from pointing out with clarity if the internal or external evaluations are of better technical quality. Moreover, the technical quality is not the only issue to consider, since the utility of the evaluation could be of similar importance. What is crucial is that evaluators have a clear understanding of their role in specific situations.

The evaluation of the PR-CETP is carried out by a committee called the "Evaluation Component" headed by a central level coordinator, an assistant, and evaluators from each one of the participant institutions. The basic design of the evaluation was developed when the proposal of the project was submitted to the funding agency. However, it has been collaboratively refined and implemented by this committee. The carried out evaluation combines elements of both internal and external evaluations, although the former are more prominent. On one hand, the institutional evaluators are professors at the participant institutions (internal element), but they were recruited expressly to carry out evaluation functions in the project (external element). That is, although they generally are members of the faculty of each participant institution, they began working in the project when they were recruited to be evaluators. Additionally, the evaluation coordinator has an office in the facilities of the central level of the project and answers to the coordinating committee at this level (internal element). However, she was also specifically hired to carry out the evaluation (external element). Another external element of the evaluation is that one of the members of the National Visiting Committee of the funding agency has served as external consultant of the evaluation committee; strengthening the qualitative component of the evaluation has been one of her contributions.

The frequent contact with the personnel of the project and those that make decisions have improved the evaluators' influence in the planning and implementation of the project's work; thus, the use of the evaluation results has been enhanced because evaluators are in good harmony with the necessities of internal stakeholders. We also consider that the technical quality of the

evaluation has not suffered much because of measures taken to systematize evaluation procedures in the different institutions. Monthly meetings are carried out to plan and coordinate activities; and, an Evaluation Manual with detailed guidelines to systematize all the data collection and analysis processes has been developed. Maintaining technical quality of the evaluation enhances accountability to external stakeholders. Moreover, one of the tasks of the evaluators' coordination has been to promote evaluators' understanding of their role in specific situations.

### **Responsibility for the Evaluation**

Another controversy in the field involves whether an independent person or entity should do the evaluation or, on the contrary, if it should be done collaboratively. On the one hand, it has been pointed out that the evaluations designed and supervised in an independent fashion have the advantage that more control can be exerted on the evaluation activities and thus research processes could be more systematically carried out. On the other hand, it is adduced that collaborative evaluations can do more with less resources and, since this involves a larger number of people in the evaluation, a greater commitment to the use of the results can be achieved [6].

The evaluation of PR-CETP is collaborative. As previously stated, it is carried out by a team of evaluators with representation from all participant institutions. Since the project involves seven different institutions that vary in size, complexity, and type of teacher preparation programs, representation from each institution enhances the pertinence of the evaluation for each institution. This is one of the main lessons learned from using this arrangement. Moreover, since evaluators are professors from each campus, they have the standing and contacts to facilitate data collection and, their relationship with the project institutional coordinators enhances the use of results, as previously stated. In order to overcome a limitation of collaborative evaluations, evaluation processes in the different institutions have been systematized. Monthly meetings are carried out to plan and coordinate activities; an Evaluators' Manual with detailed guidelines to systematize all the data collection and analysis processes has been developed. Although this systematization has enhanced the evaluation's technical quality, a limitation has also been identified. Since the collaborative arrangement implies less control on research processes and personnel at the central level, it has caused data gathering procedures to be slower than they probably would be by using a more direct supervisory arrangement.

The evaluation of PR-CETP has other collaborative elements. People who are directly involved in carrying out project activities have also participated in the planning and implementation of the evaluation. For example, institutional coordinators have been actively

involved in carrying out “flashlight projects” with evaluators. These are small action research projects that focus on issues of special interest to the institutions. Topics such as, effectiveness of specific reformed courses and identification of future teachers who are not classified as education majors, have been researched. Another instance of collaborative evaluation is the development of portfolios by professors who are piloting reformed courses in the different institutions. In these portfolios, they document the changes carried out in their practices of teaching and assessment, and evaluate the obtained results. They also reflect on their own practice and the way they could use the obtained results to improve their practice. The approach used is that of reflexive practitioners to carry out action research in their classrooms [16]. To implement this strategy, a guide for the development of the portfolios was developed. Meetings with the professors before and after developing them were carried out. During the latter, they evaluated their work, as presented in the portfolios, using a rubric that had been previously developed by project staff and evaluators. Throughout this process, the development of a community of apprentices was promoted in which all people collaborate toward the achievement of a common goal. The latest evaluation of portfolios indicated that, although changes in the aimed direction have occurred, many transformed courses still do not reflect the PR-CETP constructivist philosophy to the degree that we would expect. These results were recently presented to institutional coordinators, and institutional plans are going to be developed to overcome this limitation. In a recent planning meeting, a more comprehensive collaborative professional development model that integrates a cycle of in-service training, reflective follow-up, and formative evaluation carried out in collaborative groups was discussed. The main aim is to strengthen the development of the community of apprentices.

### **Utilization of Evaluation Results**

Another debate in the evaluation field concerns the use of results produced by evaluations [2]. One of the important elements of this debate focuses on the responsibility that evaluators are supposed to have for the use of evaluation results [17]. On the one hand, it has been argued that stakeholders and other potential users are solely responsible for the use of evaluation results. The role of the evaluators is to carry out methodologically sound evaluations. This was the position of evaluation theorists belonging to the first stage of the development of program evaluation [2]. Theorists such as Striven and Campbell represent this position.

In later stages of program evaluation development, it was pointed out that the worth of the evaluations must be judged by their utility [1]. Program evaluation loses sense if the findings are not used. Therefore, promotion of use is now considered one of the main responsibilities of

evaluators. This position posits that evaluators have to balance technical rigor with utility. Research results document this position. Weiss and Bucavalas, in Rossi, Freeman, and Leviton, studying reactions of decision-makers to actual research reports, found that decision makers apply both a *trust test* and a *utility test* [1]. Truth was judged on the basis of research quality and on conformity to prior knowledge and expectations. Utility was judged on the basis of feasibility potential and degree of challenge to current policy. These results evidence the complexity of the utilization process.

Diverse strategies have been developed to foment the use of results; they involve tasks that should be carried out before, during, and after the evaluation. In the planning stage of the evaluation, it is important to identify potential users and on what aspect of the program they would like the evaluation to focus. It is also important to identify the type of information that the identified users need and involve them in the planning of the evaluation.

During the implementation of the evaluation, it is important to frequently interact with potential users in order to stay alert about the need for useful evaluation information. Based on these needs, the evaluation design should be adjusted. It is also recommended that potential users be invited to participate in this phase of the evaluation and then provided timely partial results as the evaluation progresses. During the evaluation, as well as after its conclusion, evaluators should prepare brief executive summaries, present findings and recommendations in diverse forums, and present them in forms that are suitable to the specific audience. In our project, we frequently present results in different formats and forums. For example, to present findings from the review of portfolios several exemplars illustrating the observed results were developed and presented in a coordinators meeting. These were analyzed by the coordinators to identify strengths and weaknesses. Using a nominal group technique, some strategies for dealing with the problem were explored and prioritized.

Evaluators can promote diverse types of use and they should adapt the promotion strategies to the type of use and target audience. Several types of uses have been identified [1]. Instrumental or direct use involves the documented and specific use of evaluation findings by decision makers and other stakeholders. Conceptual utilization refers to the use of results to influence thinking about issues in a general way. In the case of educational programs, the issue may center on specific aspects of education; for example, the teaching-learning process. Persuasive utilization refers to use of evaluation findings to support or to refute political positions, that is, to defend or attack the status quo.

The type of use that has been mainly promoted in PR-CETP has been instrumental for direct utilization, since the project is in the fourth year of a five-year term. The use of results for improvement of the project as it is developing has been promoted. During the planning stages, project administrators and institutional coordinators were identified as potential users of evaluation results. These personnel participated in diverse ways in the refinement of evaluation plans and development of initial data gathering instruments. During the implementation stage, frequent interaction with these potential users have occurred in meetings, as well as in informal conversations in order to stay alert about the needs for evaluation information. Based on the identified needs, the evaluation design has been adjusted. Partial results from the evaluation have been provided in different ways. Institutional evaluators provided information to institutional coordinators about results coming from yearly student and professor focus groups, interviews with deans or directors, and the professors' collaborative survey. In fact, some coordinators have participated in some of these data gathering processes. At the central level, results are presented in both informal and formal ways. An example of the former is the presentation of exemplars illustrating the results obtained from the review of portfolios that was previously described. Examples of the latter are formal oral presentations to coordinators, administrators, and other project participants, as well as written reports for the NSF. Conceptual use is starting to be promoted through publication of articles in this special edition.

### **Final Comments**

Upon facing an evaluation, it is necessary to make many decisions. One of them is the epistemological position that will sustain it. Many times, this position is taken based on the training the evaluators have received. However, this should not be the main element that prevails in this decision. Recent developments in contemporary science indicate that there is no one single paradigm or method that allows us to better understand a phenomenon. Each of them has strengths and limitations. From this position, it follows that the selection of methods should be based on their utility for specific purposes. Moreover, the use of mixed methods could provide a better understanding of the studied program than can be achieved with any one method alone. Upon facing the task of making evaluations, it is thus no longer pertinent to ask which of the two approaches, qualitative or quantitative, should be used. Rather, it is pertinent to ask what method or what combination of methods would be more appropriate to achieve the established purposes and answer the posed evaluation questions in the context of the specific program.

Other decisions faced when carrying out an evaluation are interrelated to the epistemological one. The fact that most evaluators no longer believe that their methods yield



absolute and objective truth, but rather all data collection, qualitative as well as quantitative, operates within a socio-cultural context and is affected to some extent by the perceptions and beliefs of investigators and data collectors, has influenced how evaluation is conceived and practiced today. For example, it is no longer considered necessary for evaluators to maintain a distance from program personnel in order to avoid biases, but rather that they have a clear understanding of their potential influence and deal with it professionally. Moreover, the need to balance technical rigor with utility has also influenced how evaluation is practiced. Promotion of use is now considered one of the main responsibilities of evaluators. Internal evaluations can enhance instrumental use since evaluators can more intimately understand the programs and be more attuned to stakeholders' information needs. Collaborative evaluations also enhance utilization since close collaboration with individuals who will use evaluation findings will ensure that the evaluation is responsive to their needs and produces information that they can and will actually use [6]. The PR-CETP evaluation is an example of an evaluation with these characteristics. Evaluators can collaborate with science, math, and education faculty to promote changes that enhance teacher preparation. ■

## Bio

Milagros Bravo is Professor of Educational Research Methods in the College of Education, at the University of Puerto Rico, Río Piedras, and Coordinator of the Evaluation Component of the Puerto Rico Collaborative for Excellence in Teacher Preparation (PR-CETP).

## References

- [1] P.H. Rossi, H.E. Freeman, and M.W. Lipsey, *Evaluation: A systematic approach*, Sage Publications, Thousand Oaks, CA, 1999.
- [2] W.R. Shadish, T.D. Cook, and L.C. Leviton, *Foundations of Program Evaluation: Theories of Practice*, Sage Publications, Newbury Park, CA, 1991.
- [3] T.D. Cook and C.S. Reichardt, *Qualitative and Quantitative Methods in Evaluation Research*, Sage Publications, Beverly Hills, CA, 1979.
- [4] Y.S. Lincoln and E.G. Guba, *Naturalistic Enquiry*, Sage Publications, Newbury Park, CA, 1985.
- [5] E.G. Guba and Y.S. Lincoln, *Fourth generation evaluation*, Sage Publications, Newbury Park, CA, 1989.
- [6] M.Q. Patton, *Qualitative Research and Evaluation Methods*, Sage Publications, Thousand Oaks, CA, 2001.

