

Science Graduate Students in K–8 Classrooms:

Experiences and Reflections



The SOUTHEAST EISENHOWER
REGIONAL CONSORTIUM at
for MATHEMATICS and
SCIENCE EDUCATION **SERVE**

Science Graduate Students in K–8 Classrooms:

Experiences and Reflections



Penny J. Gilmer,
D. Ellen Granger,
& Wilbert Butler (Eds.)

The SOUTHEAST EISENHOWER
REGIONAL CONSORTIUM at
for MATHEMATICS and
SCIENCE EDUCATION | **SERVE**TM

The SERVE Center at UNCG

*Associated with the
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University of North Carolina
at Greensboro*

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The Southeast Eisenhower Regional Consortium for Mathematics and Science Education @ SERVE



The Southeast Eisenhower Regional Consortium for Mathematics and Science Education @ SERVE is one of ten regional consortia created by Congress to improve mathematics and science education throughout the nation. The Consortium has three objectives:

- ↳ Coordinating mathematics and science resources
- ↳ Disseminating exemplary mathematics and science educational instructional materials
- ↳ Providing technical assistance for the implementation of teaching methods and assessment tools for use by elementary and secondary school students, staff, and administrators

The Consortium frames its work through the following focus areas:

- ↳ **Collaboration and Communication.** Joining forces with other mathematics and science education organizations at the national, state, and local levels
- ↳ **Programs and Curricula.** Identifying and disseminating exemplary mathematics and science materials with and through the Eisenhower National Center and other educational agencies
- ↳ **Professional Development.** Providing for the training of teachers, administrators, and other trainers in the use of exemplary mathematics and science materials, methods, and assessments
- ↳ **Curriculum Frameworks.** Assisting in the development and implementation of standards-based state curriculum frameworks
- ↳ **Technology.** Facilitating the use of telecommunications technology as a tool for mathematics and science instruction
- ↳ **Equity.** Supporting programs and activities that meet the needs of underserved groups in mathematics and science
- ↳ **Informal Education Agencies.** Supporting the use of informal mathematics and science agencies through disseminating information and encouraging collaboration
- ↳ **Community Outreach.** Promoting dialogue with community groups to engage them in meaningful ways to support mathematics and science

We offer the following services to promote our objectives:

Networks

- ↳ Collaborating with existing networks of mathematics and science educators
- ↳ Building and supporting new networks
- ↳ Providing opportunities for educators to share ideas and observations about what works in mathematics and science education
- ↳ Sponsoring conferences, teleconferences, meetings, and symposia

Access to Promising Practices in Mathematics and Science

- ↳ Identifying successful mathematics and science programs
- ↳ Publishing information on effective programs

Technical Assistance

- ↳ Helping schools and districts adapt and use new programs, policies, equipment, and resources
- ↳ Identifying the training needs of mathematics and science educators
- ↳ Developing effective training to meet identified needs through a Technical Assistance Academy for Mathematics and Science Services (TAAMSS)

Resources

- ↳ Providing access to SERVE products and services
- ↳ Helping educators gain access to local, state, regional, and national resources

Free and Low-Cost Materials

- ↳ Developing practical resources schools can use, including publications, video tapes, resource lists, and policy briefs that address concerns from schools, districts, and state education agencies

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About **SERVE**

The SERVE Center for Continuous Improvement at UNCG, under the leadership of Dr. Ludwig David van Broekhuizen, is an education organization with the mission to promote and support the continuous improvement of educational opportunities for all learners in the Southeast. The organization's commitment to continuous improvement is manifest in an applied research-to-practice model that drives all of its work. Building on research, professional wisdom, and craft knowledge, SERVE staff members develop tools, processes, and interventions designed to assist practitioners and policymakers with their work. SERVE's ultimate goal is to raise the level of student achievement in the region. Evaluation of the impact of these activities combined with input from stakeholders expands SERVE's knowledge base and informs future research.

This rigorous and practical approach to research and development is supported by an experienced staff strategically located throughout the region. This staff is highly skilled in providing needs assessment services, conducting applied research in schools, and developing processes, products, and programs that support educational improvement and increase student achievement. In the last three years, in addition to its basic research and development work with over 170 southeastern schools, SERVE staff provided technical assistance and training to more than 18,000 teachers and administrators across the region.

The SERVE Center is governed by a board of directors that includes the governors, chief state school officers, educators, legislators, and private sector leaders from Alabama, Florida, Georgia, Mississippi, North Carolina, and South Carolina.

SERVE's operational core is the Regional Educational Laboratory. Funded by the U.S. Department of Education's Institute of Education Sciences, the Regional Educational Laboratory for the Southeast is one of ten Laboratories providing research-based information and services to all 50 states and territories. These Laboratories form a nationwide education knowledge network, building a bank of information and resources shared and disseminated nationally and regionally to improve student achievement. SERVE's National Leadership Area, Expanded Learning Opportunities, focuses on improving student outcomes through the use of exemplary pre-K and extended-day programs.



This monograph is dedicated to Lisa Upham who provided excellent secretarial, technological, and editorial help throughout the entire GK–12 grant, including this GK–12 SERVE monograph.

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Foreword

This monograph is timely. For many years university scholars have participated in outreach activities with the goal of improving K–12 education. With the advent of a National Science Foundation program to fund collaborative projects between K–12 and university scientists, there was a clear need for a scholarly publication that described how a project was planned and enacted, explored the successes and contradictions, and considered what improvements were necessary. This monograph does just that by using a variety of data resources and sociocultural theoretical frames to highlight the benefits, contradictions, and directions for the future based on research and evaluation of a NSF-funded project from the Graduate Teaching Fellows in K–12 Education program (hereafter referred to as GK–12).

When done well, the sort of project described in this monograph has the potential to substantially improve K–12 science education. Most would agree that scientists should be major stakeholders in K–12 science education, and if they can successfully collaborate with K–12 teachers, there seem to be strong prospects for enacting high-quality science curricula. Yet effective collaboration between participants can be elusive. Plans for collaboration that appear persuasive and elegant on paper can be replete with contradictions and require consistent tinkering when enactment occurs. An assumption underlying successful collaboration is mutual respect among participants. If this is to occur, the identities of all participants need to be secure. Ideally each participant must feel confident that he or she has something to offer and each must be prepared to learn from the other.

However, unlike the project described in this monograph, many GK–12 programs were developed around deficit ways of thinking about the quality of K–12 science education. Plans often focused on the shortcomings of teachers and teaching, especially on the inadequacies of teachers' subject-matter knowledge and whether they knew enough to successfully teach science. From this perspective there is some appeal in plans to provide additional science subject matter experts to offset the deficits in the resident teachers' knowledge. Not surprisingly, such approaches to collaboration are not well received by most teachers who regard themselves as well-qualified, professional, hard working, and effective in the circumstances in which they have to teach. Projects that begin with deficit perspectives have a lower likelihood of success than those in which it is realized that all participants in collaborative projects can learn from others through active coparticipation.

From the perspective of the science graduate students, it is important that they have understandings about teaching, learning, and curriculum so that their conversations with teachers are informed by up-to-date knowledge about appropriate resources, models, theories, and research. In this project, the graduate students were involved in a course that dealt with such topics prior to beginning their collaboration with teachers. Subsequently, they have to understand how to successfully interact with teachers and, in so doing, become resources for enhancing their learning and teaching. Such interactions should expand the teachers' identities as science educators. At the same time, the science graduate student should approach all interactions with the teachers as a learner intent on learning from their knowledge and wealth of experiences. Hence, being willing to learn from others while being their tutor is a central tenet of successful collaborative ventures. Classroom teachers also should see themselves as teachers and learners in collaborative projects such as the one featured in this monograph. Furthermore, it is essential that they create structures to allow the graduate science students (GK–12 Fellows in this monograph) to actively participate in a full range of roles so that they can use their

expertise in science to create opportunities for students to learn science and for coteachers to learn about teaching science.

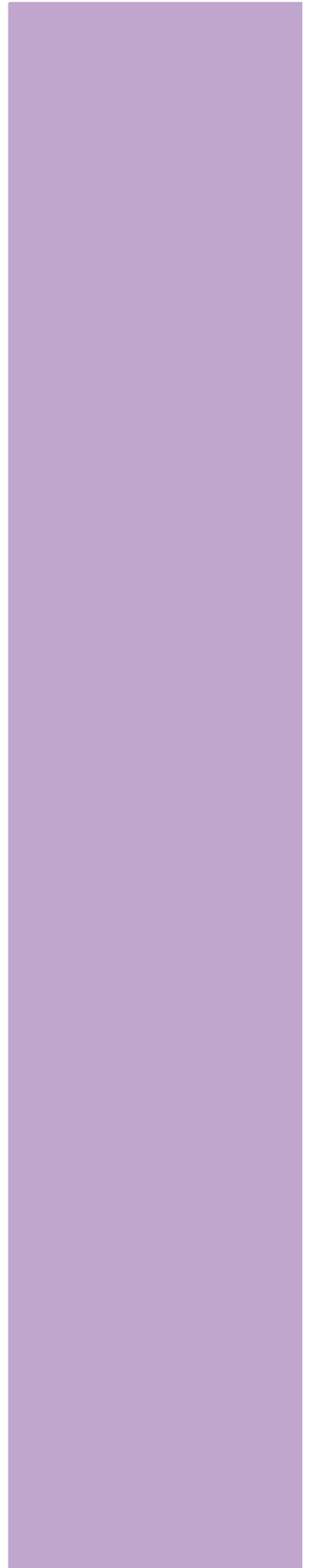
The uses of coteaching in this project open the door for each coteacher to learn from the other. Accordingly, if both teachers teach at one another's elbow, then there is scope for learning to occur consciously and unconsciously. In a seven-year project of collaborative research, we found experienced and less experienced teachers learning from one another about how to more effectively teach science to urban youth who were ethnically and socially different from either coteacher. Also, we found that experienced science educators learned more science subject matter when they cotaught with others. Hence, the uses of coteaching may be a primary means for achieving the goals of this GK–12 project. What caught my eye in this monograph was the possibility that the coteachers' goals progressed from personal growth and change to collective growth and change in the context of cotaught classes.

A feature of the monograph is its inclusion of practitioner research from a GK–12 program that made a conscious effort to ascertain what was happening and why it was happening. There is considerable merit in participants undertaking research on their own practices and, on the basis of what is learned, effecting changes so as to improve the quality of enactment. Most often these forms of educational engineering involve identifying contradictions and dealing with them—in some cases eliminating them because they are deleterious and in other cases increasing the incidence of desirable, but infrequent, practices. Hence, taking what was done in this GK–12 project and using practitioner research to enhance the quality of collaboration has the potential to improve the quality of what is attempted in the participating science classes while providing bases for disseminating to others what is learned from the research.

The topics dealt with in this monograph cover the terrain of interests for science educators and include the infusion of good science into curricula, personal learning and growth as a teacher, inquiry and the use of models such as the learning cycle, cooperative learning, effective teaching, and learning science with understanding. Just how these issues arose during a GK–12 collaborative project set in K–8 classes is illustrated in nine chapters written by some of the participants. The result is a volume that is bound to catch the attention of school and university personnel who are open to establishing partnerships to benefit K–12 science education. As is shown in these chapters, they may get more than they bargained for. Not only are improvements likely in K–12 education but also in the quality of college science education. One of the more exciting aspects of the project described in this monograph is that college science faculty learn about learning, teaching, and curriculum, and then, through their activities in K–8 classrooms, they develop knowledge of science education that has the potential to be applied for the benefit of improving not only subsequent populations of K–12 students but also the quality of college science teaching and learning. The prospects of creating a critical mass of science faculty in universities with the motivation and skills to collaborate not only with colleagues in the college of education within their own university but also with K–12 teachers are appealing and auger well for the long term prospects of science education in the U.S.

Kenneth Tobin

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Florida State University Science Graduate Students Working With K–12 Teachers and Students

By D. Ellen Granger

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Ellen Granger, co-Principal Investigator on the GK–12 grant.

Why I chose my fields:

My first love, brain research, is one of the “final frontiers” of science to me. I love discovering how this intricate organ enables different species to solve their “problems of life.” My second love, science teaching and learning, evolved from my first. How do we better communicate our scientific findings? How do we ensure a scientifically literate public? How do we ensure a continued pipeline of young students interested in entering science as a human endeavor? These questions, combined with my love of teaching, have driven my passion for science teaching and learning.

Why I wrote the GK–12 program proposal:

To help scientists make more meaningful contributions to K–12 science teaching and learning. I feel that this is critical for a scientifically literate public and for a continued pipeline of young students interested in entering science as a career. The best time to reach scientists and give them a chance to learn about K–12 science teaching and learning is during their formative years as graduate students. Hence, I wrote the GK–12 grant proposal.

What I gained from the GK–12 program:

I have learned a tremendous amount about science teaching and learning from the GK–12 teachers, the GK–12 graduate fellows, and my science colleagues at FSU as a result of this program and would like to thank each of them for this. I have also learned about how to help science graduate students become better teachers at any level, K–20.

Addressing Our Country’s Needs

How can we make sure that the next generation is prepared to supply the mathematics and science core forms of knowledge? With less than 10% of our public judged to be scientifically literate and our children performing almost last of the 41 countries participating in the Third International Mathematics and Science Study (TIMSS) by high school graduation, will we be prepared to sustain our products, services, standard of living, and economic and military security?² What should we be doing to maintain the pipeline of bright, young scientists and mathematicians and to create the scientifically literate populace necessary to make informed decisions about science policy as it impacts society?

Several recent reports have addressed these questions,^{1,3,4,5,6} and the answers are multifaceted. It is clear that to achieve the desired results, scientists and mathematicians must become more involved in the answers: our teaching practices in science and mathematics at the K–12 and undergraduate levels must be changed. This is not as easy a task as it may seem at face value. Just as the background of most K–12

From mathematics and the sciences will come the products, services, standard of living, and economic and military security that will sustain us at home and around the world. From them will come the technological creativity American companies need to compete effectively in the global marketplace... mathematics and science will also supply the core forms of knowledge that the next generation of innovators, producers, and workers in every country will need if they are to solve the unforeseen problems and dream the dreams that will define America’s future.

— Report to the Nation from the National Commission on Mathematics and Science Teaching for the 21st Century (Glenn Commission)¹

teachers has not provided them with adequate opportunities to learn about scientists and the process of science, the background of most scientists has not provided them with adequate opportunities to learn about the educational challenges surrounding the teaching of K–12 students. Nor have most university faculties researched their undergraduate teaching to discover more successful teaching practices. Most scientists, therefore, are not prepared to bridge the gulf between their profession and the K–12 classroom so as to make significant contributions to K–12 science and mathematics teaching and learning, nor are they comfortable doing so. Some do make well-intentioned efforts to contribute to K–12 classrooms, but their lack of sufficient preparation and experience often results in less than satisfying outcomes for both parties. Preparation for undergraduate teaching suffers from the similar neglect. Likewise, most K–8 teachers are not prepared to incorporate inquiry-based science into their classrooms.

Enacting the GK–12 Program

Addressing the Goals of the Program

One effort to address these issues is the National Science Foundation’s (NSF) Graduate Teaching Fellows in K–12 Education (GK–12) program. This program “supports fellowships and associated training that enable graduate students and advanced undergraduates in science, technology, engineering, and mathematics [STEM] disciplines to acquire additional skills that will broadly prepare them for professional and scientific careers in the 21st century.”⁷ The goals of the NSF for this program are:

1. To support highly qualified graduate students in NSF-supported STEM disciplines through Fellowships to provide them with an opportunity to acquire additional skills that will broadly prepare them for professional and scientific careers in the 21st century.
2. To improve STEM instruction in K–12 schools.
3. To provide institutions of higher education with an opportunity to make a permanent change in their graduate programs by including partnerships with K–12 schools in a manner that is of mutual benefit to their faculties and students.⁸

The Florida State University (FSU) GK–12 project funded by the NSF is designed to promote meaningful interactions between science professionals and K–12 teachers and students by educating future science professionals (graduate students in the sciences) about K–12 science teaching and learning and by educating K–12 teachers about science inquiry, *and* to give all successful experiences in the same. The goal of our GK–12 project is to increase the number of science professionals who are prepared and willing to make *meaningful* contributions to the K–12 science and mathematics enterprise and to enhance the science and mathematics teaching practice of K–12 teachers. Our objectives for this project are:

1. To teach GK–12 graduate fellows about the teaching and learning of science. Instruction includes child development; how students of different ages, abilities, cultural backgrounds, and learning styles learn; and how best to communicate science and mathematics content on the basis of these principles.
2. To train GK–12 graduate fellows in the use of curriculum resources for elementary and middle school students.
3. To teach GK–12 graduate fellows about assessment alternatives for K–12 science.
4. To allow GK–12 graduate fellows the opportunity to use their expertise in science, mathematics, and technology and new-found knowledge about learning processes and knowledge transfer in the classroom to enhance elementary and middle school science teaching and learning.

5. To add to local science teachers' arsenals of high-quality inquiry-based activities that engender scientific habits of mind in their students.
6. To help local teachers incorporate science inquiry activities into their teaching practice.
7. To evaluate the effectiveness of these objectives in terms of graduate student outcomes and K–12 student and teacher outcomes.

GK–12 Fellow, Mabry, reflecting on the density lesson the GK–12 Fellows did with elementary-school students as their first foray into the classroom.

Preparing the GK–12 Fellows to Teach

Doctoral students were recruited from science departments at FSU to become NSF GK–12 Fellows. Selected students engaged in extensive learning to prepare them to become valuable classroom resources for K–12 teachers and students. To achieve this, we designed a graduate course, *Science Teaching and Learning*, which focused on two themes: (1) child development and learning and (2) effective communication of science content (see sample syllabus in Figure 1). The course was grounded in the *National Science Education Standards*.³ It began with a unit on child development and how people learn, how this learning is affected by various factors, and how to use this knowledge about cognition effectively in the science classroom that was taught by faculty from the Department of Psychology in the College of Arts and Sciences and from the Educational Psychology program of the College of Education.



The second unit of the course was on “Communicating Science” designed by a collaboration of educators at the University of California, Berkeley, Lawrence Hall of Science with scientists from its science departments. The FSU Office of Science Teaching Activities, where this GK–12 program is administered, had previously been one of the test sites for this curriculum. This unit introduced the Fellows to a series of effective, widely tested, K–8 instructional materials as exemplars of important educational strategies in science teaching. In it, the theoretical aspects of teaching were interwoven with practical lesson applications. As a result of their experience with the benefits of inquiry-based activities designed for K–8 students, we expected the Fellows to engage in the process of learning science and reflection upon their teaching. This experience gave them a chance to examine and analyze a variety of best practices in science teaching and informed them about some high-quality instructional materials for teaching science at the same time. The course ended with an exploration of high-quality curriculum resources for classroom use. After the course, Fellows continued formal study and discussion of teaching and learning through monthly meetings. The Fellows increased the depth and breadth of their knowledge about the process of learning and knowledge transfer through discussion of their classroom experiences and a “journal club” format of readings from current science teaching-and-learning literature.

Enacting the Teaching and Learning Process

In the semester after course completion, Fellows began working in K–8 classrooms. Fellows and their partnering K–8 teacher, designated as a GK–12 Teacher, utilized a co-teaching format. Fellows served as content and curriculum resources as well as participated in classroom instruction. As the program evolved, we learned that Fellows need to spend at least one-half of an academic year in each classroom for a productive partnership to develop between the GK–12 Teacher and



Child testing density of objects in a GEMS activity.

An NSF GK-12 teacher, Jen Simmons, supervised Mabry in a seventh-grade Earth science classroom. She was our teacher representative to the national GK-12 meeting in Washington, D.C. in 2004.

Fellow. For their classroom placements we tried to give Fellows a broad experience in teaching. All had assignments in at least one elementary and one middle school classroom. Fellows generally rotated from teaching in a standard “suburban” type class one semester to a Title I school during the following semester.

During summer semesters, GK-12 Fellows and Teachers participated in a variety of summer programs to enhance their teaching practice. The Fellows either served as teaching assistants or participants in one of the summer professional development experiences offered for K-12 teachers at FSU administered by the Office of Science Teaching Activities in the College of Arts and Sciences or by the National High Magnetic Field Laboratory also at FSU, or they participated in a *Saturday-at-the-Sea Summer Camp*—a week-long immersion in marine-science inquiry for middle school students, also administered by the Office of Science Teaching Activities.

Science graduate students are at a stage in their academic development in which they are open and willing to respond to what constitutes quality science teaching. The format of this instruction is critical—it must employ the methodology that we advocate. After experiencing the power of reform-based methodology first hand through formal education and by employing it in the classroom, the Fellows are more likely to become supporters of the principles learned.

Actualizing the Benefits of the Program

Short-term benefits of this project included the learning and the experience that the program immediately brings to the Fellows. This learning and experience enhanced their communication and teaching skills and thus their value as educators not only for the K-12 community

but also for the undergraduate classroom. The GK-12 Teachers have benefited from their participation in summer institutes and the participation of the Fellows

in their classrooms. Participation of young scientists in the classroom brings an approach to science teaching that provides more relevance for



D. Ellen Granger, co-PI on NSF GK-12 grant, seated (center) with some of the GK-12 Fellows after a monthly group meeting.

K–12 students and enriches their learning of science.

In the long term, as the Fellows move into their science professions, we expect that the number of K–12 teachers and students benefiting from their expertise will multiply. The GK–12 Teachers will continue to influence the science knowledge and attitudes of new groups of students who pass through their classrooms. The chapters that follow, written by some of our GK–12 Fellows (and one co-written with one of the GK–12 Teacher partners), detail features of the experience that each Fellow has considered to be particularly meaningful. Our program’s internal evaluator, Penny J. Gilmer, with Martin Balinsky, a science education graduate student who has worked with Dr. Gilmer on this project, conclude the monograph with a look at what our data collection on the program indicates about its impact.



Child finishing up her data chart from inquiry experiment.

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Figure 1: The syllabus for the course I offered the cohort of nine GK–12 Fellows at the start of the program.

Syllabus, BSC 5936—Teaching and Learning Science—Fall 2002

M & W 8:00-10:00; Room 236 Conradi

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Text: National Science Education Standards, National Research Council, 1996.

Principles of Teaching and Learning

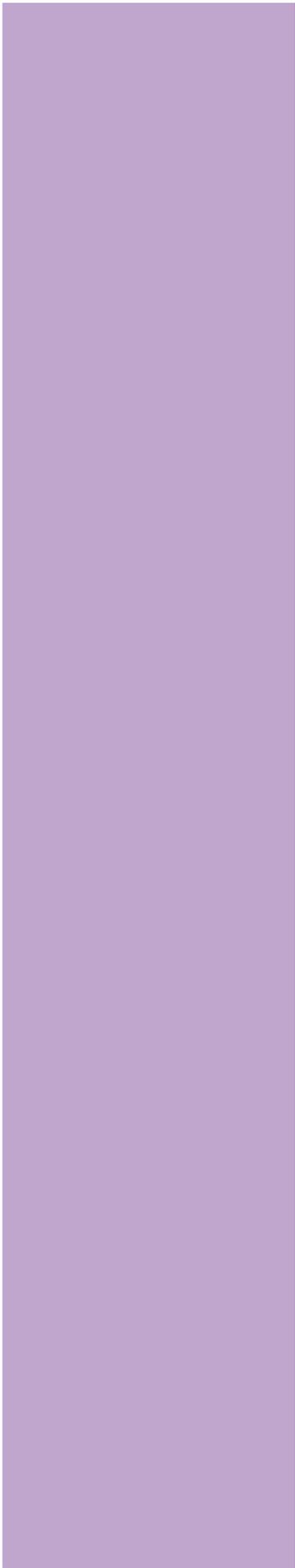
08/26	Course Introduction	Dr. Ellen Granger, Office of Science Teaching Activities (OSTA)
08/26	Cognitive Development of Children	Dr. Richard Wagner, Dept. of Psychology
08/28		
09/03		
09/09	How Students Learn and Related Issues	Dr. Marcy Driscoll, Dept. of Education, Psychology and Learning Systems
09/11		
09/16		
09/18		
09/23	Science Standards	Dr. Ellen Granger
09/25	Classroom Management	Ms. Coveta Grant, Sealey Elementary School, Ms. MaLynn Kelso, Belle Vue Middle School