- [7] J. Frechtling and L. Sharp (eds.), *User-Friendly Handbook for Mixed Method Evaluations*, National Science Foundation, Arlington, VA, 1997.
- [8] F. Capra, *The Turning Point: Science, society and the rising culture*, Bantam Books, New York, 1982.
- [9] R. Descartes, "Discourse on the method," in E. Anscombe and P.T. Geuch (eds.), *Descartes Philosophical Writings*, Bobbs-Merrill, Indianapolis, IN, 1971.
- [10] D. Polkinghorne, *Methodology for the human sciences: Systems of inquiry*, State University of New York Press, Albany, NY, 1983.
- [11] J.G. Greene and C. McClintock, "Triangulation in Evaluation: Design and Analysis Issues," *Evaluation Research*, **9** (1985) 523-547.
- [12] A. Fink, *Evaluation for Education and Psychology*, Sage Publications, Thousand Oaks, CA, 1995.
- [13] C.E. Depner, E. Wethington, and B. Ingersoll-Dayton, "Social Support: methodological issues in design and measurement," *Journal of Social Issues*, **40(4)** (1984) 37-54.
- [14] E. Chelmsky, "The Politics of Program Evaluation," in D.S. Condray, H.S. Bloom, and R.J. Light (eds.), *Evaluation Practice in Review*, Jossey-Bass, San Francisco, CA, 1987.
- [15] A.J. Love, *Internal Evaluation: Building Organizations from Within*, Sage Publications, Newbury Park, CA, 1991.
- [16] G.E. Mills, *Action research: A guide for the teacher researcher*, Merrill, Upper Saddle River, NJ, 2000.
- [17] M.Q. Patton, *Utilization Focused Evaluation*, Sage Publications, Thousand Oaks, CA, 1997.

# **The Journal of Mathematics and Science:**

COLLABORATIVE EXPLORATIONS

Volume 4, Number 2    Fall 2001

## **PART II: REGULAR JOURNAL FEATURES**

### **i. PROGRAMS THAT WORK**

First three articles selected for special recognition by the Virginia Mathematics and Science Coalition.

### **ii. EDUCATIONAL RESEARCH**

Virginia Mathematics and Science Coalition



# PROJECT MATRIX: IDENTIFYING THE MATHEMATICALLY TALENTED AND MEETING THE MATHEMATICAL NEEDS OF ALL

---

M. K. MURRAY

*Charlottesville City Schools, Charlottesville, Virginia 22903*

## **Project Overview**

In January 1999, Charlottesville City Schools began a three-year project, Mathematics and Talent Recognition: Instruction for Excellence (Project MATRIX), designed to identify young children with strong mathematics potential among populations typically underserved by gifted programs.

Along with developing techniques for talent recognition, Project MATRIX leaders have created a differentiated mathematics curriculum with the goals of meeting the needs of these gifted learners, as well as of challenging all learners at an appropriate level. Training in mathematics pedagogy and content is provided for participating teachers to ensure successful implementation of the Project MATRIX identification strategies and the accompanying curriculum.

## **Setting and Audience**

The Charlottesville City School system serves 4,000 students and is made up of six elementary schools (grades K-4), one upper-elementary school (grades 5-6), one middle school (grades 7-8), and one high school (grades 9-12). The student population is comprised of approximately 50% African-American students, 47% Caucasian students, and 3% Asian or Hispanic students. Of the six elementary schools, five have at least 50% of their students qualifying for free or reduced-price lunch; this statistic serves as an indicator of the low socio-economic status of many of the families served by the school system. Project MATRIX is being implemented in three of these elementary schools, with the remaining three schools serving as controls.

Project MATRIX was developed to address several concerns of teachers and administrators within the Charlottesville school system. First, the fact that few African-American *children*, as well as students from economically disadvantaged backgrounds, enrolled in upper-level mathematics classes by seventh and eighth grade was an indicator that these students were not identified as talented in mathematics early on in their educational careers. Charlottesville City Schools felt a strong need to ensure that children from all sectors of the school population who are talented in mathematics were identified as such, and that they received instruction at a suitably challenging level.

A second issue, generated from the first concern, was to provide challenging, meaningful mathematics instruction for students of all levels. In order to do this, a well-articulated, differentiated mathematics curriculum for all grade levels would have to be developed. This

curriculum would need to meet the requirements of the 1995 Standards of Learning for Virginia Public Schools (SOL), as well as align with the national standards as outlined by the National Council of Teachers of Mathematics [1,2].

Along with the aforementioned issues, school administrators and teachers had been concerned for several years about the low pass rates of Charlottesville City School students on the SOL end-of-year mathematics exams, especially at the elementary and middle school levels. Reasons for low achievement are unclear, but possible solutions include a more cohesive curriculum, consistently implemented from school to school, along with increased opportunities for staff development for mathematics teachers. As stated above, Project MATRIX is addressing the issue of improving the curriculum. In addition, to help ensure successful implementation of this enhanced curriculum, Project MATRIX has provided extensive staff development for project participants, including intensive workshops in mathematics instruction, mathematical content knowledge, and issues surrounding gifted children and their academic, social, and emotional needs.

### **Cognitively Guided Instruction**

By far the largest component of Project MATRIX has been staff development in Cognitively Guided Instruction (CGI), a research-based instructional method developed at the University of Wisconsin-Madison [3-6]. CGI is based on the belief that young children enter school with a great deal of mathematical knowledge, and are capable of solving problems requiring addition, subtraction, multiplication, and division without direct instruction from their teachers. By posing different types of problems, and then observing how the child solves those problems, a teacher may assess a child's mathematical achievement level and then plan appropriate instruction. One aspect of the research describes different types of problems, and discusses why some problem types are easier, or more difficult, to solve. Another facet of the research discusses strategies children use to solve problems, from a relatively unsophisticated counting strategy to the fluent use and application of number facts.

For instance, certain types of problems imply some type of action taking place: either joining or separating. Examples of joining problems include:

Bob had 5 candies. His sister gave him 3 more. Now how many candies does Bob have? (This is a Join, Result Unknown problem. Here, we know the amount Bob starts with, and we know the amount by which the original set will change. We do not know the final result—how many candies Bob has now. )

Bob had 5 candies. His sister gave him some more. Now Bob has 8 candies. How many candies did Bob's sister give him? (This is a Join, Change Unknown problem. In this problem, we know the amount Bob starts with, and we know the result when the amount changes. We do not know the amount by which the original set changes.)

Bob had some candies. His sister gave him 3 more. Now Bob has 8 candies. How many candies did Bob have at first? (This is a Join, Start Unknown problem. We know how much the original set changes, and we know the result—how many candies Bob has in the end. We do not know the amount Bob had at the start.)

The first of these problems is relatively simple for a child to solve if they can count to eight. In fact, a child may act out the solution to such a problem: the child will put out five candies, put out three more candies, and then push the groups together. To find a solution, the child will count the total number of candies.

The next two problems are not as clearly demonstrated, and prove to be more difficult for children when first encountered. For the second problem, a child may put out five candies, and then put out eight candies. If the implied action of the problem is not clear, the child may add the two groups and come up with an incorrect answer of eight. Or a child may attempt to add candies to the original pile of five, but fail to keep track of the number of candies added to the pile. With experience, however, the student will learn to reason out these problems and solve them correctly in ways that are meaningful to him.

As children become mathematically sophisticated through repeated and varied experiences, they not only solve more difficult problems, but they do so using complex strategies. Initially, a child may use a strategy that involves counting each object in the story. With experience, a child will learn to count-on, as in “I have 5, 6, 7, 8. There are 8 candies.” When appropriate, children will also begin to use easily learned facts to solve problems. For instance, to solve the problem, “Bob had 3 candies. His sister gave him 3 more. Now how many candies does Bob have?” a child might count-on, but will often say, “I know 3 and 3 is 6. Bob has 6 candies.”

Eventually, a child will be able to use knowledge of some basic facts to derive other facts. For instance, to compute the sum of six and seven, a child may say, “I know double-6 is 12, and since 7 is one more than 6, 6 plus seven is one more than 12. The answer is 13.” Finally, a child will use their developed ability to recall all facts in solving simple problems, and will be able to extrapolate this knowledge to solve problems involving multi-digit numbers.

Perhaps the most important aspect of CGI is implementation in the classroom. The technique is similar whether used with a small group, with an individual, or as a whole-class

activity. The teacher poses a problem for the child, or children, to solve. The child chooses tools he will use to solve the problem—manipulatives, hundreds boards, or pencil and paper—and then attempts to solve the problem. If the child cannot solve the problem, the teacher may provide another problem, either by choosing an easier type of question, adjusting the size of the numbers, or by making another decision based on her knowledge of the student. If the children solve the problem, or think they have solved the problem, solution strategies are shared. The goal is not simply to highlight the correct answer, but to have children model different successful strategies. In doing so, other students gain insights into the particular problem. In addition, the children are learning to support their thinking and to provide mathematical proof.

### **Some Initial Results**

Perhaps the most enduring result of Project MATRIX is the changes teachers have made in mathematics instruction as a result of participating in the project. During the first year of implementation, kindergarten teachers at the participating three schools, as well as their instructional assistants, received training in CGI. In addition, three Project MATRIX staff members were available in each teacher's classroom at least once a week, to either model a lesson, instruct a small group, or to observe and provide feedback on the lesson the teacher delivered. All staff members were certified teachers who had chosen to work part-time for the year, and received initial CGI training with project teachers.

At first, the kindergarten teachers were skeptical about their students being able to solve the problems posed. However, after watching children of all abilities develop problem-solving skills, as well as facility, with numbers far beyond those required by the Virginia Standards of Learning by the end of the school year, many teachers had altered views of what children could accomplish. The result is that teachers are asking more of their students, both in terms of the content presented to children, as well as the complexity with which children are expected to handle that content.

During the second year, kindergarten teachers continued training and implementing CGI, while first-grade teachers were brought on board and began CGI training. First-grade teachers noted the same skepticism felt by the kindergarten teachers the previous year. But, just as before, these teachers soon began reporting that their students were better problem-solvers, especially in their willingness to persevere to find a solution. In addition, first-grade teachers reported that children had a better grasp of doubles facts (2 plus 2, 5 plus 5, et cetera) and seemed to be



learning other facts more quickly than students in previous years. At one school where second-grade teachers were trained during the second year (all kindergarten and first-grade students and teachers were involved in the project during its first year), comments were similar to those of first-grade teachers at other schools at the beginning of the year. However, by the middle of the year, these second-grade teachers were reporting that their students were indeed further advanced than students from previous years. In fact, a second-grade teacher who taught third grade the previous year stated that her second-grade students were further along than her third graders were the year before.

At the end of the second year of the project, a series of interviews were completed with a random sample of students in kindergarten and first grade from each of the participating schools, as well as from two of the elementary schools not in the project. In addition, all students in the division were administered a system-wide, end-of-year test, created by a committee of teachers with representatives from each elementary school. This assessment is based on expectations set forth by the Virginia Standards of Learning. Initial analysis of these assessments indicate that Project MATRIX students are at least as successful on the division-wide, end-of-year test; at the same time, they are demonstrating stronger problem-solving skills, including the ability to solve more complex problems with more sophisticated strategies. This indicates that our focus on problem solving is not detrimental to the development of basic skills; furthermore, children in Project MATRIX schools appear to have developed higher-level skills for problem solving. A complete analysis of this data will be available in the next few months.