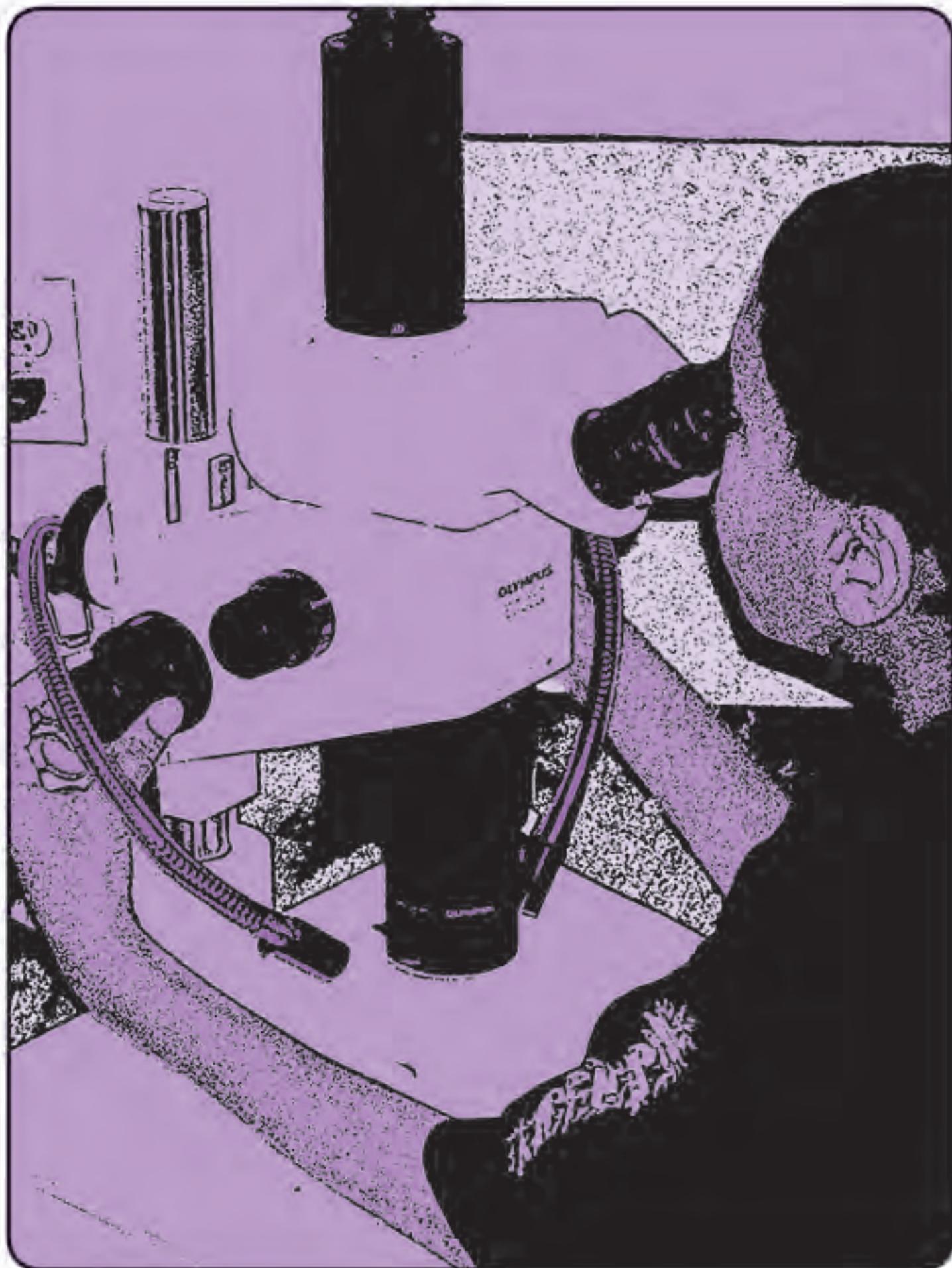
Communicating Science

09/30	Nature of Science	Dr. Ellen Granger, OSTA
10/02	Teaching Approaches	Granger
10/07	Blank Slates or Clever Minds: A Constructivist Approach	Granger
10/09	Questioning Strategies	Granger
10/14	The Questions Lab (at Sealey Elementary School)	Granger
10/16	Promoting Discussion	Granger
10/21	Introduction to Assessment	Granger
10/23	Inclusive Learning Environment	Granger
10/28	Designing a Lesson	Granger
10/30	FCAT and Other Assessment Issues	Dr. Al Oosterhof, Dept. of Education, Psychology and Learning Systems

K–12 Exemplary Curriculum Units

11/04	Great Explorations in Math and Science “GEMS”	Mr. Todd Bevis, OSTA
11/06		
11/13		
11/18	Curriculum Activities Designed by National High Magnetic Field Laboratories (NHMFL)	Dr. Pat Dixon, NHMFL
11/20		
11/25	Activities from Saturday-at-the-Sea (SATS) and Marine Activities, Resources, & Education (MARE)	Ms. Barbara Shoplock and Mr. Bob Lutz, OSTA
12/02	Activities from Science on the Move	Mr. Lance King, OSTA
12/04	Final Course Assessment	Dr. Penny J. Gilmer, Dept. of Chemistry and Biochemistry





Incorporating Physics Into the Middle School Science Curriculum

By David Graf

Biographical information:

David Graf, Ph.D.
Ph.D. in the Department of Physics at Florida State University
Major advisor Dr. James Brooks
First GK-12 Fellow to graduate with his doctorate

Ph.D. Dissertation Topic:

“Magnetic Field-Dependent Electronic Structures of Low-Dimensional Organic Materials”

Why I chose my field:

I enjoy “hands-on” experimental work and the National High Magnetic Field Laboratory is unparalleled in the world for its facilities and the magnetic fields available.

Why I applied for the GK-12 program:

In my three years in graduate school before joining the program, I saw how wide the gap was between international and domestic students in terms of science/mathematics education (at least in physics). Trying to work with children in their early years to show them that science can be fun and exciting was important to me.

What I gained from the GK-12 program:

I am far more comfortable working with groups of children. I have learned and used valuable lessons about the learning cycle, classroom management, and how to correlate science standards with classroom activities (an important consideration as every teacher in Florida worries about the Florida Comprehensive Assessment Test—FCAT—and the No Child Left Behind Act).



David at the start of the GK-12 Fellow program.



GK-12 fellow, David Graf (2nd from right), with his wife and parents, standing by a sculpture of Jack Crow, founder of the National High Field Magnetic Laboratory. David is the first person named as the Jack Crow Postdoctoral Fellow. Jack Crow was a dedicated scientist and educator, and David follows in his footsteps. David's new fellowship started shortly after defending his dissertation in June 2005.

Introduction

Some teachers in middle school classrooms find the transition from earth science and biology lessons to physics intimidating. The reason for this anxiety is not completely clear. Perhaps it is because many find it difficult to give a clear explanation in physics within the context of middle school mathematics. It could be due to the lack of exposure to both the content they are teaching and the equipment that the students use for experiments and activities. Nobel Laureate Leon Lederman takes note of the problem when discussed within the context of a typical high school curriculum, “[S]tudents were still taking biology (or earth science) in ninth grade, with 50% going on to a year of chemistry and maybe 20% taking a third year, the dreaded physics, as juniors or seniors.”¹ The answer to this decrease in science involvement is exposing students to physics earlier and in a more engaging manner. If students develop a fear of physics before their high school years, maybe the reason lies in their lack of experience with the subject in middle school.

The Third International Mathematics and Science Study (TIMSS) in 1999² found that U.S. students in the fourth grade score well in mathematics and science in comparison to other countries. That interest seems to decline by the eighth grade, as reflected through declining test scores from that age group. In short, if science classes in middle school do not engage students, it is unlikely the students will continue to build a strong foundation in mathematics and science in the future. John Glenn,



A fifth-grader adjusting the microscope so that he can better visualize the material.

Chair of the Senate Committee, quoted this TIMSS study in the U.S. Senate report *Before It's Too Late*, a product of the National Commission of Mathematics and Science Teaching (NCMST).³ The TIMSS and NCMST reports paint a grim and urgent picture of how science teaching in the U.S. must improve if today's domestic students are going to compete for the top positions in an increasingly global marketplace.

These findings, along with my teaching observations of the past two years, made me curious about student performance in physics. Is it really too late? Especially in the area of physics, in which students will need to pursue futures in fields of technology or engineering, are we past a point where we can improve things? Is what I read in these reports what I actually saw in the classroom? What do the teachers with whom I worked think we can do to improve science and specifically physics education at the middle school level? With these questions in mind, I returned to the Tallahassee middle school classrooms where I had co-taught as a GK–12 fellow. Through an informal interview with each of the two eighth-grade

science teachers with whom I worked, I learned their views on teaching physics, their comfort level with the topic, and the ways they thought teaching could be improved. I also interviewed Luke Jackson, who runs a FSU program providing science equipment and lessons to local schools. He also directs a summer workshop for middle school science teachers in which I have worked for two summers. I have tried to incorporate my observations from working with these teachers and our collective opinions to answer some of the above questions.

Teaching Experiences and Observations: Learning Environments, Veteran Educators, and Meeting Standards

What It Is

In Fall 2002, I entered the Florida State University (FSU) chapter of the National Science Foundation (NSF) GK–12 Fellowship program. This initiative enables graduate students from various areas of science to “co-teach” in elementary and middle school classrooms. The idea behind co-teaching allows GK–12 fellows to work in a science classroom along with a teacher with the goal of enhancing the way we communicate science through lessons and activities. In my first and third semesters of teaching in the program, I worked in different eighth-grade science classrooms. Each of the teachers with whom I worked was a veteran eighth-grade instructor.

Working with Mary was my first co-teaching experience in the GK–12 program. We worked together for four mornings each week, with two classes each day. During the semester, we covered a number of topics, including forces and motion, waves, energy, cells, ecosystems, space, and even how to use a microscope. Wanting to get off to a good start, I tried to think of activities that the students could do that would get them out of their seats and keep them interested.

I observed that the learning environment is a critical factor in a student's education process. The environments within the two middle schools in which I worked were very different. Mary Kopp's school (referred to hereafter as Tallahassee Middle School #1 or

Science night.



TMS1) had discipline policies in place, but students were much more likely to break the rules. It was clear at times that some of the students in Mary's school thought that learning science was a waste of their time.

There were other challenges in addition to the problems associated with classroom discipline. For example, a Florida⁴ report showed that 75% of students in TMS1 were considered "economically disadvantaged."⁵ TMS1 accepts federal resources to fund, among other things, the students who cannot afford to buy a full-priced lunch. Accepting this federal funding means trying to meet the federal guidelines for student achievement under the No Child Left Behind Act (NCLB). TMS1 must also meet the Sunshine State Standards (SSS) requirements for eighth-graders. These standards require a set of assessments in February and March of each year (the Florida Comprehensive Achievement Test or FCAT) to test students' writing, reading, mathematics, and science skills. TMS1 was rated as a "C" school based on the 2004 results, placing it into the lowest academic 30% of schools in the district. The learning environment, social, and economic factors, as well as the pressure to meet standards all warrant attention because of their obvious impact on the classroom environment and time constraints in teaching the topics.

Mary, one of my GK–12 Teachers, studied geology in Tennessee after serving in the U.S. Navy. She also completed a master's degree in science education from FSU. She has been teaching at TMS1 for 15 years. Mary is certified by the National Board and prides herself in helping other teachers reach these goals. With her background in geology, Mary considers herself a "rock hound." When exploring her storage room for laboratory equipment, I ran across a couple of bins filled with rocks. While I would have only thought of them as paperweights, she knew many scientific names and origins. What impressed me most about Mary was her presence in the classroom. Mary is tiny in stature; nonetheless, most students showed her proper respect and listened to her.

For our first experiment with the students, Mary enthusiastically accepted the idea of using a lab that I wrote, which measured the speed and acceleration of toy cars rolling down a ramp. We tried to incorporate the concepts of measuring time and length and observing the effects of acceleration from gravity. I quickly learned that the eighth-grade classes did not enjoy mathematics but were happy to do any activity rather than listen to a lecture. I do not know if the attention spans of eighth-graders vary, but I believe they are easily distracted by various elements in the classroom, especially by the behavior of their peers.

During the semester, we developed labs that required full class periods for exploring wave motion, the phases of the moon, and why the seasons of the year depend on the tilt of the Earth's axis. Mary was very open to using my ideas, and this made me feel like my input counted for something. I will admit that I did not feel comfortable speaking in front of her class as much as I did contributing by developing ideas and preparing the experiments. Three more semesters in the program have given me a more solid background as a speaker for both elementary and middle school children. Mary did a fine job of giving pre-lab instructions, and I assisted her by working around the room during the lab to help any student who seemed confused or needed further instruction.

The reading level of students at TMS1 is low (as tested by FCAT standards), and the students' attention spans are short; therefore, conventional reading, lecturing, and testing are not successful teaching strategies. On a positive note, instructors at



GK–12 Fellows, Mabry Gaboardi and David Graf, having their first experiences in teaching science to elementary-school students.



GK-12 Fellow, David Graf, on the job at an elementary school.

all levels of science teaching are beginning to abandon this out-dated approach and replace lectures with well-structured, hands-on activities.⁶ Students at TMS1 do not respond well to homework, and many seem to receive little support at home to finish it. As a result, many labs or worksheets become class work. Using this strategy, teachers can offer help to students who need it while checking that assignments are completed. The assignments must be collected from the students on a daily basis and retained by the teacher so that they are not lost, forgotten, or thrown away. On several occasions, I found assignments that I had handed out just moments earlier on the classroom floor as the students left the room.

Following a semester of teaching in the fifth grade, I had the opportunity to work in another eighth-grade classroom at another middle school in Tallahassee (hereafter referred to as Tallahassee Middle School #2 or TMS2). Tammy has been teaching science at the eighth-grade level a few years longer than I have been alive. I found out that I liked working with the older students more because they had the potential to work on topics at a deeper level. By this point in time, I felt comfortable teaching and a little more seasoned in my duties associated with the GK-12 program. Though I felt ready to contribute, I found that Tammy was reluctant to let me take charge in any section of the curriculum. A lot of her material was quite good, so I was happy to assist her with teaching and file away the ideas for future use.

Tammy is well organized and has teaching strategies for every topic. She is a designated physical science teacher, so the topics in her course do not vary from year to year. She prides herself on staying current with science content in the news and especially with new teaching technology. Rather than resorting to a typical lecture using an overhead projector or marker board, she is much more likely to use Microsoft PowerPoint and a laptop computer. This gives her a better opportunity to discuss topics and work with her class as she goes through the lesson. Tammy proposed and was awarded a grant that funded a new science building where her classroom is approximately 1,500 square feet of open space, ideally suited for lab activities.

Tammy's school has strict policies on attendance, coming late to class, respect toward peers and teachers, and even attire. Physical conflict is an unlikely occurrence in Tammy's school but is much more common in Mary's school. Though violence can have obvious physical implications, it is a further nuisance because fights draw the focus away from learning for every student. The guilty students are often the students who need academic help. They are suspended from school and, consequently, miss valuable lessons. From what I observed, the school's no-nonsense guidelines regarding physical conflict and otherwise strict policies made an overall comfortable learning environment for the students. The students with whom I worked in TMS2 were easier to teach because they were less disruptive in comparison to students in TMS1. The 2004 School Public Accountability Reports (SPAR) results were announced in a letter to parents. The principal of TMS2 noted that it had been an "A" school for five consecutive years. This ranks the school in the upper half of all district schools.

During her time in college, Tammy said that chemistry was her favorite science topic, and she reflects that enjoyment in her instruction of the subject. She is certain to incorporate a number of different learning methods into every area she teaches. I joined her class halfway through the academic year while she was teaching the students organic chemistry. While studying this subject, the students heard lectures and did worksheets, but Tammy incorporated further teaching strategies. The students also had to make a model of an organic compound and explain where and why the bonds were placed as they were. Tammy said that she heard that a person should hear something at least seven times if he or she is expected to remember it. She tries to repeat parts of each topic in a variety of ways to expose students to topics more than once.

We co-taught two days each week, four classes per day. Two of the classes were considered to be for "gifted" students. This is where Tammy thought that I made the strongest contribution. Many of the students in the gifted classes, especially the

male students, seemed comfortable in asking me questions beyond the scope of the lessons that they were in the process of learning. They were very up-to-date on technology and events happening around the world. Tammy does not believe the saying that “anyone can teach the smart ones” and told me that my interaction with these students helped to maintain their attention.

I also turned to Luke Jackson for a different perspective on teaching physics in middle schools. He is the director of a program at FSU called *Science on the Move*. Luke drives a large truck to schools all over Leon and surrounding counties to assist in teaching science, most often physics. Though he works with elementary and high schools, he said that middle school teachers needing help with teaching science sought his help more than other teachers. Often the topics with which they need help are motion, forces, and energy. Luke is also the instructor of a summer workshop called Motion, Forces and Energy (MFE), which Mary and Tammy attended following their co-teaching experiences with me.

Luke had been a high school physics teacher in the Tallahassee area for nine years before the Science on the Move outreach program began. His previous classroom experience was a valuable asset before going to meet a fresh set of students almost every day. He knew the pitfalls to avoid and also what would keep the students interested. The program originated from the idea that some teachers in the community who are knowledgeable in physics may not have experience working with science equipment or that the equipment, especially high-tech equipment, may not be available to them for use in their classrooms.

Because of the vast amount of experience he gets in a variety of learning environments each year, I wanted to get Luke’s opinion on what he thought could be done to improve the way we teach physics in middle schools. Below is a summary of insights that I received from Luke, Mary, and Tammy. I also have included some of my own ideas to enhance teaching physics in middle schools.

What Can Be Done

Improvements need to be made in several facets of physics education for promoting the understanding of physics among the students in middle schools. Some suggestions are specific to enhancing physics education whereas others have a broader view to all of science teaching.

What School Districts and Administration Can Do

In TMS1, teachers are grouped together into teams. Each team is comprised of a teacher from the following areas: science, reading, mathematics, and social studies. That is one of the reasons that Mary loves teaching at TMS1. In this type of group, science and mathematics teachers have the opportunity to collaborate and discuss the mathematics skills that may enhance or impede the pace of students’ learning in science class.

Programs like *Science on the Move* are an immense help to science teachers, but the programs are available for a limited number of teaching appointments each week. For example, *Science on the Move* is available for no more than one week per class. Teachers need better access to science equipment, as well as training on how to use it. Rarely can a lecture get the concepts across to students better than a hands-on activity or experiment. Even if funds are available to buy new equipment, the teachers need proper training on how to use the equipment. Teachers are allowed to sign out equipment from Luke’s program but are often reluctant to do so because they are not comfortable enough with it to use it to facilitate learning in a classroom setting. A reasonable



David teaching science to his fifth-grade science class.

solution might be a summer workshop focused on increasing the comfort level of middle school teachers in using specific, available physics equipment. Further, teachers may be more willing to attend these workshops if school administration demonstrates an interest in purchasing an adequate amount of equipment for the classroom.

Additionally, it is critical that teachers must feel comfortable with using technology within the classroom setting. Tammy enjoys using technology in her classroom. When I visited Tammy to interview her, she was beginning to work with an “active board.” She learned about it during a conference on the use of technology in the classroom. An active board works like a giant touch screen. It gives students feedback about what they are doing in comparison to an old-fashioned marker board. The Internet is yet another tool that offers students a wealth of information about science when they are given adequate access to computers and educationally appropriate websites.

A problem that all teachers face is a lack of time to teach everything that they would like to teach. This becomes a larger problem when working with a large group of students on a lab. Students should have lab periods in blocks where they can continuously work on a lab and have ample time to finish it. Less than an hour is not enough time to set up a lab for an incoming class, clearly explain the instructions, complete the lab, and clean up for the next class. Schools need to recognize that science education requires varying lengths of time ranging from regular class hours for lectures to additional hours for hands-on activities and experiments and use alternative scheduling strategies accordingly.

After evaluating the two different eighth-grade classrooms in which I participated or taught, it is clear that the schools need to have strict guidelines regarding discipline. As teachers, we are convinced that every student has the potential to learn. The classroom should not have to accommodate students who repeatedly display a lack of interest in learning. School administrators need to make it clear to students that following an adequate number of warnings, they will be removed from the classroom if they continue to impede the learning process of other students. There is no good reason to allow a few students to ruin a good learning environment for other students who want to learn. After comparing TMS1 and TMS2, it was obvious that the students of TMS2 knew Tammy had a “no-nonsense” principal backing her decisions. This made the learning environment very relaxed since both the teacher and students knew the consequences that would result from bad behavior.

What Teachers Can Do

Mary does a great job in the classroom of giving students individual jobs to make the classroom run more smoothly. She tries to employ Harry Wong’s techniques of classroom management⁷ that give the students a sense of purpose and investment in the classroom. For example, the students begin each class by answering a question that they could see on the FCAT. They write this question down with the answer in their science journals, which are handed out and collected by students who volunteer for the job. More time can be devoted to learning if students know their roles in the classroom and help tasks run smoothly rather than impede progress.

Summer workshops are already available to teachers in many content areas. Some of them even offer free equipment, college credit, or financial incentives to teachers who attend. Although Mary and Tammy did not become completely comfortable with every topic taught in the workshop that they attended, they were glad to revisit some of the topics, work with the equipment needed to teach the topics, and exchange ideas with other middle school teachers on how they could disseminate the science information to middle school students.

While talking with Luke about how to maintain interest in physics among students, he surprised me with the simplicity of his answer. He said, “The learning cycle is the key.” Although everyone hears about the learning cycle during training to become a teacher, many of us forget its power when it comes time to apply it. If students are

properly introduced to a topic, they are more likely to get excited about it and want to explore it further. This process helps teachers to hone the students' understanding of concepts and then allow them to apply these skills towards problem solving or activities. Our GK–12 preparation course emphasized the use of the learning cycle, and, as teachers, we need to continually remind ourselves to restructure our lessons with this as an organizing principle. Following is an example of the cycle used in the classroom, the steps of the learning cycle are described in Table 1.

An Aside: An Example of Using the Learning Cycle

An opportunity to use the learning cycle took place while Mary and I were discussing how to incorporate some of the state-required science “benchmarks” regarding space into her curriculum. Mary does a very good job of discussing current science events in the news with the students. It is usually easy to find something recent about NASA, the Hubble telescope, or space exploration to talk about. Following a brief general discussion, we try to narrow the focus of the conversation in the direction we would like to go by offering an open-ended question such as “Does the Earth rotate or does it revolve? What’s the difference?” Without trying to give away the answers, we propose a set of questions for the students to investigate.

The students were given a lamp without a shade, a plastic white ball on a stick, and some markers. Labeling different spots on the ball represents locations on Earth with the stick from the bottom being the Southern axis point. The lamp can be plugged in and turned on as their “sun.” Questions during this period are meant to guide the students and give them the chance to explore, discuss within their groups, and discover the answers. For example, the question is proposed, “Make a mark on your ball which represents Tallahassee. Now, how is the Earth positioned around the sun during summertime in Tallahassee?” Leaving several open questions like this on the blackboard or overhead projector, we leave the students to work and discuss with other members of their groups. At this point, we only try to mediate fruitful discussions while Mary and I patrol the classroom. The focus is not on answering the questions correctly but on thinking about science and problem solving. Later in this period, a smaller ball might be introduced to each group as a “moon.” The students are asked, “When you see a full, bright moon where do you think the Earth and moon are located in relation to each other and the sun?” Members from each group can learn from each other, which helps students who are not comfortable discussing with the entire class.

After enough time for exploring has been given, a break from the activity is called and the students are asked, “Did anyone come up with correct explanations to the questions?” Some students may call on previous knowledge they had of astronomy. Others may have misconceptions that need to be corrected. Mathematics can be added to the lesson by discussing a number of topics. “Is the Earth’s rotation axis closer to being perpendicular or parallel to its orbit around the sun? Is 23.5° an acute or obtuse angle? The Earth is 92 million miles from the sun. How many meters is that and how do scientists write large numbers like this?” This is also an excellent avenue to discuss concepts from geography. The students’ recent work with their model Earth-sun systems keeps their focus on learning as we introduce definitions and accurate concepts to compare with their own observations.

Armed with a clearer view of the material, the students are then asked to figure out a set of problems with their groups. “Using what you have learned, would Tallahassee get more daylight during the summer or winter? What about if you lived in Sydney, Australia? What time of year would provide the most daylight?” Using the complete learning cycle promotes interest, gives students the opportunity to think like scientists, and improves how much content they take away from a lesson and how long they remember it.



Tallahassee fifth-grader investigating NaCl through the lenses of a microscope.

Table 1. The Four Steps of the Learning Cycle

Steps:	Description:
<p style="text-align: center;">1 Invitation</p>	<p>Approaches such as demonstrations, discussions, and open questions can be used to prepare the class to learn. Links should be made between past and present lessons and activities. The goal is to focus the students' attention to upcoming activities and the topic at hand as well as creating interest.</p>
<p style="text-align: center;">2 Exploration</p>	<p>Students become engaged in investigating the topic like scientists. The purpose is to search for answers, ask new questions and share their discoveries or ideas. The students should have some direction from the instructor but also have the freedom to uncover new ideas on their own.</p>
<p style="text-align: center;">3 Concept Introduction</p>	<p>Using the student interest to the teacher's advantage, new concepts can be taught. Following the students' opportunity to explore, preconceived notions can be addressed at this point. The students' experiences can be used as the basis for clarifying the material and introducing formal vocabulary and definitions.</p>
<p style="text-align: center;">4 Application</p>	<p>The students should now be able to use the new ideas towards problem solving or continuing the cycle to a more advanced level.</p>

It is the responsibility of each teacher to seek out those who can help the students learn science better. If students have difficulty in writing laboratory reports for their work, the teacher might seek out an English teacher for help. If a teacher does not feel comfortable explaining atoms to his or her students, assistance is mostly likely available from a local university, online resource, or fellow instructor. For another example, students need to be able to measure distance, time, temperature, and mass properly for some physics experiments. They often understand how to use a scale to measure distance but express confusion in writing down their readings. Which unit should they use? Where does the decimal place go? This offers a good chance for the science and mathematics teachers to collaborate and discuss with the students the topic of significant digits. When I took mathematics and science classes, I did not know why the teacher would throw this disjointed topic into her course. Later, I saw that a partnership between mathematics and science teachers would have made the “how” and “why” of this topic come together.