Yet another indicator of success comes from reports of the school-based, gifted education specialists. Each spring, these teachers are involved in the system-wide identification of gifted students. Several standardized ability tests are given to children, including the Wechsler Intelligence Scale for Children-R (WISC-R). According to the gifted education specialists at Project MATRIX schools, the mathematics portion of the WISC-R took far longer to administer this year, in comparison to prior years: confident, practiced students persevered in solving problems when they may not have tried as hard in the past. Because of their persistence, children were able to advance further in the test than in previous years. Again, initial comparisons of student scores on the WISC-R seem to indicate that students at Project MATRIX schools have stronger problem-solving abilities. Also, Project Matrix schools appear to have more students from underserved populations either working above their grade level in mathematics, or being recommended for gifted services.

### **Areas for Further Action**

Project MATRIX has been very consistent in providing teachers with opportunities to learn and to use mathematical instructional methods. In applying these methods, teachers are developing new ways to identify students with mathematical talents through classroom activities. At this juncture, we must begin to turn our focus to curriculum development and implementation. While teachers are gaining experience applying the concepts of CGI to number sense and operations, there is still a lot of progress to be made in applying CGI to other mathematics curriculum areas, such as geometry, probability, and statistics. Some progress has been made toward creating a “scope and sequence” for grades K-2 that reflects the higher levels of achievement teachers are beginning to expect of their students. Now, teachers need to try to follow this “scope and sequence,” as well as recommend revisions and additions.

Teachers in the project commented that while they are now better equipped to provide differentiated mathematics instruction, especially for advanced students, they are still unsure of how to help the struggling learner. There are programs available that are closely related to CGI that focus on early mathematics remediation. This is a topic on which future staff development needs to focus.

Finally, one of the reasons that Project MATRIX has been supported so well by teachers and has shown such positive results is that throughout the project, there have been half-time project assistants working daily with teachers in the classroom. These assistants are all qualified teachers: they have served as tutors, observers, sounding boards, problem writers, videographers, and curriculum developers. Their effectiveness has resulted in plans for mathematics resource teachers in each school.

### **Budget and Funding**

Project MATRIX is funded by the United States Department of Education as part of the Jacob K. Javits Gifted and Talented Students Education Program. The grant totals \$516,739. Funding began in January 1999, and ends in January 2002, with the possibility of a no-cost extension for any remaining funds. The grant has paid for the following components of the program: project personnel (one grant coordinator, and several part-time assistants each year); stipends for teachers participating in training throughout the project; contracted services, including CGI trainers and evaluators; materials for classroom teachers, both print and manipulatives; travel and conference reimbursement; computers and video equipment; and,

supplies. The school division has contributed secretarial time, office equipment and costs, and additional money for supplies.

Javits grants run in two-year cycles and are due in the beginning of May of that year. Assuming Congress approves the funds, the next grant application will be due in spring of 2002; grant applications may be obtained by contacting the United States Department of Education. The grant should be written in narrative form, and should include background information addressing the need for the grant, a description of the project design, a description of personnel and their responsibilities, a budget, and an evaluation plan.

### **Alternative Settings**

Any school district concerned with providing differentiated mathematics instruction should explore the possibilities that may emerge with Cognitively Guided Instruction. CGI is an invaluable tool for helping teachers assess a child's level of mathematics achievement, as well as for aiding in planning instruction appropriate for each child in the class. Research on CGI has shown that it can be an effective method of mathematics instruction in all types of settings, from middle- and upper-class suburban schools to poorer inner-city schools [3-6]. Children taught in CGI classrooms are generally stronger mathematical problem-solvers than peers in non-CGI classes; at the same time, CGI children develop skills that are the focus of traditional mathematics instruction at the same, or greater, level than peers in non-CGI classes. ■

### **Acknowledgements**

Project MATRIX is funded through the Office of Educational Research and Improvement (OERI) which administers the Jacob K. Javits Gifted and Talented Students Act of 1994, authorized under Part B of Title X of the Elementary and Secondary Education Act (Award # R206A990004).

### **References**

- [1] *Standards of Learning for Virginia Public Schools*, Board of Education, Commonwealth of Virginia, Richmond, VA, 1995.
- [2] *Principles and Standards for School Mathematics*, National Council of Teachers of Mathematics, Reston, VA, 2000.

- [3] T.P. Carpenter, E. Fennema, P.L. Peterson, and D.A. Carey, "Teachers' Pedagogical Content Knowledge of Student's Problem Solving in Elementary Arithmetic," *Journal for Research in Mathematics Education*, **19** (1988) 385-401.
- [4] T.P. Carpenter, E. Fennema, P.L. Peterson, C. Chiang, and M. Loef, "Using Knowledge of Children's Mathematics Thinking in Classroom Teaching: An Experimental Study," *American Educational Research Journal* **26** (1989) 449-531.
- [5] E. Fennema, T.P. Carpenter, and P.L. Peterson, "Learning Mathematics with Understanding: Cognitively Guided Instruction," in J. Brophy (ed.), *Advances in Research on Teaching*, JAI Press, Greenwich, CT, 1989.
- [6] T.P. Carpenter, E. Fennema, M.L. Franke, L. Levi, and S.B. Empson, *Children's Mathematics: Cognitively Guided Instruction*, Heinemann, Portsmouth, NH, 1999.

**INTERVIEW WITH MEGAN K. MURRAY**

**Q: What career path did you follow to reach your present position? Is this what you originally aimed for, or were there a few twists and turns that brought you here?**

**A:** I actually started off as an engineering school student, which lasted all of one year. At that point, I took a year off from school (at my father's request), worked as a nanny for a year, returned to school, and graduated from University of Virginia (UVa) with a degree in Latin American Studies. I did nothing with that degree, but after a year or two bartending in Washington, I decided to actually do what I had really always wanted to do—teach, so I got a job as a teacher in a preschool. After working at that job for two years, I returned to UVa to get my teaching certificate, as well as a Master of Teaching Degree in Elementary Education (K-8). I had always wanted to teach middle school math (honestly! and it is still my favorite age to teach!) and taught seventh and eighth grade math, algebra, and geometry in Charlottesville for seven years. During the past three years in Charlottesville, I have also served as half-time mathematics curriculum coordinator.

**Q: Have you been involved in similar programs before? Was there a particular moment, or stimulus, that caused you to begin this project?**

**A:** Several things occurred as I worked as a curriculum coordinator. First, I realized that I did not know enough about mathematics, or about curriculum, to be as comfortable with the job as I would have liked. Second, I had opportunities to see lots of math at lots of levels, and began to think that to really change mathematics instruction, we need to start a program in kindergarten and follow it through middle school; this idea was to emerge as an impetus for Project MATRIX. Third, I took a course on *Curriculum for Gifted Children* and decided I had to go back to school full-time to learn math, to learn about curriculum, and to get a Ph.D. I would never have guessed that one of those graduate courses, *Underserved Gifted* with Professor Carolyn Callahan, would open the door for my creation of Project MATRIX.

**Q: Have there been any unique, or unexpected consequences for you resulting from your project?**

**A:** I have learned a great deal about kindergarten, first, and second grades, especially about math education in those grades, through Project MATRIX. I have also been able to spend time looking at the specifics of how what is taught in primary mathematics develops for children as they move through elementary school and middle school. I am now very familiar with the curriculum at these levels, what we can expect of children at various ages, and have developed very firm beliefs about the elements of quality instruction. More importantly, I have grown to appreciate the many faces of good instruction since I have watched many teachers, with very different styles, deliver instruction that is engaging, meaningful, and challenging to children. I don't want to sound too sweet (I don't consider myself a sweet person!), but I have been overwhelmed by the amount of trust teachers have had in me—allowing me to observe them teach a subject they do not consider their strength, as they implement teaching methods that I am convinced will work, but of which they are sometimes skeptical. I am able to share, on a regular basis, great triumphs with the teachers in the school system as we see a child show deep understanding for the first time, or as we watch a child develop a new strategy of which no one else had thought.

**Q:** **Are you able to identify the greatest lesson you have learned and the rewards you have gained through working on Project MATRIX? What is the greatest benefit you see coming to students, and to teachers, through their engagement with this project?**

**A:** The greatest benefit coming to students and teachers through their engagement with Project MATRIX has been the change in attitude toward mathematics and math instruction. I think children involved with Project MATRIX really like mathematics: they enjoy solving problems, and demonstrate a determination to learn when faced with a situation that is new to them. Likewise, teachers appear to be attending more closely to the meaning behind their mathematics instruction. Teachers are watching carefully as children solve problems, and are engaging children in deep discussions of solutions. Teachers are becoming more adept at creating mathematical tasks that challenge children at all ability levels. And I have seen teachers rework activities they have done in the past so that the activities develop mathematical thinking in children, rather than focus on less demanding skills, such as learning by rote.

## SATURDAY MORNING PARENT AND CHILD EDUCATION (PACE)

---

D. J. BAGBY

*Title I Parent/Family Resource Center  
Richmond Public Schools, Richmond, Virginia 23223*

P.A. PRIESTAS

*Mathematics & Science Center, Richmond, Virginia 23233*

### Introduction

The Mathematics & Science Center, located in Richmond, Virginia, challenges and inspires thousands of students, teachers, and parents each year through its unique educational programs. The Center provides exemplary mathematics and science programs to support participating school divisions' development of 21st-century citizens who are productive, ethical, and responsible members of our global society. Seven Virginia school divisions make up the Center's consortium: the counties of Chesterfield, Goochland, Hanover, Henrico, King William, Powhatan, and the City of Richmond.

The Center has a longstanding tradition of providing children and parents with engaging educational lessons on Saturday mornings. This project, called the Parent-Child Program, began in the mid 1970s to provide opportunities for family exploration of the world of mathematics and science, as well as to develop an appreciation of the relevance of mathematics and science in daily living, for careers, and for society. Patricia Priestas has been the coordinator of the project since 1993.

Special one-day experiences are offered to students in kindergarten through fourth grade, and include parental participation. Typically, these lessons carry fees ranging from \$10.00 to \$14.00 per student and parent(s). These fees cover the materials for the lessons, primarily hands-on activities. In the past, these fees have prohibited many economically disadvantaged families from participating. For this reason, the Mathematics & Science Center's collaboration with the Title I Parent/Family Resource Center, located on the campus of George Mason Elementary School in Richmond, has been crucial to increasing the involvement of children at risk of failing courses in math and science.

Title I, the largest federal aid program for students, helps disadvantaged children meet challenging content and student-performance standards. It is the largest federal aid program for our nation's schools. Part A of Title I provides financial assistance to meet the educational needs

of children who are failing, or of those most at risk of failing, to meet state requirement standards. Of the 31 elementary schools in the Richmond Public Schools system, 26 currently meet the criteria of high poverty levels for Title I eligibility. The general rule for Title I eligibility is that at least 50% of the children enrolled in the school, or residing in the school attendance area, are from low-income families.

Presently, approximately 11,000 elementary students receive Title I services. Title I regulations specifically require sustained and meaningful involvement of all participating parents. The Title I Parent/Family Resource Center provides programs that are designed to encourage parental and family involvement in activities during regular school hours, evenings, and weekends. Also, the Title I Parent/Family Resource Center maintains a budget line-item that is designated specifically for parent and child activities.

Delores Bagby, the Title I Parent Liaison Specialist for Richmond Public Schools, recognized the powerful link between parental involvement and student achievement. Nearly four decades of research confirm a strong correlation between a child's academic success and the level of parental and family involvement in their education [1,2]. It was during a Richmond Public Schools staff development session, held at the Mathematics & Science Center, that Ms. Bagby approached Executive Director Dr. Julia Cothron about making the Parent-Child Program available to Richmond's Title I population. Thus, Parent And Child Education (PACE) was born.

PACE provides Title I students and their parents the opportunity to participate in the Mathematics & Science Center's Parent-Child Program at convenient locations and without cost to the participating families. In the past, this population has been underrepresented in the Parent-Child Program since the fees for the classes and the inaccessibility of the program locations prohibited many families from participating. Saturday Morning PACE classes are currently held at the Title I Parent/Family Resource Center or at George Mason Elementary School. Classes have also been held in the southside of Richmond at the Boys & Girls Club and at the Northside YMCA, located in Ginter Park.

The PACE program began in the spring of 1996 with two lessons offered: *Learning with Duplo Blocks* for kindergarteners and *Science from Toys* for first graders. The number of classes and participants has steadily increased since 1996. From school year 1997-1998 to school year 1998-1999, Richmond Public Schools' total participation in the Parent-Child Program rose from



364 to 667. This dramatic increase was surpassed by an enrollment of 840 children and parents for 1999-2000; this year's totals are nearly equal to last year's at 828. This increase in Richmond Public Schools' total participation in the Parent-Child Program can be attributed directly to the enrollment of students and their parents in the PACE Program: 25% of the participating families are served by PACE.

Furthermore, our enrollment data shows that, once a parent and child attend one of the lessons, they usually return for additional lessons during the school year. This past year, our *What's What Up There?* lesson was so well-received that seventeen students and eighteen parents from the PACE Program attended the follow-up lesson at the Virginia Air & Space Museum in Hampton. Title I funds paid the fees for these attendees. Involvement in this popular trip was surpassed in March 2001 when 54 parents and children participated. Also, parents who are familiar with PACE classes through the attendance of one child frequently come back in future years with their other children.

### **Program Details**

Currently, ten parent-child lessons are offered by the Mathematics & Science Center throughout the school year: four of these lessons are offered to Title I PACE students at George Mason Elementary; and, the other six lessons are either field trip experiences or are only offered on site at the Center. As a result of participation in the four PACE lessons, parents may elect to attend the other Mathematics & Science Center parent-child lessons with funding provided by the Title I Parent/Family Resource Center.

The first PACE lesson in the sequence, offered in December for third and fourth graders, is *Calculator Capers*. Each student is given a hand-held calculator, which they may then keep after the class is over. This lesson is made up of lively activities and games that engage both the students and their parents. Parents are provided with printed instructions of all the activities and games covered in class, as well as additional activities for use at home. Students are encouraged to make their calculators "talk" by entering numbers on the display that appear as letters in a word when the calculator is inverted. Using their calculators, parents and children play games, such as "The Greatest Sum," that emphasize place-value. During "The Greatest Sum," children are placed in groups of four. The children each take a turn at rolling four cubes that are numbered. Each child places the cubes to form two two-digit numerals, which when added

together form the greatest sum possible. This sum is recorded on a score sheet and the player with the greatest total score at the end of five rounds is the winner.

“Wipe-Out!” another place-value activity, encourages the students to “wipe-out,” or change to zero, a specific digit in a number. For example, the student is instructed to enter 98541 on their calculator and then told to “wipe-out” the 8. The student must subtract 8000 in order to replace the 8 in this number with a zero. This game focuses on learning, as well as reinforcing, mathematical concepts and on reviewing the SOLs. At the same time, it encourages interaction between parents and children as they play together.

Our second lesson, *What's What Up There?* held in February, deals with the night sky, covering the properties of the planets, stars, and constellations. Numerous activities help second graders relate to the universe. Students use the knowledge they have acquired about the planets to create, with their parents, a creature that is adapted to exist on a particular planet. While spinning and twirling, the children sing “The Planets Go Spinning” to the tune of “When Johnny Comes Marching Home” in order to learn about the rotation and revolution of the planets around the sun. As mentioned before, this class has the added bonus of a follow-up trip in March to the Virginia Air & Space Center in Hampton, Virginia.

The third in our series of lessons is for first graders, *Science from Toys*. This very popular lesson allows the students to interact with their parents as they investigate and make low-technology toys that illustrate the fundamentals of physical science. Students make a balancing robot that they place on their finger or tip of their nose. When weighted properly with pennies, the robot balances.

Making an electrical circuit, one of the final activities of this lesson, is another favorite. Parent and child are supplied with a template, motor with leads, baseboard, paper clips, and brad fasteners and are asked to create a closed circuit. While parents tend to do most of the construction of this “toy,” the children work with them to complete the project successfully, usually by making a propeller or color wheel to mount on the end of their motor shaft.

The fourth lesson in our sequence is *Learning with Duplo Blocks* for kindergartners, which utilizes the large Lego blocks called Duplos to illustrate and develop many elementary math concepts. Concepts include color, size, shape, and symmetry. One activity involves a parent and their child sitting back-to-back, each with five of the same Duplo blocks. The child

constructs a model and then communicates the block location to the parent. The parent attempts to construct an identical model. SOL correlations are provided to the parents and the students may keep a small set of Duplo blocks.

### **Budget and Funding**

The seven participating school divisions provide the operating budget for the Mathematics & Science Center. Other school divisions, including the counties of Prince George and Charles City, the City of Hopewell, the Stewart School, and St. Bridget's School, also participate through institutional membership. The Mathematics & Science Center establishes costs for each parent-child lesson, including materials, teacher-training expenses, and a stipend for the instructor.

The Title I Parent/Family Resource Center covers the entire cost for each family in the PACE program. School divisions receiving Title I funds in excess of \$5,000 must have an educational program with parental involvement at its core. The structure of such programs varies by school division. The decision on whether or not to set up a program based on the Title I Parent/Family Resource Center will depend on a number of factors; such as, available funding, personnel, program goals, and learning objectives.

### **Challenges**

One of the initial challenges for this program was getting the targeted audience to attend classes through PACE. Delores Bagby promotes the program by meeting with principals and teachers of Title I schools and discussing program initiatives, as well as providing detailed information on how to enroll. Brochures are designed and printed by the Title I Parent/Family Resource Center and distributed only to Title I schools. The brochures highlight descriptions of lessons, dates, times, locations, and include an application form that, when completed by interested families, must be returned to the Title I office for processing. PACE is well received by participating schools as evidenced by the cooperation from administrators, teachers, and staff.

Another challenge has been the failure on the part of some parents to follow through on their initial commitment to attend these classes. Title I staff sends acceptance and confirmation letters, as well as class reminders, in an effort to encourage attendance. These letters serve as a motivational tool, as well as help the staff to determine expected enrollment in order to provide adequate materials, space, and refreshments. The Title I Parent/Family Resource Center is

considering surveying all parents in order to further understand the reasons that some fail to attend after registering.

### **Details of Evaluation**

At the end of every class, evaluation forms are given out to the parents who have attended. Many positive responses have been received: “Very enjoyable!” and, “I believe these activities are good stepping stones for preparing for the SOL assessment. I know now what I can do to help my son achieve his goals. Thank you for a very interesting morning.”

The PACE Program cannot take full credit for the gradual improvement in the mathematics and science SOL test scores for Richmond Public Schools, but we can be sure that these activities enrich and enhance the conceptual understanding, problem-solving, and math and science skill sets of the students who attend. Parents frequently tell us that they and their children have learned so much: “I believe that I enjoyed this program more than my son. I look forward to the very next program with Title I”; and, “Thank you for providing a fun and educational workshop to promote reasoning skills. My child really enjoyed working with me in this setting.” In addition to the qualitative assessments, we intend to measure the possible quantitative impact made by the program by comparing the third grade SOL scores of the PACE participants to those of their peers.

### **Conclusion**

PACE certainly may be adapted for use in alternative settings. The model could be used for other subject matter with targeted groups, such as special-needs students. The following components should be considered when developing a similar program: creative lesson development; recruitment and training of dedicated, caring, and competent teachers; procurement of appropriate materials; logistical arrangements; advertising; and, enrollment of the targeted population. It should also be noted that if Title I funds are used for the program, it must be in accordance with Title I guidelines.

PACE lessons are designed to develop the curiosity and enthusiasm that motivates students and parents to become lifelong learners. We’ve been pleased to watch students and parents leave the lessons with a sense of accomplishment and satisfaction. ■

**References**

- [1] J.L. Epstein, "Paths to Partnership: What We can Learn from Federal, State, District and School Initiatives," *Phi Delta Kappan* **72**(5) (1991) 344-349.
  
- [2] A.T. Henderson and N. Berla, *A New Generation of Evidence: the Family is Critical to Student Achievement*. National Committee for Citizens in Education, Washington, DC. 1994.

**INTERVIEW WITH DELORES J. BAGBY**

**Q: What career path did you follow to reach your present position? Is this what you originally aimed for, or were there a few twists and turns that brought you here?**

**A:** This position was not on the career path that I planned. I began working in the Richmond Public Schools (RPS) system as a fifth grade teacher; my first teaching assignment had been in the Washington, D.C. Public Schools system. After enrolling in a summer teacher in-service program on elementary mathematics, I was asked to take a position as a Title I mathematics teacher. I remained in that position for ten years. My interest in computers led me to a summer assignment teaching parents basic computer skills. After that particular experience, the director of Grant Programs for RPS invited me to coordinate the parent-involvement component for their Title I program.

**Q: Have you been involved in similar programs before? Was there a particular moment or stimulus that caused you to begin this project?**

**A:** I am always interested in organizing and providing educational experiences that involve parent and child interaction. PACE is unique in that it has a strong hands-on emphasis with specific objectives correlated to state standards, which, of course, makes it especially attractive as a program that also satisfies Title I parental involvement requirements.

**Q: Have there been any unique, or unexpected, consequences for you resulting from your project?**

**A:** I can truthfully say that there have been no unexpected consequences. This continues to have only positive results. I am not only fortunate to have the opportunity to provide a valuable service to our parents and children, but working with Pat Priestas has been a delight.

**Q: Are you able to identify the greatest lesson you have learned and rewards you have gained through working on Saturday Morning PACE? What is the greatest benefit you see coming to students, and to teachers, through their engagement with this project?**

**A:** The greatest lesson learned is that it takes time to grow as a program. As we noted in the article, the number of participants has gradually increased, and this has been a wonderful reward.

Schools now recognize PACE as one of our signature programs, with the result that administrators and teachers are more actively encouraging parents to participate. When children see that their parents are interested, and willing, to spend a Saturday morning with them participating in this project, this is certainly a benefit. Too, PACE supports what the classroom teacher is doing, so that is another benefit. Ironically, several teachers and their own children have participated in PACE. The overwhelming response from participants is that PACE is a program that must be maintained.

**INTERVIEW WITH PAT A. PRIESTAS**

**Q: What career path did you follow to reach your present position? Is this what you originally aimed for, or were there a few twists and turns that brought you here?**

**A:** My career in education began after graduation from the University of Maryland in College Park. I was hired to teach sixth grade in Prince Georges County, Maryland. When my husband finished his graduate degree in 1975, we relocated to Richmond. Once again, I was hired to teach sixth grade, first at Laburnum Elementary and then at Hermitage Middle School, which is now Moody Middle. With my daughter's birth in 1978, followed by my son's arrival in 1981, I became a full-time mother and part-time educator at the Mathematics & Science Center. At first, I taught only on Saturdays for the Parent-Child Programs and, later, in the Saturday Discoverers and Questers Program. Eventually, I added weekday instruction to my schedule. In 1993, I took over Parent-Child Programs and have continued leading this program to the present. I also hold a second part-time contract as a math educator for grades 4-8.