Luke summed it up simply and accurately—teachers do not have to “re-invent the wheel” each time they address a topic. In other words, there are already mountains of materials and lessons available for almost every topic in physics. Finding Internet resources, consulting with other science teachers, and using activities from the textbook can actually yield good, ready-made lessons. As a result, teachers are free to use their time refining the lesson guided by the learning cycle, preparing explorations, and dealing with the many other responsibilities associated with teaching. Rather than trying to conceive completely original ideas, the focus should be on keeping students who are eager to learn on the correct path and inspiring those who are less motivated.⁸

What the Community Can Do

Nearly 10 years ago, Tammy had a professor who visited from Auburn University and worked with her class using light boxes. They learned about lenses, mirrors, and

the properties of light rays. Since then, Tammy bought a set of light boxes for her classroom and currently teaches an extensive section each year about light, mirrors, and lenses. Without a friendly and thorough introduction to the topic, Tammy might not have pursued it further. Consequently, her students would have missed out. This really demonstrates a “trickle-down” effect of transfer of content knowledge from a skilled scientist to a teacher keen on learning.

Thus, universities offer rich academic resources to teachers who would like to develop a mastery of subject matter and teaching methods. Universities have numerous people available, who are trained at a high level to explain difficult topics in any branch of science. Often professors are happy to provide explanations and even work with teachers. TMS1 uses the Computer Assisted Personalized Approach (CAPA) to provide homework that is customized to each student’s level of performance. CAPA was initiated in the school by a FSU physics professor. The computer provides immediate feedback as to the number of questions that the student answered correctly and which topics the student needs to still study. This saves the teacher considerable time and again shows the results of a partnership between those who want to teach better and those who want to help.

I really liked one of the ideas that Mary shared. It would be nice if each teacher had a “science consultant” for assistance with difficult topics. Teachers would likely benefit from having a person who could come to their classroom before or after school several times each semester to discuss ways to use equipment and the approach to teaching a topic clearly. Mary and Tammy are wonderful teachers, so they might only need a person to assist them with the details of a topic. For example, every teacher understands that objects that are accelerating are speeding up, but they may be confused about appropriate units (i.e., m/s^2). Even a quick e-mail would go a long way to clarify concepts for teachers and help them feel more confident about teaching difficult topics. Hopefully, more university professor/K–12 teacher collaborations will be one result of the GK–12 programs around the nation.

Both of my GK–12 co-teachers signed up for Luke’s MFE workshop for a small group of middle school teachers (approximately 20) to work with them on concepts of MFE. Mary attended the workshop the first time that Luke offered it in the summer following our co-teaching experience. Tammy attended the workshop in the following summer.

Mary said that the workshop was not “an uplifting experience.” Though she was glad to spend some time reviewing material, she did not feel at ease in the “climate” of the workshop. The level of knowledge of the teachers attending the workshop varied widely. There were a few high school teachers on the roster who were very vocal about their quick comprehension of each topic. This did not encourage the middle school teachers, who would have liked a slower pace. Tammy had a similar experience when she was partnered with a former high school teacher who was already familiar with the subject matter. Mary worked in the workshop with teachers from her own school and enjoyed the camaraderie as she tried to learn. She only wished that the teachers were not rushed through the material. Tammy suggested switching partners more often so that they could take turns as teacher and student, depending on who was more comfortable with the material.

In summary, every idea on enhancing the teaching of middle school physics points to the following key ideas:

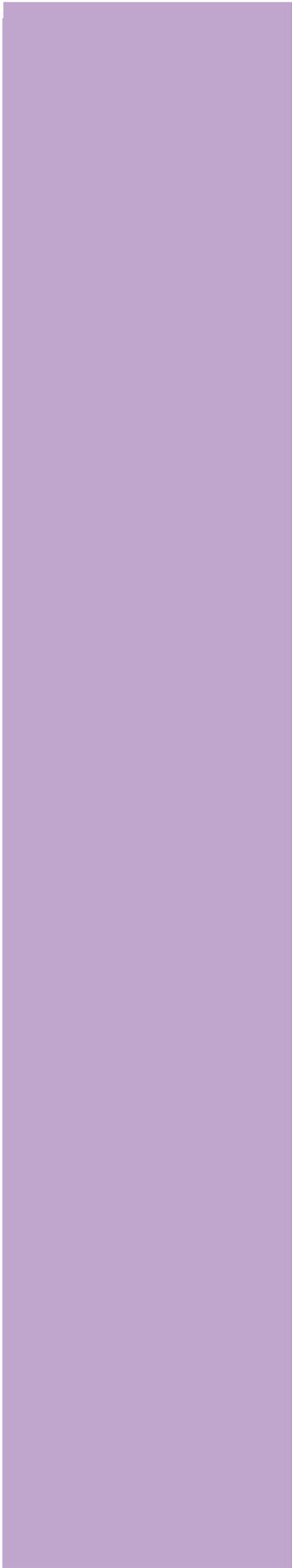
1. Teachers need training in both course content and with equipment.
2. Learning is greatly accelerated within the proper type of environment.
3. Schools must provide resources and support to those who want to become better science teachers.

Notes and References

1. Lederman, L. (2001). Revolution in science education: Put physics first! *Physics Today*, 54(9), 11–12.
2. The TIMSS is a collaborative project, taking place every four years, by the International Association for the Evaluation of Educational Achievement (IEA). The results of 2003 study are available at <http://timss.bc.edu/timss2003.html>.
3. National Commission of Mathematics and Science Teaching (NCMST) (2000, June). *Before it's too late*. Retrieved June 11, 2005, from www.ed.gov/americaaccounts/glenn.
4. Results for each Florida public elementary, middle, and high school are available at <http://schoolgrades.fldoe.org>.
5. The percentage of the students considered “economically disadvantaged” is based on how many students apply for free or discounted lunches at school.
6. Powell, K. (2003). Spare me the lecture. *Nature*, 425, 234–236.
7. Wong, H. (2001). *The first days of school: How to be an effective teacher*. Mountain View, CA: Harry K. Wong Publications.
8. Carmichael, M. (2004). Stirring up science. *Newsweek*, 144, 54–55.

David explaining how the pulse magnet he is holding works during a tour of the Magnet Laboratory.





Impacts of the GK-12 Experience on the University

By Danielle Sherdan

Biographical information:

Danielle Sherdan
Ph. D. candidate in the Department of Biological Science
at Florida State University

Dissertation Topic:

My dissertation research is part of a series of experiments testing a hypothesis regarding water-use efficiency in plants. Specifically, I am studying the effects of humidity on the expression of genes related to carbon metabolism in guard cells, the cells that regulate water loss and CO₂ uptake by plants.

Why I chose my field:

Plant biology grabbed my interest while I was in a botany course as an undergraduate. I was amazed when I first saw plant cells under the microscope. I became interested in understanding the complexity of plant cells and plant physiology.

Why I applied for the GK-12 program:

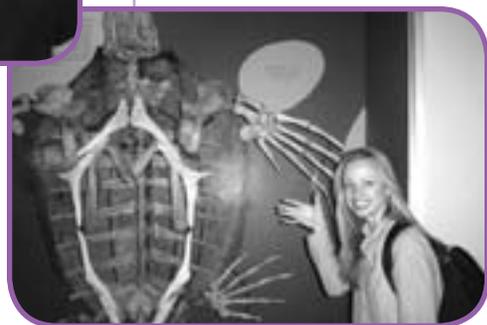
I enjoyed teaching as a teaching assistant at the university, and I wanted to share my passion for science with others. Also, I wanted to better understand human cognition.

What I gained from the GK-12 program:

From the GK-12 program, I gained confidence in teaching and speaking, a better understanding of the nature of science, and a deepening and broadening of my science background. I also realized the science of education and ideas about ways that I can improve my teaching and social skills. I also learned much about human cognition. I am certain that this experience will positively impact my career and my life.



GK-12 Fellow, Danielle Sherdan, excited about the new GK-12 program.



GK-12 fellow, Danielle Sherdan, visiting the Smithsonian Museum of Natural History after participating in the GK-12 Annual Meeting in Arlington, VA, is fascinated by the morphological similarities evident in the skeletons of various animals on display.

My Changing Perspectives Through GK-12

Just a few feet from the laboratory where I conduct plant-biology research as a Ph.D. candidate in biological science, there is a classroom where professors teach undergraduates and graduates upper-level biology classes. Over the past three years in my graduate training, I have been a fellow in the National Science Foundation Graduate Teaching Fellows in K-12 Education (NSF GK-12) program.¹ During this period, I have noticed a change in my perspectives on the events occurring in that biology classroom across the hall from my laboratory.

My participation in the NSF GK-12 program and my training at the university have changed my ideas. Through the NSF GK-12 program, I am discovering the science of education and the value of effective teaching skills in science. Teaching strategies learned and practiced for effectively teaching K-12 students can be applied to all learning situations, whether K-12 or higher education. From the GK-12 experiences and the skills I have acquired, I feel inspired with these ideas and how I might bring these into the university classroom, in general, and how I can now communicate science more effectively. Now when I walk by that same university classroom and the professor is still standing in front of the class lecturing to a body of disengaged students, I realize that I can utilize the lessons I learned from the GK-12 experiences and bring them to college-level or any other teaching situation.

GK-12 Fellow, Danielle Sherdan, listening to another Fellow's idea.



Principles for Effective Learning

The principles of inquiry, engagement, and application are effective for learners of all ages. Instead of lecturing to students, elaboration among students within the class would be a more effective method for enhancing the learning environment. The elaboration likelihood model (ELM) stresses that under conditions of high elaboration when individuals engage in thoughtful, effortful processing of arguments, individuals' concepts alter through the process.²

Another issue of importance is how the professor chooses to assess his/her students' understanding. Does the professor really expect to fairly assess what the students have or have not learned from a test that will be given weeks later? How are the professors assessing what the students have learned when they never assessed what the students knew at the start?

Formative assessment can be a powerful way to both

encourage learning and see the growth of students in terms of what they learned and how they can apply that learning to solving problems.³

Many university professors have never learned how to make adjustments to accommodate the diversity of learning styles that may exist in their classrooms. As a result, they are not successful in communicating their construction and understanding of massive amounts of knowledge. Expertise often negatively impacts teaching because it is difficult for an expert to anticipate what is easy and what is difficult for students to learn.⁴

Also relevant to the learning process is diversity in the modes of presentation utilized.⁵ The use of different methods of presentation makes the information available to a larger population and increases the possibility for enhanced learning. How we present material greatly influences students' interest in the material.⁶ In the GK–12 program, by working with several different K–12 teachers, I practiced and learned several approaches for engaging the students, for example, relating the concepts being presented to the students' daily culture, such as what they watch on television or the sports in which they have interest. I discovered their interests through “fun” questions on their worksheets and by listening to their conversations. Other examples of engagement strategies include demonstrations (especially with unexpected results), hands-on explorations, challenging problems, and competitions.

Even more effective is engaging interest in the context of what students already know and what students want to know.^{7,6} To do this, university professors must begin to assess entry-level understanding. Students of colleges and universities enter courses with a range of prior knowledge, skills, beliefs, and concepts that significantly influence how they organize and interpret new information.⁴ I have learned that recognition of students' preconceptions is vital to effective teaching because new understanding builds on the framework of previous knowledge. To form new conceptions, previous misconceptions must be identified and challenged causing students to question their current understanding and develop new understanding.⁴ Therefore, recognizing what students currently know is an important step to teaching.

Furthermore, it is equally relevant to assess and question the effectiveness of the teaching strategies being used. I learned strategies to analyze classroom events to recognize effective teaching from my GK–12 experiences (e.g., when I worked with a K–12 teacher that was trying to become National Board certified, I saw how she assessed her teaching strategies). My experiences have supported the idea that “minds



Observing and comparing different common fruits like an apple, grape, tomato, green bean, and peanut. Students were identifying parts of the fruit that correspond to previously learned parts of the flower.

that want to know, inquire.” You know you have engaged your students when they begin asking questions about the subject matter.