**Q: Have you been involved in similar programs before? Was there a particular moment or stimulus that caused you to begin this project?**

**A:** Delores Bagby and I began this program after meeting at the Mathematics & Science Center. Dr. Julia Cothron, the Executive Director of the Center, was the catalyst in this area. Her suggestion that we look at ways of increasing attendance from Richmond Public Schools in our Parent-Child Programs stimulated discussions that eventually led to the development of the Saturday Morning PACE Program.

**Q: Have there been any unique, or unexpected, consequences for you resulting from the project?**

**A:** I suppose the most unexpected consequence was how successful we became after the first two years. Large numbers of families returned for additional classes the next year. I expected our numbers to increase, but not as rapidly as they did. My planning for materials and the number of teachers had to be reevaluated. Ultimately, additional materials needed to be ordered and a Title I teacher had to be hired and trained just for the Saturday Morning PACE Program.



**Q: Are you able to identify the greatest lesson you have learned and the rewards you have gained through working with Saturday Morning PACE? What is the greatest benefit you see coming to students, and to teachers, through their engagement with this project?**

A: The greatest lesson I have learned from this project is that if you expect to succeed, you will. Delores and I realized from the start that this was a good program. We kept the faith even when our numbers were disappointing at the beginning. It took a couple of years to mature, but now it is rolling along. When I visit the PACE program site on a Saturday, I see parents and children engaged in working together with a caring teacher on a positive educational experience, and they are succeeding. That, in and of itself, is a great reward. I've also learned that Delores is a fantastic educational partner, someone with whom I hope to continue working for a long time.



# BRIDGES TO THE BACCALAUREATE PROGRAM AT J. SARGEANT REYNOLDS COMMUNITY COLLEGE AND VIRGINIA COMMONWEALTH UNIVERSITY

---

D. NEELY-FISHER

*J. Sargeant Reynolds Community College, Richmond, Virginia 23285*

## Abstract

This paper describes a research apprenticeship to encourage and to inspire minority students to major in disciplines that lead to careers in biomedical research.

## The Challenge

The National Institutes of General Medical Sciences, National Institutes of Health (NIH) Bridges to the Future programs are designed to encourage individuals underrepresented in the sciences to pursue careers in biomedical research. In 1997, the percentage of doctorates awarded to United States citizens in science, engineering, and mathematics (SEM) fields included 84.2% Whites, 2.2% Blacks, 3.2% Hispanics, and .03% Native Americans [1]. In *Wanted: A Better Way to Boost Numbers of Minority Ph.D.s*, Jeffrey Mervis writes that, though the challenge to produce more minority Ph.D.s was made over ten years ago, the numbers remain low for all but Asian Americans (6.8%). Although 23% of our population is comprised of underrepresented individuals, only 4.5% of them hold scientific doctorates [1].

Anti-affirmative action referendums in several states, such as California's Proposition 209, have further exacerbated the problem. Also dismaying are the results from the Alfred P. Sloan Foundation's *Project Talent Flow* that indicate that minority enrollment in higher education in the SEM disciplines actually is declining [2]. *Project Talent Flow*, a study initiated to determine why scientifically talented Black and Latino students do not choose careers in the SEM fields, found that this decline in interest occurs after enrollment in college [2]. Results confirm that, while a lack of encouragement from SEM faculty contributed somewhat to the decline in interest in SEM careers, the overwhelming factor appeared to be a feeling of alienation among the students created by the restrictive nature and difficulty of college-level SEM work [2].

## Meeting the Challenge

One of the key transition points for success in biomedical research careers occurs when students transfer to a baccalaureate institution. The goals of the NIH Bridges to the Baccalaureate program are to nurture students' interests in research careers at associate degree-granting institutions and to increase the likelihood of success for these students once they transfer to

baccalaureate degree-granting institutions. Our particular partnership, between J. Sargeant Reynolds Community College (JSRCC) and Virginia Commonwealth University (VCU), uses an intensive research apprenticeship to encourage and inspire minority students to major in disciplines that lead to careers in biomedical research.

The JSRCC/VCU Bridges program follows minority students from their entrance into JSRCC, nurturing their interest in scientific research with hands-on activities in an employee-employer relationship with research faculty mentors from VCU. The student's transition to VCU is eased by early introduction to, and interaction with, research faculty mentors who monitor their progress from their entrance at JSRCC to their graduation from VCU with the Bachelor of Science degree.

Recruiting faculty volunteers has not been problematic. We originally asked ten professors to come on board, and only one turned us down due to heavy involvement in other projects. Since then, everyone we have asked has joined us. Most researchers who already work with undergraduate students in their labs are very open to the idea of mentoring Bridges students. And, once they have worked with our students, they appreciate having the opportunity to be part of the program. Benefits are also accrued by the mentors: researchers have extra help in the lab for two years, and given the unpredictable nature of grant funding, this helps ease the pressures of hiring outside help.

JSRCC is a three-campus institution that enrolls 10,761 students and currently offers 25 two-year associate degree programs, 19 one-year certificate programs, and 47 career studies certificates. The JSRCC-VCU Bridges to the Baccalaureate program is housed at the downtown campus of JSRCC (JSRCC-DTC). This campus is located within the city of Richmond, at Eighth and Jackson Streets, across the street from the Virginia Biotechnology Research Park and the Health Sciences campus of VCU. A total of 3,091 students were enrolled at JSRCC-DTC in the fall of 1999: 48.9 % of those students were African-American, 44.6% were White, and 6.5% were categorized as Other [3]. The Carnegie Foundation ranks Virginia Commonwealth as a doctoral/research university-extensive. It consists of a medical and academic campus, both of which are located within an easy commuting distance to JSRCC.

### **Participant Requirements**

Students selected to participate in this program must belong to one of the groups considered underrepresented in the sciences: these groups include African-Americans, Hispanics,

Native Americans, or Pacific Islanders. In order to be admitted into the program, they must attend JSRCC and have a high school or college grade point average of 2.5. Participants sign contracts agreeing to complete the Associate of Science degree at JSRCC and to transfer to VCU to pursue the bachelor's degree in a discipline that will lead to biomedical research careers. Although we cannot require a student to attend VCU, the contracts provide a means of ensuring student cooperation and participation. It also provides the student with an "easy out": if they feel they cannot maintain their contractual obligations, they can be released from their agreement.

Upon entering the program, students are paired with a research mentor at VCU and are trained as research assistants in the mentor's laboratory. Mentors work with a research assistant for one and a half years and, potentially, for an additional two years when the student transfers to VCU. Research mentors also receive \$1,000 per year in replacement supplies for agreeing to work with the students. As research assistants, the students are paid as employees, working in the laboratory from eight to fifteen hours per week during the academic year and up to forty hours per week during the summer months. In addition to learning the basic research techniques in their mentor's laboratory, students complete a research project of their own and present their results to the Virginia Academy of Science (VAS) at the end of their second year in the program.

### **Apprenticeship Model**

Bridges students are trained to work in the laboratories by either their mentors or by another trained student working in the mentor's laboratory. This type of nurturing and attention is usually reserved for graduate students, although it has been successfully used to introduce undergraduates to the research experience. Bridges students meet weekly with the project coordinator from VCU throughout the entire length of the program, either formally in class or informally. They use this time to discuss their research and any other problems they might have encountered during the week. Cross-institutional activities have both students and faculty moving between schools: this fosters relationships among the faculty and provides the program participants with an added sense of security when they transfer to VCU.

Students receive a VCU identification card that gives them unlimited access to the school's library and Internet resources, as well as free access to VCU's transportation services. Other student benefits include the use of a laptop computer for the length of their undergraduate career, paid Internet access at home for two years, in addition to mentoring at both institutions. JSRCC received \$350,000 for the first two years of this program from the NIH, with a sub-award

going to Virginia Commonwealth University. A successful renewal application provided funding for an additional three years to recruit up to five new students per year.

### **Formal Training in Research Methods**

In addition to working in a research laboratory for one and a half years, students receive formal training in three specialized courses that focus on research methods. The first course, *Introduction to Biomedical Research* is taken at VCU's medical campus and helps develop students' critical thinking skills. The students are required to attend a series of seminars given by different biomedical researchers and to use ideas from each presentation to devise how they might solve a particular medical problem. The students found this first course taken outside the community college setting to be particularly intimidating.

Not only were they taking a course at a senior institution for the first time, they were also attending classes with graduate students. Plenty of handholding occurred in order for the students to reach an understanding that they were just as capable of succeeding in this course as were the graduate students. The same factors that initially intimidated them provided them with an additional boost of confidence once the course was completed.

The second course, *Introduction to Instrumental Analysis*, is team-taught by faculty from both institutions at JSRCC. The students learn to use basic laboratory equipment, such as gas chromatography, and infrared and ultra-violet spectrophotometry. They also bring their laptops to class and learn how to use the latest computerized probe-ware to conduct and analyze the results of chemistry experiments.

During the last semester of the program, students take *Introduction to Research Methods*. This is a course taught by VCU faculty at JSRCC. Students learn how to statistically analyze and graphically represent the data they have generated in their laboratory projects. They also prepare their presentations for the VAS during this course.

### **Lessons Learned**

In the fall of 1998, ten young J. Sargeant Reynolds Community College women (eight African-American and two Hispanic) eagerly signed contracts agreeing to work in scientific research laboratories at Virginia Commonwealth University. Within the first two semesters of the program, five of the students dropped out. The principle investigators and faculty mentors were not prepared for this action. One very young, talented chemistry major dropped out because of a

conflict with child-care and child-rearing. A second student dropped out because of legal difficulties and at least two other students were not prepared for the time commitment that a program like this requires. Although the initial attrition was disappointing, we learned that students with complex life styles that include families and full-time jobs were not as likely to be successful in this particular program.

This realization led to the reorganization of the structure of the program to allow interested students to participate at different levels. Students that are not quite academically prepared or cannot make the necessary time commitment participate only in the weekly meetings and seminars. Students who have achieved the appropriate grade point average, who do not require additional developmental courses, and who are prepared to make the time commitment are given research positions.

### Successes

The stamina, grit, and determination of the successful participants have, from time to time, overwhelmed us. A single mother of five completed the requirements for both an Associate of Science in social science and in science. She is currently working at JSRCC as a laboratory specialist, supervising the preparation of all of the science teaching laboratories. She is also a part-time student at VCU. A second student continued to work at her full-time job the entire time she was in the program. She used her personal leave-time and weekends to complete her research assignment. Through persistence and hard work, she earned a scholarship for tuition, as well as authorship on a publication from the laboratory in which she worked. Two other graduates have been hired to work as part-time laboratory technicians at JSRCC. Five students successfully completed this program in the spring of 2000 by presenting electronic posters at the VAS [4]. ■

### References

- [1] J. Mervis, "Wanted: A Better Way to Boost Numbers of Ph.D.s," *Science*, **281**(28) (1998) 1268-1270.
- [2] B.C. Clewell and S.V. Brown, "The Non-SEM Field Choices of Black and Latino Undergraduates With the Aptitude for Science, Engineering, and Mathematics Careers," *Making Strides: Research News on Minority Graduate Education*, **1**(1) (1999) 8-11.
- [3] *Statistical Profile Book*, J. Sargeant Reynolds Community College, 1 Richmond, VA.
- [4] J. Sargeant Reynolds Community College Web Page, <http://www.jsr.vccs.edu>

**INTERVIEW WITH DEBORAH NEELY-FISHER**

**Q. What career path did you follow to reach your present position? Is this what you originally aimed for, or were there a few twists and turns that brought you here?**

A. My high school career was a disaster; I liked partying and playing and never did any school work. Add to this the fact that I was the first member of my immediate family to complete college and you have an individual who really was clueless about college and career choices! I started out wanting to be a writer, but I hated the criticism of my writing so I decided biology was a better choice. I could sit in the back of the room, take good notes, and make good grades. I had decided at that point that I wanted to go to vet school, but after one day of volunteering in a vet's office, I almost fainted from the smell and realized quickly that this would probably not work out as a career choice.

Eventually, I had the opportunity to do research in a lab at VCU and I had several really good developmental biology courses that used hands-on, inquiry-based labs that made me think and learn in new ways. This encouraged me to continue in science as a graduate student. After I graduated, I had the opportunity to continue to do research as a laboratory technician where I got involved in writing papers, as well as portions of grants. I enjoyed the challenge, but needed to add the responsibility of teaching labs to help pay the bills. Although I enjoyed teaching labs, I was so shy (no one ever believes this part of the story) that it took me several years to get up the courage to teach lectures at VCU. So my career path to teaching at a community college was anything but straight. I think that being involved in community college education continues to offer me challenge after challenge and that is why I enjoy it so much.

**Q. Have you been involved in similar programs before? Was there a particular moment, or stimulus, that caused you to begin this project?**

A. I grew up during the '60s and '70s and really believed in the Civil Rights Movement. I still get chills when I hear Martin Luther King's speeches. I know that many minority children who are located within my college's service area live in poverty and that their K-12 education does not always prepare them for college. In a sense, I think that my own experience was similar, but maybe for different reasons. Even in this anti-affirmative action climate that we are in, I feel like I am doing the right thing and am trying to address one of our society's inequities. These kids are not exposed to much science, engineering, and technology, and they certainly do not



have access to role models in their classrooms, or even at their local colleges and universities, who could introduce them to these types of careers. If I had not had the opportunity to participate in an undergraduate research experience, I might have left the field and worked at something else.

**Q. Have there been any unique or unexpected consequences for you resulting from your project?**

A. I think that working on this project has made me even more aware of the fact that many students who come from lower socioeconomic backgrounds lack access to a K-12 education that will prepare them for college work. They are not exposed to the different career paths in science, engineering, technology, and research. Even as adults, transportation issues limit these students; many rely on public transportation. Unfortunately, our city bus line does not extend far into the more suburban areas. Programs located out of their geographic range are, therefore, off-limits to them since they can't get there. At my college, this includes all of the engineering programs. I am pleased to report that we are finally beginning to address this problem. Equal access to educational opportunities and career paths must be considered since we, as a country, have decided that affirmative action programs are no longer needed at our colleges and universities.

**Q. Are you able to identify the greatest lesson you have learned and the rewards you have gained through working on Bridges to the Baccalaureate program? What is the greatest benefit you see coming to students, and to teachers, through their engagement with this project?**

A. I believe that the greatest benefit of this program is yet to come, and I believe that it will benefit everyone, not just our underrepresented students. I think that undergraduate research programs can be used to excite students about science, engineering, and technology, but I also believe they can serve as a bridge between science faculty at two-year and four-year institutions. If you expand undergraduate research to include all scholarly activities and service learning projects, I think we can develop an educational infrastructure that will connect the K-12 school systems to community colleges and to universities, thus involving faculty who will participate more easily in ways that are meaningful to them.



## EDUCATIONAL RESEARCH ABSTRACTS

---

G. BASS, JR. - Section Editor  
*The College of William and Mary, Williamsburg, VA 23187*  
gmbass@wm.edu

Editors' Note: As noted in previous issues of the *Journal of Mathematics and Science: Collaborative Explorations*, the purpose of this Educational Research Abstract section is to present current research on issues relevant to math and science teaching at both the K-12 and college levels. Because educational research studies are published in so many different academic journals and presented at so many different professional conferences, it is a rare public school teacher or college professor who is familiar with the range of recent reports on a particular instructional technique or curricular advancement. Indeed, the uniqueness of various pedagogical strategies has been tacitly acknowledged by the creation of individual journals and professional organizations dedicated to teaching in a specific discipline. Yet, many of the insights gained in teaching certain physics concepts, biological principles, or computer science algorithms can have generalizability and value for those teaching in other fields or with different types of students.

In this review, the focus is on “cutting edge” research. Abstracts are presented according to a question examined at a recent national educational research conference. Hopefully, such a format will trigger your interest in how you might incorporate new educational findings in your own teaching situation. The abstracts presented here are not intended to be exhaustive, but rather a representative sampling of recent research investigations. Please feel free to suggest future teaching or learning themes to be examined. Please send your comments and ideas via e-mail to gmbass@wm.edu or by regular mail to The College of William and Mary, P. O. Box 8795, Williamsburg, VA 23185-8795.

### **Cutting Edge Educational Research**

“On the cutting edge!” What associations does that phrase generate? Current? Forefront? Fashionable? “Research on the cutting edge.” What does that phrase produce? Cancer cures? DNA mapping? Nano-chips for 21st century technology? “Educational research on the cutting edge.” Now what does that phrase engender? A comparison to military intelligence? Business ethics? Administrative wisdom? Is educational research an oxymoron with all the contradictions and irony of a “plastic glass,” an “original copy,” or a “divorce court?” Or could cutting edge educational research be a sharp slice into the Gordian knot of educational complexities and unknown solutions?

At the April 2001 Annual Meeting of the American Educational Research Association, thousands of educational researchers met in Seattle for a week of “cutting edge” research reports

and discussion. As at any large educational conference, the topics covered were eclectic, the quality of those presentations varied, and the practical worth was very often idiosyncratic. So will cutting edge educational research lead you to more enlightenment or to more skepticism, or maybe just to new potential funding opportunities?

Some reformers have suggested the phrase “Technology on the bleeding edge.” It is good to be on the “cutting edge,” but much more dangerous to be on the “bleeding edge.” Be a leader; be out front, but not too far ahead of the pack or you will leave them behind and perhaps get lost yourself. Even worse, the earliest pioneers always leave their backs unprotected and vulnerable to the arrows of outrageous fortune fired by critics and detractors or by collaborators trying to figure out what exactly to do. And arrows in the back leave a bloody trail only vultures are eager to follow.

Cut? Bleed? Penetrating thrusts into the realm of truth. Dull drubbings at the same old saws? Insightful conclusions that give us a new edge to persistent challenges? Misguided speculations that go over the edge? You be the judge. The following is a non-random selection of some papers presented at the premier educational research conference that relate to math and science education. Since these papers are indeed on the cutting edge, future revisions and additions are likely. A contact e-mail address or personal website URL is provided if you want to follow up on these cutting edge investigations.

- **What do school districts want math teachers to teach and what do the teachers actually do?**

What teachers are expected to teach and what they actually teach are not always the same thing. In fact, the tension between professional teachers making informed teaching decisions versus slavishly following a district curriculum guide or state curriculum standards has become much greater during this era of state-mandated, high stakes student assessments. The Ohio Mathematics and Science Coalition was especially interested in revitalizing and improving Ohio’s mathematics and science education from preschool to university. They believed that four key questions must be answered before progress toward a world-class mathematics and science education system in Ohio could be accomplished: (1) What should students learn? (2) Who delivers the instruction? (3) How is instruction organized? (4) What have students learned?

In 1999, the North Central Regional Educational Laboratory (NCREL) conducted a survey of 280 high schools, middle schools, and primary schools in Ohio. The sample of schools was stratified by geography and school size. A school-wide survey was sent to each school's principal and samples of individual teachers at each school were also sent surveys. A total of 99 school surveys were received which resulted in a return rate of 35%. A total of 506 teachers returned the survey which resulted in the following grade level return rates: grades 3 & 4 - 59%; grades 7 & 8 - 62%; grades 12 - 51%.

Substantive findings:

Often the same mathematics topics are in the curriculum for many different grades. For example, seven mathematical topics (e.g., common fractions, estimating quantity and size) are listed for over ten consecutive grades.

Ohio's school district mathematics curricula repeats many math topics grade after grade. The average intended grade level for 24 of the 40 Third International Mathematics & Science Study (TIMSS) math topics falls in grade seven or eight in Ohio's math curricula.

Elementary and middle school teachers teach fewer math topics than their curricula demands.

Differences between Ohio and U.S. teacher patterns are minimal while Ohio teachers report covering many more math topics than their equivalent grade level teacher in Japan.

Most Ohio teachers rely on textbooks in more than half of their weekly math instruction. However, the variety of math textbooks used raises the question whether empirical research might identify which commercial textbook series most supports optimal student learning.

Teacher-led instruction was dominant at all levels—primary, middle school, and high school. However, whole class, small group, and individual work done under independent conditions were used to some degree by almost all reporting teachers.

Practicing computational skills and explaining the reasoning behind mathematical ideas dominate how students spend their math instructional time at all grade levels.

The authors conclude that these data from Ohio are likely typical of the state of mathematics instruction throughout the United States. Fundamentally, they believe these data reinforce a most common sense conclusion: school districts and individual school teachers must think carefully about *what* math is to be taught, *when*, *to whom*, and *how*.

To accomplish such a challenge, teachers need assessment tools that tell them whether this week's instructional lessons were more or less effective than last week's. A reliance on once a year standardized exams will not provide such feedback when teachers most need it. Teachers also need access to instructional tools and encouragement to use them in creative ways. As the authors point out, teachers' classroom approaches are "enmeshed in a web of local practice and belief and history and constraints." Only when schools support teachers' instructional initiatives and provide resources that let those teachers be reflective about what really works with their students will world-class mathematics learning be accomplished.

*Investigating Schools' Mathematics Curricula and Teachers' Instructional Practices Statewide: An Application of TIMSS-derived Tools in Ohio.*

Arie van der Ploeg, NCREL

E-mail: [arie@ncrel.org](mailto:arie@ncrel.org)

- **What is the difference between an “idea-based” and a “case-based” approach in teaching adaptation and evolution in a high school zoology class?**

Teachers certainly want to provide their students with learning experiences that enrich and change their lives; or, at least, provide experiences that allow students to perceive and interpret the world in new ways. John Dewey wrote about such an experience that leads an individual to act with a fresh outlook, to change one's world view, and to reprioritize one's values. Kevin Pugh has applied this idea of a “transformative experience” to the realm of science education. What might happen if students were introduced to powerful scientific ideas that could inspire action and emotion?

Students in two high school zoology classes participated in the study. One group of eighteen students was randomly chosen to experience a two and a half week unit using an idea-based, transformative experience intervention while the other group of 22 students received a case-based learning activity. The idea-based approach used adaptation as a way to think about and appreciate how animals act. The case-based approach involved an inquiry lesson focused on endangered species. The idea-based class took an artistic crafting of content to change students' perceptions, meanings, and values (i.e., how to experience science ideas) while the case-based approach used class inquiry to help students understand the biological concepts of adaptation and evolution (i.e., how to do science.) Toward the end of the intervention, both classes took a field trip to a zoo, a context where the concepts of adaptation and evolution could be applied.