Impacts on University Teaching

In this research-driven time for scientists, professors spend 15% less time on teaching than they did 30 years ago.⁸ Professors need to become efficient and effective teachers for the benefit of their own careers, the departments and institutions in which they work, their students, their community, and the scientific enterprise. Education is at the top of the list of problems facing the United States.⁸ The following are observations and ideas of how the NSF GK–12 program is impacting and will continue to impact universities, primarily university classrooms, now and in the future.

I think the changes in universities will be evident in the hiring of future faculty members who have GK–12 experiences. Graduate students are in a great position to initiate long-term improvements in university teaching. Most graduate students spend at least some time teaching in the university and, therefore, can learn how to analyze and improve teaching skills and put those skills into practice. Graduate students can apply the skills they learn from the GK–12 experience to their own learning and develop activities to communicate the concepts of science. For example, after making concept maps with the K–12 students with whom I was working, I found myself making a concept map to organize a seminar that I presented at the university.

Most current science graduate students do not have a set of effective teaching strategies. However, as a result of engagement in the science of education, GK–12 Fellows may be more apt to try new teaching strategies. The combination of teaching strategies and the skills to analyze classroom activities may result in some very effective learning enhancement tools.⁴ For example, after attempting to teach general science concepts, I realized that I needed to assess the depth and breadth of my knowledge and give myself opportunities to review and broaden my understanding of the concepts that I have learned throughout my education. Graduate students that participate in programs like the NSF GK–12 program will be future higher-education faculty with enhanced knowledge of effective teaching strategies and ideas about how to implement the strategies. One outcome of the program that I have observed is graduate students in science redirecting their career paths towards education and away from science. Although this outcome may be viewed as a disadvantage to the scientific community, it is certainly an advantage to the education community.

In my experiences, one of the major complaints of university professors is that the students do not *want* to learn the material or that the students “do not care.” Many professors may not feel it is their responsibility to interest students or to excite them, but rather to be a source of information. Many professors feel that it is the responsibility of each student to learn, and of course this is true, but it is also the responsibility of each professor to provide a learning environment that engages the learners.⁶ Students enter the classroom with a certain level of understanding, but they do not necessarily understand why they need to know the concepts or how the concepts relate to either what they already know or how the concepts connect to real life situations. With new crops of recent doctoral graduates entering the workforce, I expect that the graduates of the NSF GK–12 program will change the teaching culture within the universities as they are hired as tenure-track assistant professors.

When a student enters a classroom, the professor has usually already predetermined what and how s/he will teach the course. Since the student was not included in the decision-making process, there was no opportunity for transfer of ownership of



Danielle Sherdan examining the sample of mosquito larvae used in discussion of life cycles in aquatic habitats.



Danielle Sherdan, GK–12 Fellow, showing a sample of *Daphnia* as part of the food web of an aquatic habitat.

Children drawing conclusions from experiments from a class on plant germination and growth.



the learning to the student, thereby resulting in low student participation.⁹ Action research indicates that students tend to be more participatory when they have some input into what they are going to do or study. Additionally, effective learning occurs when students want to learn, so teachers must first engage the students.⁴

The common, current processes for university teaching are no longer effective for a student who has experienced effective inquiry-based and engaging teaching techniques. For instance, the following example demonstrates how engagement and inquiry can be brought into the university. One day I overheard the biology professor talking about sedimentation on the sea floor. Immediately, I thought each table in the classroom should have a jar that had been shaken before the class and allowed to settle during the class. This would be a simple way to allow the students to become more engaged in the discussion, and the students may then inquire about sedimentation because they are witnessing the process. In my experience, inquiry-based teaching results in genuine interest in the learning activity and in persistent and applicable knowledge. During the semester, I never observed the professor demonstrating anything, showing

interesting pictures that might stimulate inquiry, utilizing the available media, mediating class discussions, or engaging the students. Participating in the GK-12 program has enhanced my consciousness to be sensitive to the needs of the students. According to the National Research Council, many professors need to improve their teaching,¹⁰ so change must be initiated. Programs like the NSF GK-12 program, in which future faculty members are made aware of the science of education, represent one way to accomplish this goal hopefully leading to a chain reaction of educational improvements.⁴

Students testing for type of bacteria on coins from different parts of the world.



Often, a major outcome of engaging students and addressing their preconceptions is developing their curiosity and further investigation during which students reason through new concepts. Usually, in universities, all of the hands-on opportunities occur in separate laboratory courses that are in many ways disconnected from the classroom concepts by being scheduled on different days, with different teachers, and usually without much connection to the lecture content. Currently, most of the college laboratories are “recipe” experiments that the students do not really need to understand to complete. The students are not genuinely interested in the outcome of these experiments, except for the grade. Students spend the laboratory session learning how to follow directions, and although this is a valuable lesson, it is not the primary objective of the activity. Practicing inquiry-based teaching methods in the program has led me to conclude that students are more interested in experiments aimed at answering questions that the students themselves have asked and/or designed. David Ausubel’s theory states that “to learn meaningfully, individuals must choose to relate new knowledge to relevant concepts and suppositions they already know.”⁷

As a teaching assistant in the university, I had the opportunity to assist in teaching a course that was, in my opinion, exemplary in inquiry-based science and a good example of how these teaching strategies can be implemented in the university. We spent the first couple of weeks becoming familiar with the system through small challenges (e.g., “Can you figure out what is wrong with this mutant?”). Then, the inquiry began. Each student tried to determine the phenotype of a set of mutant

organisms for which the phenotypic alteration is already known but not revealed to students until they tried to determine them using observation of behavior and response to stimuli in comparison with a wild-type organism. After this challenge, each student was given a set of mutant organisms that hadn't been studied beforehand to screen for phenotypic alterations in behavior and/or response to stimuli. Afterwards, each student formulated questions and hypotheses regarding the biological system that they were studying. Students designed and executed experiments to investigate their hypotheses regarding mutants that had previously been investigated or novel mutants identified during the mutant-screening activity. Finally, each student presented the experiment to the class and wrote a paper in scientific-journal format.

Every semester that the university offers this course, I hear students talking to each other about their projects in the halls and in the laboratory. These interactions are vital to the learning process and are important for student social skills. These students are applying what they are learning to a real system in a real laboratory, doing novel experiments, and thinking scientifically. By the end of the course, the students are teaching the professor and teaching assistants something new. Now that is effective and rewarding teaching, and as a result, students are learning! Not only the students but also the professor benefit from this course. Each semester, students investigate mutants that may be of interest to the professor's research team. When professors begin thinking about inquiry-based curriculum and the abilities of their students, they will be better able to design experiments that can incorporate undergraduates in research and teaching, also increasing funding opportunities.

In addition to enhancing the quality of education, enhancing teaching skills will positively impact science. When asked how the GK-12 program has impacted the GK-12 Fellows, one of the first responses is that it has improved the communication skills of the Fellows.¹¹ Being able to effectively communicate at several levels of depth will result in effective communication of science, in both oral and written presentation formats.

In addition to enhancing the quality of education in the university, experiences in K-12 classrooms for future faculty may also lead to development and enhancement of outreach programs that impact the community. These programs can help support university departments from the administration and through grants. The increased funding can provide employment and opportunities for undergraduates, graduate students, and faculty. Outreach programs can have major impacts on the public's perception of universities. Participation in GK-12 experiences will provide experiences for graduate students and future faculty that can lead to strategies for implementing outreach ideas.

In summary, there is much that GK-12 Fellows can contribute to the universities when they become future science faculty. The first impact will come to individual universities and colleges that hire future faculty with GK-12 experience. Overall the Fellows will impact the overall quality of higher education in the nation. Such future faculty will assess their students' prior knowledge so that they can direct their lessons and students' learning. They will give the students problems that they may face in their everyday situations and encourage them to ask their own questions that they can explore in



Utilizing a digital microscope connected to a laptop computer to encourage and motivate the students to look under a regular microscope. The student is actually looking at an ant.



Girls working together to characterize different parts of a plant.

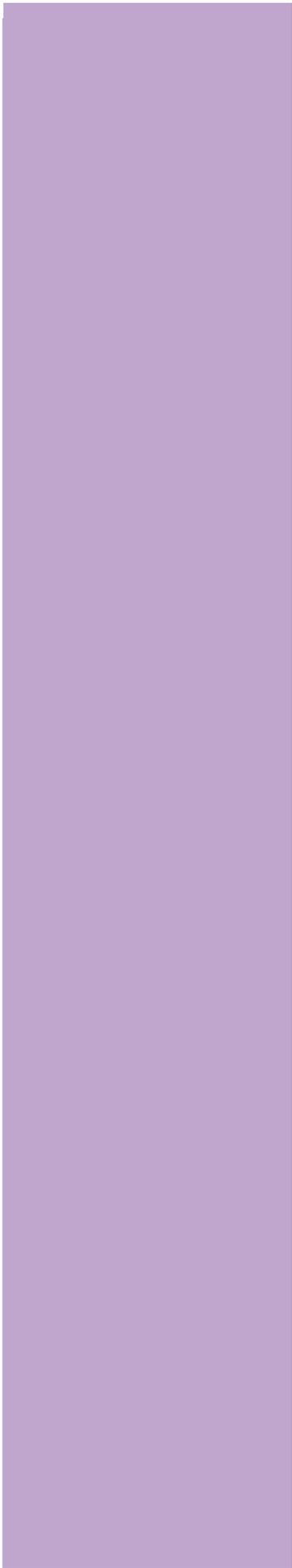
inquiry-directed activities. Seldom do institution rules bind us, and when they do, they are usually regarding things that do not pertain to the procurement of knowledge but rather to grading policies, etc. So in my mind, let's think beyond selecting a textbook and following it chapter by chapter and administering examinations in formats so commonly found. We can do better for our students and the future of our country.

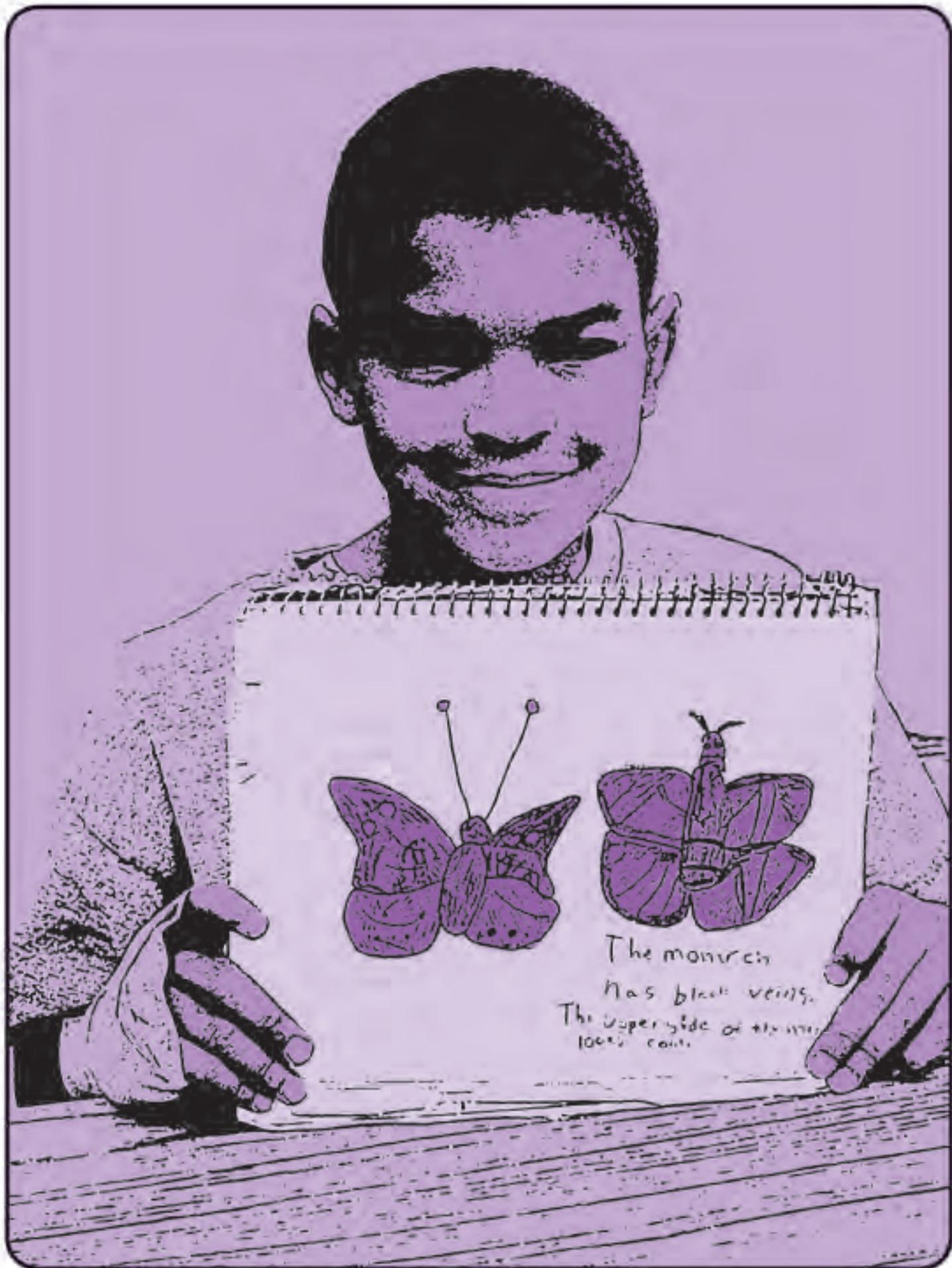
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GK–12 Fellow, Danielle Sherdan, while mentoring the young women, discusses the importance of crop species for humans.