Pugh used an initial survey with both classes to identify their interests in the zoology course content, learning about animals, and the concepts of adaptation and evolution. This pre-test also measured their current conceptual knowledge and use of adaptation, evolution, and zoology content. The two classes were comparable on this initial assessment. After the first week of the intervention, Pugh found that 71% of the students who experienced the idea-based approach reported thinking or talking about examples of adaptations while only 17% of students in the case-based class reported thinking about adaptation. While students in the idea-based class reported more thinking about adaptation and evolution while visiting the zoo, the differences did not reach statistical significance compared to the case-based students. However, there were statistically significant differences in the frequency that idea-based students reported talking about these biological concepts in everyday life compared to the case-based students. There were no differences in the interests or values each group of students expressed toward animals or the ideas of adaptation and evolution.

One of the most surprising results Pugh found was that the students in the idea-based class performed significantly better on two essay questions about adaptation and evolution than the students in the case-based class. Conceptual understanding was not expected to be affected to the same degree as perception, interest, and value. Pugh does acknowledge there was substantial individual differences within each class on the variables assessed and that the concept of adaptation was more actively used, valued, and understood by all students than the concept of evolution. Nevertheless, he concludes that his research does indeed support the possibility that idea-based, transformative science experiences can lead to enduring changes in how students see, understand, value, and act in the world outside the classroom.

Kevin Pugh, University of Toledo

E-mail address: kevin.pugh@utoledo.edu

- **How well do college students use the Internet to find scientific information?**

Trumpeting the unparalleled access to information through the Internet has almost become a 21st century cliché. Even the phrase “information highway” has been so overused that it is hard not to have heard the strained analogies pundits have created: “Don’t be roadkill on the information superhighway!” “Where is the off-ramp on the information superhighway?” “I want less congestion and more speed on my information superhighway.” “Lots of highway and no good places to go.” “Who gets to put up toll booths on the information superhighway and what will access cost me?” and “I invented the information superhighway.” Past research has identified four factors that contribute to an individual’s success in finding information in an electronic environment: domain knowledge, search expertise, situational interest, and individual interest.

MaKinster, Beghetto, and Plucker presented in-depth case studies of college students’ use of the Internet to discover scientific information. Seven students with differing self-reported Internet use (one to five hours average per week) were given the task to gather information from the Internet to be used in constructing a web page on Newton’s Third Law (i.e., whenever one body exerts a force on a second body, the second body exerts an equal and opposite force on the first.) Students were given twenty minutes to search the Internet for this information and paste it into an HTML document while a videotape and computer activity-tracking program recorded their actions. At the end of the twenty minutes, students were shown the videotaped session and asked to explain what they were doing at each point in their search. An audiotape was made of their “think aloud” answers. The researchers analyzed all the available information to differentiate among the three categories of Internet searchers that emerged -- successful (two students), moderately successful (two students), and unsuccessful (three students.)

The researchers concluded that three factors impacted successful searching: understanding how scientific content is organized; evaluating the descriptors and contents of a web page, and using keywords in search engines. Two students were successful in finding the most relevant information in the fastest time. With respect to “domain knowledge,” they showed



a use of very specific search terms, probed for deeper levels of information, displayed a deliberate search strategy, and recognized the way information was organized in web pages. With respect to “search expertise,” they used sophisticated search strings in their search engine of choice and also showed a purposeful strategy in judging the results. Finally, the successful searchers showed low distractibility with the extraneous features and diversions so evident on the Internet. These successful students were very conscious of what they were looking for and how they could use that information to construct an effective web page on Newton’s Third Law.

The implications of this study for educators who want their students to retrieve information via the Internet is clear. Even college students with reasonable familiarity to the Internet differ greatly in their abilities to find, judge, and use web-based scientific information. Teachers cannot assume all students are equally competent in their web search strategies or their critical thinking decisions in using whatever information they find. If teachers expect students to use the Internet as a science resource, they must provide more direct instruction and organizational assistance to develop the skills students will need to keep from crashing on the information superhighway.

*Why Can't I Find Newton's Third Law?: Case Studies of Students Using the Web as a Science Resource*

James MaKinster, Indiana University; Ronald A. Beghetto, Indiana University; Jonathan A. Plucker, Indiana University

Contact info: <http://inkido.indiana.edu/presentations/aera/2001/>

• **What research tool can give an accurate report on teachers’ instructional practices?**

One critical challenge in relating classroom teaching reform efforts with student achievement is having a valid way to document what instructional practices teachers are actually using. Without an accurate method to document teachers’ teaching actions, there is no trustworthy way to identify what classroom practices actually improve students’ learning. While many studies have asked teachers to describe their own teaching, doubts regarding the reliability and validity of these self-reports have been raised. Shim, Felner, Shim, and Noonan have directly addressed the psychometric attributes of one such self-report instrument, the High Performance Learning Community Assessment (abbreviated HiPlaces Assessment.)

The HiPlaces Assessment asks teachers to report on the frequency of their use of various instructional practices. Teachers use a 7-point scale ("Daily"; "Several times a week"; "Weekly"; "Several times a month"; "Monthly"; "Several times a year"; "Never") to answer 56 items characterizing different possible classroom routines. Many of the 56 items originated from a 1976 instrument, the Classroom Instructional Practices Scales, with additional items added or modified by the authors during their survey work with middle school teachers in the early 1990s.

To verify the reliability and validity of the current instrument, Shim, *et al.* used factor analyses, internal consistency calculations, and correlations between teacher and student reports of instructional practices. Between 1992 and 1997, over 25,000 sixth to eighth grade teachers in sixteen states completed the HiPlaces Assessment.

Factor analysis on the annual survey data supported an eight-factor solution (confirmatory factor analyses during the five years ranged from .83 to .86.) These eight factors were given sub-scale labels that best captured the constructs being assessed: "Small group active instruction"; "Community-based learning opportunities"; "Citizenship and social competence instruction"; "Integration and coverage of health topics"; "Integration and interdisciplinary practices"; "Critical thinking enhancement practices"; "Mastery-based assessment and student recognition"; and, "Practices for heterogeneous groups." Some items which loaded on multiple factors were identified to be modified on future versions of the instrument which should lead to even stronger sub-scale factors.

Using coefficient alpha statistics on the HiPlaces Assessment data each of the five years, Shim, *et al.* found that six sub-scales had Cronbach Alpha values that varied between .77 and .91. Two scales ("Mastery-based assessment and student recognition" and "Integration and coverage of health topics") showed less internal consistency with alpha coefficients in the range .76-.78 and .58-.62, respectively, during the five years. The overall reliability of the total scale was consistently high during the five years—.95 for the first four years and .96 for the fifth year.

During the 1992 to 1997 period in selected classrooms, student reports on the frequency of their teachers' instructional practices were also collected. Items from two sub-scales ("Small group active instruction" and "Integration and interdisciplinary practices") were given to both teachers and students. There were statistically significant correlations between teacher and

student reports on the two sub-scale items—.52-.66 and .61-.76, respectively, across the five years.

Because the cost of repeated classroom observations to document teachers' instructional practices is so high, the use of self-report questionnaires is a much more cost-effective way to accomplish the same result. However, those questionnaires must provide reliable and valid descriptions of teaching practices or low cost will also equal low value. This extensive five-year analysis of the High Performance Learning Community Assessment suggests that survey data on instructional practices can provide reasonably accurate descriptions of teachers' frequency of use of those classroom practices recommended in numerous reform initiatives.

*Multi-dimensional Assessment of Classroom Instructional Practice: A Validity Study of the Classroom Instructional Practice Scale.*

Minsuk K. Shim, University of Rhode Island; Robert D. Felner, University of Rhode Island; Eunjae Shim, University of Rhode Island; Nancy Noonan, University of Rhode Island

E-mail address: mshim@uri.edu

• **What should a classroom observer recognize and record in a science lesson?**

The teacher can teach good. If only the student would learn good! No matter how a teacher designs classroom lessons, it is how the student interprets and incorporates that experience that produces real learning. The Multiple Representation Model is a system-based procedure to examine science lessons by depicting the relationships of the teacher's external representations and the student's internal representations. It focuses on science lesson activities such as manipulating, pictorializing, symbolizing, and concrete modeling as they interact with the student's generalizing new ideas into "mental models" or "schemas."

Carol Stuessy has developed a Multiple Representation Model Observation Protocol (MRMOP) which prompts an observer to record the representations received and used by learners during a science lesson. Specifically, the observer records the number and durations of lesson segments, the types of representations (objects, symbolic, pictorial) received by learners, and the student-centeredness of each segment. Five categories are used to characterize student-centeredness: students listening; students responding orally or in writing; students doing the

same task in pairs or small groups under teacher supervision; student groups working on different tasks under teacher supervision; students working together with little teacher supervision; and, students carrying out plans independently with minimal teacher input.

In her work with pre-service teachers, she has reported that the MRMOP serves as a useful reminder for organizing classroom learning experiences. It helps pre-service teachers think about how to translate concrete classroom experiences into symbolic and pictorial representations. In order to help novice teachers think even further about the ways students receive and respond to lesson segments, Stuessy has added a six-point complexity scale from Replication (students listen, observe, measure, recall, show) through Rearrange/Transform (students organize, compare, classify) to Generate/Create (students analyze, summarize, design, model, evaluate).

Stuessy proposes future uses of the MRMOP in developing "lesson profiles" of exemplary science teachers to identify the best balance of lesson segments, lesson complexity, and their effects on student receiving and responding. She is also in the early stages of designing a computer-based system to facilitate the data entry, storage, manipulation, and visualization of MRMOP observation results. Such formal measures of lesson structure should prove valuable for mentoring novice teachers and for evaluating the impact of initial training and professional development programs.

*A Systems Approach to Classroom Observation of Multiple Representations in Teaching and Learning in Mathematics and Science*

Carol Stuessy, Texas A&M University

E-mail: [carolsd@tca.net](mailto:carolsd@tca.net)

- **What would reformed teaching look like and how can I document that?**

“Reform teaching? I really can’t define it, but I know it when I see it!” Maybe, but it is a supreme court fast break from an intuitive understanding of a concept to one that can be operationalized and tested in real classrooms. As part of the Arizona Collaborative for Excellence in the Preparation of Teachers, Michael Piburn and Daiyo Sawada have created an instrument to do just that.

The Reformed Teaching Observation Protocol (RTOP) draws on constructivist learning theory and national math and science education standards to identify prototype classroom features recommended for reformed teaching. RTOP consists of 25 items divided into three sections: lesson design and implementation (5 items); content—propositional and procedural knowledge (10 items); and classroom culture—communicative interactions and student/teacher relationships (10 items). Observers use a five-point scale (“Never occurred” to “Very descriptive”) to characterize what they see in the math or science classroom. Sample items related to lesson design include: “The instructional strategies and activities respected students’ prior knowledge and the preconceptions inherent in them” and “In this lesson, student exploration preceded formal presentation.” Sample items for content include: “The lesson promoted strongly coherent conceptual understanding” and “Students made predictions, estimations and/or hypotheses and devised means for testing them.” Sample items for classroom culture include: “There was a high proportion of student talk and a significant amount of it occurred between and among students” and “Active participation of students was encouraged and valued.”

Psychometric characteristics of the RTOP were also calculated during the Fall 1999 Semester. Two trained observers simultaneously made sixteen independent observations in Arizona Collaborative reformed math and physics courses using the RTOP. The inter-rater correlation for these sixteen paired observations was  $R^2 = 0.954$ . Two other observers visited eight biology classes and the correlation of their RTOP ratings was  $R^2 = 0.803$ . Construct validity was supported by using individual subscales as predictors of the RTOP total score. An exploratory factor analysis of 153 classroom observations from 62 university courses, 26 community college courses, 37 high schools, and 28 middle schools revealed three factors—“inquiry orientation,” “content propositional knowledge,” and “collaboration.”

Predictive validity was supported through an analysis of six university-level courses involving six mathematics instructors, six physical science instructors, and four physics instructors who gave students content pre-tests and post-tests. Each instructor was also observed a minimum of two times during the semester using the RTOP. The correlation between the RTOP mean observation score and normalized student gain scores for these six math and science courses was 0.88 which was statistically significant at the .01 level.

Piburn and Sawada are continuing to examine the factor structure of the 25 items to discover the interrelationships among sets of items. As is typical of most social science instruments, the items constructed for each subscale do not always match the subscales reflected in the factor analysis. While some future item revisions may make the RTOP even more “factorially distinct,” the RTOP now offers an acceptably reliable and valid instrument to operationalize reformed teaching. If you want to document whether a math or science classroom fits the reformed teaching model, using the RTOP is a legitimate strategy to employ. In fact, the RTOP items could also be given to beginning and experienced K-16 teachers as a self-rating exercise to operationalize what reformed teaching could mean in their own math and science instruction.

*Developing and Utilizing an Observation Instrument to Define, Quantify, Assess, and Refine Reformed Teaching Practice in K-20 Science and Mathematics—The Reformed Teaching Observation Protocol (RTOP)*

Daiyo Sawada, University of Alberta and Michael Piburn, Arizona State University

E-mail: [mike.pilum@asu.com](mailto:mike.pilum@asu.com) or [dsawada@ualberta.ca](mailto:dsawada@ualberta.ca)

The Arizona Collaborative for Excellence in the Preparation of Teachers also sponsored a symposium at AERA where the impact of reformed teaching and the use of the RTOP was examined in various contexts. If any of the following questions intrigue you, contact the authors to get more details.

### **What difference does reformed teaching make:**

#### **...to pre-service education students?**

*Teacher Education for Arizona Mathematics and Science TEAMS 1996-2000: A Summative Evaluation*

Michael Piburn and Dale Baker, Arizona State University

#### **...to pre-service biology teachers?**

*Developmental Level and Overcoming Nature of Science Misconceptions Among Pre-Service Biology Teachers*

Anton Lawson, Arizona State University

**...to prospective elementary teachers?**

*An Evaluation of Reforms Instituted in Mathematics Courses for Prospective Elementary Teachers*

Irene Bloom, Arizona State University

**...to secondary science teachers?**

*Using the Reformed Teacher Observation Protocol (RTOP) as a Catalyst for Self-Reflective Change in Secondary Science Teaching*

Dan MacIsaac, Northern Arizona University; Kathleen Falconer, Arizona State University; and, Daiyo Sawada, University of Alberta

**...to college students in a large enrollment physical science course?**

*Effect of Reformed Courses in Physics and Physical Science on Student Conceptual Understanding*

Kathleen Falconer, Arizona State University; Joshua Mangala, Mesa Community College; Susan Wyckoff, Arizona State University; and, Daiyo Sawada, University of Alberta

**..in guiding student teachers?**

*Using the RTOP for Feedback to Student Teachers: A Metamorphosis of Method*

Jeff Turley, Michael Piburn, and Daiyo Sawada, Arizona State University

**...to beginning teachers during their first three years?**

*Tracking Transfer of Reform*

Eugene Judson, Arizona State University and Daiyo Sawada, University of Alberta

Contact info: <http://accept.la.asu.edu/>

- **To what degree do inquiry-based teacher practices actually influence science achievement?**

Certainly inquiry-oriented instructional practices have been widely touted as The Way to enhance students' science interest and understanding. The National Science Education Standards were developed to increase science achievement for all students. However, the student background variables of SES, race, and gender that have traditionally influenced academic

achievement have not been examined within the context of these inquiry-based instructional reforms. Clare Von Secker has undertaken such an examination.

The data for this investigation were the tenth grade follow-up survey of the National Educational Longitudinal Study sponsored by the National Center for Education Statistics. This follow-up study in 1990 comprised a national probability sample of public and private 1989-1990 tenth grade students. Von Secker used a sample of 4,377 students who had demographic data, tenth grade science achievement data, and their biology teachers' questionnaire data. Gender, socioeconomic status quartiles (based on parent questionnaire income, occupation, and education information), and minority race-ethnicity (African-American, Hispanic and American Indian) were the demographic variables used to classify the students. Five teacher practices reported on the questionnaire were used to classify their degree of inquiry-based teaching: a) student interest and engagement; b) using appropriate laboratory techniques; c) problem-solving; d) conducting further study; and, e) scientific writing. Her analysis used two-level hierarchical linear models to identify the associations of teacher practices with student achievement and student demographic variables.

A significant amount of variability in tenth grade science achievement was accountable for by gender (.48 SD lower for females), minority status (.51 SD lower), and socioeconomic status (.3 SD for every quartile increase in SES). The five identified teacher practices were associated with higher science achievement for all students with achievement increasing by .58 SD for every 1 SD increase in the emphasis teachers placed on an inquiry approach using the five practices. (Increases in student achievement for each specific practice were .22 SD, .28 SD, .33 SD, .36 SD, and .22 SD, respectively.) The real surprise was in the effects of specific teacher practices on the three-way interaction of SES, minority status, and gender. For example, in classes where the teacher emphasized student interest, majority female achievement rose almost three times more than for minority females. The effects of this teacher practice was negligible for majority males, but emphasizing interest in science was associated with less equitable achievement for minority males, especially those from low SES families.

The degree of teacher emphasis on the four other inquiry-based teaching practices also resulted in complicated interactions with gender, minority status, and SES. Each teacher practice was associated with a differential science achievement impact depending on the demographic student characteristics. In Von Secker's own words, "the impact of inquiry-based teaching is



sensitive to social context differences and these practices are as likely to exacerbate achievement gaps among some groups of students as they are to narrow them among others.” Her analysis reveals once again that no instructional practices, traditional or reform, are a panacea for low academic achievement, especially among disadvantaged students. Teachers must pay careful attention to the individual differences among students and how their various instructional practices affect those students.

*Effects of Inquiry-Based Teacher Practices on Science Excellence and Equity*

Clare Von Secker, University of Maryland

E-mail address: [clare@cais.net](mailto:clare@cais.net)

### **Next Steps?**

Hopefully, this rough cut of recent educational research has you cutting your teeth on new teaching and learning possibilities. Remember cutting edge research can cut both ways and not all of it will cut the mustard in your own classroom. So now it is time for you to cut loose, cut to the chase, and cut a deal. How can you use any of these research findings to cut a new path in your own teaching? And that’s my last cutting remark! ■



## **A I M S & S C O P E**

Articles are solicited that address aspects of the preparation of prospective teachers of mathematics and science in grades K-8. The Journal is a forum which focuses on the exchange of ideas, primarily among college and university faculty from mathematics, science, and education, while incorporating perspectives of elementary and secondary school teachers. The Journal is anonymously refereed, and appears twice a year.

The Journal is published by the Virginia Mathematics and Science Coalition.

### **Articles are solicited in the following areas:**

- all aspects of undergraduate material development and approaches that will provide new insights in mathematics and science education
- reports on new curricular development and adaptations of 'best practices' in new situations; of particular interest are those with interdisciplinary approaches
- explorations of innovative and effective student teaching/practicum approaches
- reviews of newly developed curricular material
- research on student learning
- reports on projects that include evaluation
- reports on systemic curricular development activities

***The Journal of Mathematics and Science: Collaborative Explorations*** is published in Spring and Fall of each year. Annual subscription rates are \$20.00 US per year for US subscribers and \$22.00 US per year for non-US subscribers.

All correspondence, including article submission, should be sent to:

Karen A. Murphy, Editorial Manager  
**The Journal of Mathematics and Science: Collaborative Explorations**  
Virginia Mathematics and Science Coalition  
Richmond, VA 23284-2014  
FAX 804/828-7797  
e-mail VMSC@vcu.edu

- For article submission, send three copies of the manuscript.
- The body of the paper should be preceded by an abstract, maximum 200 words.
- References to published literature should be quoted in the text in the following manner: [1], and grouped together at the end of the paper in numerical order.
- Submission of a manuscript implies that the paper has not been published and is not being considered for publication elsewhere.
- Once a paper has been accepted for publication in this journal, the author is assumed to have transferred the copyright to the Virginia Mathematics and Science Coalition.
- There are no page charges for the journal.

Copy editor: E. Faircloth

*(Contents continued from back cover)*

THE DESIGN, IMPLEMENTATION, AND ASSESSMENT OF A NEW CAPSTONE COURSE AIMED AT SCIENCE EDUCATION MAJORS R. Betancourt and J. Arce	105
CREATIVITY VS. STRUCTURE: A CHALLENGE IN DISCOVERY CHEMISTRY R. S. Lamba	115
PROGRAM EVALUATION IN THE CONTEXT OF DEBATES IN THE FIELD: THE EVALUATION OF PR-CETP M. Bravo	127

## **PART II: Regular Journal Features**

PROJECT MATRIX: IDENTIFYING THE MATHEMATICALLY TALENTED AND MEETING THE MATHEMATICAL NEEDS OF ALL M. K. Murray	143
SATURDAY MORNING PARENT AND CHILD EDUCATION (PACE) D. J. Bagby and P. A. Priestas	153
BRIDGES TO THE BACCALAUREATE PROGRAM AT J. SARGEANT REYNOLDS COMMUNITY COLLEGE AND VIRGINIA COMMONWEALTH UNIVERSITY D. Neely-Fisher	165
EDUCATIONAL RESEARCH ABSTRACTS G. Bass, Jr.	173

## CONTENTS    Volume 4, Number 2

---

### **PART I: “Fostering a Knowledge-Building Community of Practitioners”**

Puerto Rico Collaborative for Excellence in Teacher Preparation

THE PUERTO RICO COLLABORATIVE FOR EXCELLENCE IN TEACHER PREPARATION (PR-CETP): DEVELOPMENT OF A KNOWLEDGE BUILDING COMMUNITY OF PRACTICE J. Arce and S. Macksoud	1
THE TRANSITION TO COLLEGE PROCESS IN PR-CETP SCHOLARS E. Rivera, M. Rosa, A. Santiago, N. Torres, and M. Bravo	7
CONCEPT BUILDING THROUGH ACTIVE LEARNING EXPERIENCES WITH THE CALCULATOR BASED LABORATORY (CBL) N. Motta	25
APPLICATION OF BIOTECHNOLOGY TO SOLVE RELEVANT BIOLOGICAL PROBLEMS PROMOTES UNDERSTANDING OF UNDERLYING CONCEPTS P. A. Burrowes and G. M. Nazario	37
HELPING STUDENTS MASTER CONCEPTS IN MECHANICS BY GRAPHING WITH SPREADSHEETS G. F. Restrepo	47
AN INNOVATIVE UNIVERSITY COURSE FOR COOPERATING TEACHERS M. Aguirre Ortíz and L. Gaspar	59
USING MANIPULATIVES IN UNDERGRADUATE MATHEMATICS COURSES D. Moore	67
UNDERSTANDING OF THE MOLE CONCEPT ACHIEVED BY STUDENTS IN A CONSTRUCTIVIST GENERAL CHEMISTRY COURSE C. Utria-Echevarria and M. Bravo	75
THE LEARNING OF MATHEMATICAL CONCEPTS AND PRINCIPLES THROUGH THE INTEGRATION OF TECHNOLOGY IN LABORATORY ACTIVITIES E. Morera González	97

*(Contents continued inside)*