Shifting Sands and Butterfly Gardens: **Growing a Scientifically Literate Society**

By Mabry Gaboardi

Biographical information:

Mabry Gaboardi
Ph. D. candidate in the Department of Geological Sciences
at Florida State University

Dissertation Topic:
Stable Isotopic Applications for Evaluating Climate Change

Why I chose my field:
I actually chose science as my career in order to understand climate change and to help educate the public about how we are affecting our environment.

Why I applied for the GK-12 program:
I was excited to join this program to learn wonderful, creative ways of teaching science.

What I gained from the GK-12 program:
I really gained an appreciation for why I, as a scientist, need to be actively involved in K-12 science education.



GK-12 Fellow
Mabry Gaboardi.

Scientists in the university setting often ask, “Why is our government not using the data we produce to create better policy? How is it that our leaders seem to be ignoring our input?” I believe that part of the answer to these questions lies in the quality of science education our children receive in our public schools. If we do not teach children the fundamentals of science, how can we expect them to make informed decisions about science or the environment as adults? If children do not gain the necessary fundamentals in school, where can they learn them? Currently our schools perform below most other industrial nations in science and mathematics according to the Third International Mathematics and Science Study (TIMSS), which tested students from 41 nations.¹ How can we remedy this problem, and how will it affect the scientific literacy of our citizens?

Boys looking for bugs under
schoolyard stepping rounds.

Blank Stares

I have had the opportunity to teach earth science both to university undergraduates and to K-8 students who attend public schools in northern Florida. My first teaching experience was as a graduate student in geology at a research university. I began, as do most, armed with inexperience and no real guidance about how to teach or what to expect. I thoroughly enjoyed working with my students and found them to be quite capable learners but was shocked at their lack of prior knowledge about basic earth systems. Students either never learned fundamental concepts or they failed to remember them. They had become university students and potential voters with little understanding of their natural



The students mapping out the schoolyard ecology: sunlight, moisture, plant cover, and animals (A).



Measurements of plant growth in their soil fertility experiments.

surroundings. Furthermore, they did not have the necessary knowledge to think critically about scientific issues, including environmental issues, facing their community.

Throughout the four semesters that I taught undergraduate geology laboratories, I had the students discuss the following issues relevant to their community:

1. How does the use of petroleum products affect our environment?
2. Is beach renourishment, the practice of dredging offshore sand to line the beaches, a good idea for a community?

Most students were interested in these issues and lively discussion usually ensued; however, I often found that students did not use scientific reasoning to reach any sort of conclusion. When I redirected the discussion to the more basic concepts needed to analyze the issue, I only received blank stares. My students lacked prior knowledge of how natural systems work. I found them asking such questions as:

1. Where do we obtain petroleum products?
2. What other energy sources are there?
3. From where does beach sand come in a natural setting?
4. From where does river water come and where does it ultimately go?

This lack of understanding of fundamental concepts left me wondering, “How could a student make it to the university level and not have an idea about these natural systems and how they work?” Our assumptions about “what works” in science teaching is helping us become a nation of scientifically illiterate citizens who lack the understanding of earth systems so necessary for making sound scientific and environmental decisions.² The United States has identified the problem, as outlined in the report *A Nation at Risk: Before It's Too Late*.¹ What can we do, and where do we start?

Teaching Methods: Process of Finding “What Works”

One thing that must change is the manner in which we teach science in the classroom. Scientists learn by creative exploration, experimentation, and reasoning.³ Students do not learn by memorizing facts as isolated tidbits of information. It is easy for teachers to present facts, but presenting facts does not give students an *understanding* of the ever-evolving nature of real science and the process of discovery.

Students as Stenographers

Much of my own science education was based on the lecture/memorize/test approach. In fact, when I remember many of my science classrooms I do not think of a laboratory or an activity but of a darkened classroom with an overhead projector. I did learn quite a bit of information in some of my classes and did have teachers that really made me interested in the material, but I cannot say I truly grasped many whole concepts. I certainly did not understand the importance of system interrelatedness, and never did I view a scientist as part of a team jointly exploring a concept. Nevertheless, I was very adept at fact memorization. It took me a long time as a beginning scientist to understand the importance of creativity and communication in science and not to feel dread when asked a question I could not completely answer. The lecture/memorize/test approach fails students in that it does not:

1. Teach students to think analytically and creatively.
2. Give students an understanding of complex concepts and system interrelatedness.
3. Convey an understanding of the process of science or how scientific knowledge proceeds.



Pink petals and dissected flowers.

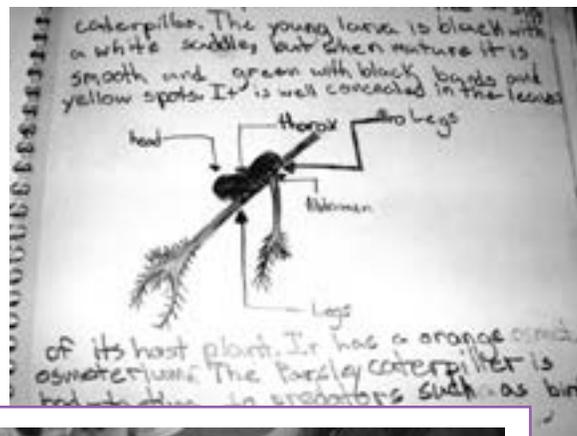
Wild Child

While we fail to engage our children in gaining an understanding of science with the lecture/memorize/test approach, too much free exploration can be equally unproductive. With no assessment of prior knowledge, concept introduction, or guidance toward concept application (e.g., inclusion of all of the phases of the learning cycle⁴), students may feel lost and discouraged. This occurred in one eighth-grade classroom that I happened to observe. The teacher, Lynn (pseudonym), wanted to do an interactive lesson about energy resources. She chose to pair the students and assign each pair a topic related to energy. Topics included renewable resources, non-renewable resources, petroleum, wind energy, solar energy, and tidal energy. Once Lynn assigned the topics, the students had about two hours in the computer laboratory to do free research on their respective areas. During the next class period she expected them to create a poster and prepare for a short class presentation. Lynn collaborated with the students' language arts teacher so that the students also had time in that class to work on oral presentations and public speaking. Finally, the students presented the information that they learned on their topic to their peers. Lynn graded the students on science content and presentation ability. Most students received a "C" or below on their science content.

Lynn was very frustrated with the outcome of the students' efforts. Why did this assignment fail to help students learn about energy resources? I think it was due to the lack of guidance and structure in the teaching. Had this activity been created with the learning cycle in mind, the students could have been much more focused in learning about a topic very important to their future. Instead, the students had no understanding of the context of their individual topics. They appeared confused by the complex information that they were expected to digest without having an appropriate background for understanding it. Most of their reports consisted of simply rewording websites (at best!) and often distorting the information due to lack of real understanding. Just before the presentations, I heard students asking questions like, "We just make oil in factories, right?" "Isn't the tide caused by wind?" and "Is gasoline renewable?" Because Lynn had done no assessment of prior knowledge, she was not aware that the students lacked these basic ideas. With no invitation, exploration, and basic background content introduction before this application activity, the students could not put the information they discovered into any context with which they had experience. They did not connect the use of energy with their daily lives, could not see how this information might be valuable to them, and were, therefore, unable to understand the content they discovered. All of these combined to make the students very uninterested in the material. Lynn never helped the students to link these "tidbits" of information to central concepts.

The activity resulted in confused, and sometimes embarrassed, students giving presentations that were full of misinformation. Lynn, very disheartened with the efforts, lectured the students about being more diligent learners without analyzing why the activity had failed. Importantly, she never cleared up the misinformation

A child's observations about a caterpillar.



Girl drawing a picture of a caterpillar in the jar in front of her.



Mabry (center) with Kathy (right) and Bonnie. Kathy supervised Mabry in her fourth- through fifth-grade classroom. Bonnie is the para-teacher who helped in the classroom. They are standing in front of the butterfly garden that the students planted.



Kathy helping her students explore the pond in their schoolyard.



Two girls inspecting the plants in their schoolyard garden.



Jen and Mabry planning lessons they would use in Jen's classroom.

delivered in the student presentations. The students had been given freedom to explore, yet this was not an effective learning experience for them. Although this activity sounded good on paper for its student-directed approach, it was not placed in the proper learning context for success. Had the teacher approached this activity differently, the students should have been able to answer the following questions:

1. Where do we obtain petroleum products?
2. Are they renewable?
3. How do they compare to other forms of energy?

Unfortunately, as was obvious during the presentations, many of these students would begin driving and continue with their lives without ever understanding that gasoline and other petroleum products are non-renewable resources.

Minds-On Teaching: Depth and Breadth

Some balance must be met between the two above teaching approaches with a little of “what works” taken from each. Many teachers already engage students’ minds, thus teaching in a “minds-on” manner. Some teachers enable students to explore questions themselves and to learn how to design experiments to discover their own answers. This process is often referred to as *inquiry*⁵ or *guided inquiry*. The teacher is no longer a lecturer but a facilitator of discussion and leader in research. The teacher allows the student some freedom of creative thought, while supplying enough guidance for the student to reach a reasonable conclusion. In short, the teacher helps the students truly learn and understand the material.

Through the NSF GK–12 program, I had the opportunity to observe teachers using the inquiry-based teaching techniques. My favorite tools used to engage students were the learning cycle and theme-based curricula. These very powerful methods enable the students to gain both depth and breadth of understanding. The learning cycle is a useful tool for structuring activities to engage students and guide them into deeper comprehension of the concepts. Theme-based curricula allow the teacher to align these activities in such a manner that

students move seamlessly from concept to concept, easily relating them to one another. In combination, these tools help students gain in-depth understanding of individual concepts and a greater appreciation for how these concepts are components of more complex systems.

I had the opportunity to use these two tools with fourth-, fifth-, and sixth-grade students and was amazed at how well they worked. These students performed better than my university students had! In the activity below, I worked with Jen, a beginning teacher of sixth-grade earth/space science. By using the learning cycle to structure the lesson that we created together, we were able to turn a simple demonstration into a true learning experience. I repeated the lesson with two other teachers, Kathy and Bonnie, teachers of a fourth- through fifth-grade class in another school. This time I quantitatively assessed how the students’ thinking changed.

Shifting Sands

In this activity, which we called Shifting Sands, Jen and I used a large pan, sand, pebbles, and water to explore the process of erosion. Inside the pan, we made a “mountain” of the sediments. We used wind (our breath) and water to show how sediments are eroded from higher elevations and transported to lower ones. Our goal was for the students to understand that the sand on our beaches in Florida had been eroded from rocks in the Appalachian Mountains and transported to the

beach by rivers. Jen and I used this information in a later lesson to describe part of the rock cycle.

Before beginning the activity, we chose to briefly review the topics related to erosion that we had already explored with the class. Although our theme was not as elaborate as the one that I would use later with Kathy and Bonnie, Shifting Sands was to be part of a month-long unit on geology that we created. In the lessons prior to Shifting Sands, we explored sediment formation, physical weathering, and chemical weathering, so we started this lesson by reviewing those concepts.

During the invitation phase of this learning-cycle structured lesson, we asked students to recall observations they had made in their own life experiences. Had they ever been to a beach? If so, what size sediments did they observe there? We also tried to understand their prior knowledge by asking questions like, “How does sand get to the beaches in Florida?” “Where does this sand originate?” and “What brings the sand here?” In Jen’s class, though I did not quantify it, I observed that the overwhelming majority of the students originally felt that the sand came from the ocean, not from rocks in the mountains. I repeated this activity later with Kathy and Bonnie’s class and made a quantitative record of the students’ prior ideas. Out of 25 students, 13 thought the sand came from the ocean, 6 thought the sand came from rocks, 5 thought it came from shells, and 1 did not respond. When asked if sand and pebbles had the same source, 12 agreed and 13 disagreed.

After the initial invitation in the lesson, the students explored geological processes by blowing on the sediments to observe wind erosion and pouring water (precipitation) down the mountain to form eroding streams and rivers. We asked them to observe sediment size, and then predict and observe the following:

1. The distance that different sediment sizes were transported.
2. How velocity of wind or water affected the ability to transport different size sediments.
3. Whether sediments were transported uphill or downhill.

After they had made observations, we introduced the term erosion and discussed how both wind and water can erode sediments. We also noted that water flows downhill due to gravity so that sediments are almost always carried to a lower elevation. We then asked the students to apply this knowledge to discover the source of the beach sand in Florida. Jen’s sixth-grade class unanimously said that the sand was the result of weathering and erosion of the Appalachians. In the fourth-through fifth-grade class, 23 students decided the sand came from rocks in the mountains, 2 still thought it came from the ocean, and none continued to believe that all of the sand at the beach came from shells. Furthermore, all 25 of the fourth- through fifth-graders concluded that sand and pebbles had the same source.

This lesson successfully helped the students answer the following questions:

1. From where does beach sand come in a natural setting?
2. From where does river water come and where does it ultimately go?

Mabry demonstrating wind erosion as part of the “Shifting Sands” activity.



Part of the “Shifting Sands” activity in which the student demonstrates precipitation on a mountain slope.

Making observations of plants and butterflies in their schoolyard garden.



Student drawing comparative anatomy of similar butterflies that he thinks he might see in the garden.

Students exploring bug ecology in their schoolyard.

Butterfly Garden



When I repeated this lesson with the fourth- through fifth-grade students, it was as part of a different theme. Kathy and Bonnie used the overarching theme “Butterfly Garden” to tie in *all* curricula for their classroom during the nine-week period. In this unit, the students observed and researched butterflies, and then used this information to design and plant a butterfly garden at their school. We designed the science curriculum around this theme, linking all topics back to their garden.

The erosion activity described above helped the students explore the soil in their garden. They first analyzed and classified soil samples from each of their own yards, then worked through the erosion exercise to learn the source of sediments within those soils.

In a follow-up activity, students planted seeds in each soil sample to decide what sediment combination would support the fastest plant growth. The relatedness of soil, flora, fauna, and climate was emphasized with a final unit on ecology, using the Great Explorations in Math and Science (GEMS) guide *Schoolyard Ecology*.⁶ By this point the students were familiar with many components of an ecosystem and could appreciate how these components interacted in their schoolyard. The class remained engaged throughout the theme because they could see how each activity would affect their butterfly garden. The end-of-theme field trip was a visit to a local nature preserve. Here the students absolutely amazed the park staff with their knowledge of butterflies and ecosystems. For me, it was priceless to hear the excitement of the students and observe their ability to learn science.



Students making observations about the butterfly life cycle using a butterfly tent in their classroom.

A Little Help

Three boys looking for eggs in the butterfly garden they planted.



Undoubtedly, the teachers must do much of the work to create inquiry-based, active learning, but most teachers are already overworked and under-funded. Without adequate help and easily accessible resources, teachers may find it impossible to revise their activities and keep current on scientific ideas. If we truly want to have a nation of excited young students learning to make informed decisions using science, we must all accept some responsibility. What can we do to help?

In the University Setting

1. Faculty should use inquiry-based, active learning within their teaching.

University faculty members need to incorporate the learning cycle and themes in the classes they teach. This may introduce future science teachers to this style of teaching and will almost certainly improve their understanding of science content. Importantly, it will model the teaching style that we hope they will use and so influence their later teaching. Most of us did not learn this way, and as a result, this type of teaching can be challenging at first.⁷ Faculty are often more familiar with direct teaching, but well-timed questions for small group discussion during lecture⁸ and thought explorations before introducing new concepts can make even the lecture hall a richer learning environment.

2. Faculty should make themselves more accessible to the community.

Teachers need resources! What can university faculty offer? Web pages are a great (and unimimidating) place to start. Incorporating an “ask the scientist” link on each faculty’s web page allows teachers or students to access a researcher’s expertise. It also helps members of the community make a connection with a local scientist. Additionally, including a brief write-up of each scientist’s research, created for the middle- or high-school level, would enable students to learn about what scientists actually do. Each department can choose an outreach coordinator and have his or her contact information included on the departmental web page. In the community, faculty can judge science fairs, give classroom presentations, and participate in neighborhood events. They may want to include in their presentations reasons why they enjoy science or why they went into their field of research. Before you can educate a child, you must first capture the child’s interest. Remember that this has the potential to affect the quality of the students that will eventually reach the university classroom *and* the citizens who will vote on important scientific and environmental issues. They may be the very ones deciding whether future science programs should receive funding.



Three girls recording their butterfly observations in their nature sketchbooks.

3. Faculty should never let science education majors off easily!

This does them and their future students a disservice. University faculty should never, *ever*, suggest that future teachers “don’t need to know that.” Science education majors should receive just as thorough an education as any other science major. Faculty should set an example of what a scientist is and how science should be taught. The impression made on these future teachers may be perpetuated for the next 30 years in a public school classroom.



Girl showing a tiny frog that she collected as a part of a GEMS’ “Schoolyard Ecology” project.

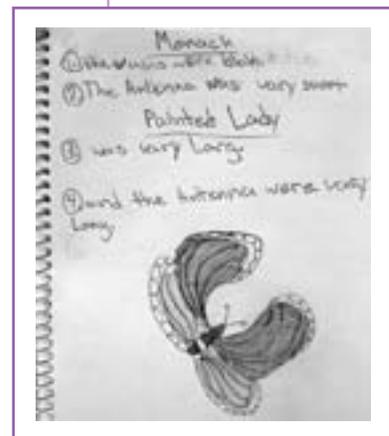
In the Home Setting

1. Parents should pay attention to what their children are learning in science.

Parents can find out what topics children are learning and, if possible, help children see how this information applies to them. For example, if they are learning about weather, make a point of watching the weather with them and observing how often the meteorologist was accurate in her prediction. How does it affect daily life? Check out the weather in other areas of the world and discuss how it can affect the children living there. Parents don’t need to be experts, but they should try to stimulate interest.

2. Take science-oriented field trips.

By taking children on fun, science oriented-outings their interest in their natural environment can be encouraged. Many communities have natural history museums, aquariums, parks, or other science centers which cater to children. In addition, university camps, like the Saturday-at-the-Sea program at Florida State University, or other events where children can interact with scientists are great opportunities for them. Due to encouragement by the National Science Foundation, many university-related laboratories now engage in some form of science outreach as a public service. For example, the National High Magnetic Field Laboratory in Tallahassee hosts an open house every spring. During these



Child’s comparison of monarch and painted lady butterflies.

events, scientists offer child-friendly displays and encourage children to ask questions and explore the facilities. Many of these field trips can be done on a small budget and some are even free.

3. Parents should donate their time and/or supplies to the classroom.

Teaching science in the way I have described often requires more preparation time and classroom supplies than traditional lecture methods. For the geology activities described above, we needed a large tray, aluminum pie plates, chalk, lemon juice, sand, pebbles, and food coloring. These were inexpensive supplies, but meager classroom budgets may preclude even these. Furthermore, teachers must shop for supplies on their own time. Jen might not have been able to do this activity if I had not purchased the supplies through the NSF funded GK-12 budget. Parents can improve this situation by offering assistance in purchasing classroom supplies, especially small ones. It is a minor contribution that can go a long way for good public education. If their budget is tight, parents can offer their time to help prepare for hands-on activities.



Student inspecting for eggs in her butterfly garden.

As a Concerned Citizen

1. Volunteer.

Volunteering is a great idea, especially for those who work in a science-related field. Even those uncomfortable with presenting or helping during an activity can still be a resource. They may have access to information or supplies that seem trivial to them but may be a treasure to a local teacher. Workplaces may even have some old supplies that can be donated. Individuals can simply call up a local school and mention their interest. A teacher will more than likely be grateful for the effort given.

2. Monitor local politicians' views toward education and museum funding.

All of us can let our representatives know we value science education. We can remind them that museums provide a unique learning atmosphere and have sparked the excitement of many future science enthusiasts. Unfortunately, funding for education and museums is not plentiful and must be approved by politicians. We need to assure them that use of our taxes to fund these programs is important to us. A vote for better education may later translate into votes for more informed scientific and environmental policy.

3. Show respect towards the teaching profession.

The effort required to teach good science lessons day after day is huge (or to teach any lesson, for that matter). Most teachers are on their feet addressing the needs of their students all day long, even during their planning period and lunch. I was surprised at how absolutely exhausting I found teaching to be. Many have little time to institute innovative curricula, yet teachers who understand the importance of their profession are willing to do just that. On a personal note, I grew up in a family of teachers and remember waking up many nights to see my mother sitting at the kitchen table after midnight, still working on lessons or grading papers. Sixty- to eighty-hour workweeks are not uncommon for a dedicated teacher, and most of those hours do not include coffee or bathroom breaks. The reward for that dedication does not come in the form of a large paycheck. It is becoming increasingly difficult to attract bright,

"It's beautiful."



dedicated young scientists into the teaching profession as many can find an easier job elsewhere, making more money and working fewer hours. If we expect to attract dedicated, educated teachers to improve our science education we must pay and respect them for the professionals they are!



Child's sketch of butterfly anatomy to compare two species.

We Are All Responsible!

Through the GK–12 program, the National Science Foundation is helping to improve the science education crisis in our country by establishing a connection between scientists and teachers. As a GK–12 Fellow, I gained a broader understanding of the earth systems with which I worked, a clearer perspective of the nature of scientific inquiry, and a new excitement for why this information is important to the public. I will take with me a stronger commitment to enhancing the quality of science education that is offered to our children. It is easy to see that good science education at the elementary- and middle-school level can lead to better students in the university classes that I will be teaching. More importantly, good science education creates a nation that is capable of making better scientific and environmental policy. Armed with an understanding of science, our children will be better able to make decisions about the scientific and environmental issues that will affect them. We all have a responsibility to provide them with that education.

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Cooperative Group Learning in Inquiry-Based Science Activities

By Katie McGhee

Biographical information:

Katie E. McGhee
Ph.D. candidate in the Department of Biological Science, Florida State University

Dissertation topic:

The role of social interactions and male aggressive behavior in sexual selection and mating success of a freshwater fish

Dissertation details:

I am a behavioral ecologist interested in the evolution of social behaviors in freshwater fish. In particular, I work on aggressive male interactions and the role they play in sexual selection. I am interested in understanding how these behaviors affect mating success as well as whether they have a genetic basis and are affected by abiotic and biotic aspects of the environment.

Why I chose my field:

I chose to work in the field of behavioral ecology because I am interested in how biotic and abiotic factors in the environment have led to the tremendous diversity of animal behaviors we see in nature. With my research, I feel I am contributing to our understanding of the complex interactions between animals and the natural world around us.

Why I applied for the GK-12 program:

I applied for the GK-12 program because I wanted to introduce students to basic natural history, evolution, and ecology as well as foster in them a greater appreciation for nature. Young students have a natural curiosity and fascination with animals and the environment, and I wanted to nurture this.

What I gained from the GK-12 program:

Participation in the GK-12 program has broadened my teaching style and encouraged me to modify my teaching to encompass several different approaches, to find creative ways to explore difficult concepts, and to incorporate interactive activities that allow students to investigate concepts on their own.

Introduction

Cooperative learning in groups can be a very positive experience for both students and teachers and can improve students' learning, attendance, self-esteem, enjoyment of school, and social skills.^{1,2,3} Research studies have shown that children often achieve higher scores, are more creative and insightful, and use higher-level reasoning skills when working cooperatively in small groups rather than working competitively or individually.^{4,2,5} However, the design of a task or activity is crucial for effective cooperative learning.⁶ If the interdependence of students' roles and the benefits of working together towards a common goal are not communicated clearly, effective group interactions and learning rarely occur.

Cooperative learning occurs when there is positive interdependence among student accomplishments so that students feel that reaching their own goals is dependent on the other students in the group reaching their particular goals.¹ In addition to positive interdependence, small group activities must also include face-face interaction among



GK-12 Fellow, Katie McGhee in her biology research laboratory.



“Two heads are better than one.”

— Heywood



GK-12 Fellow, Katie McGhee, distributing “baby birds” to students in an evolution activity.



Students recording behavior observations of salamanders.

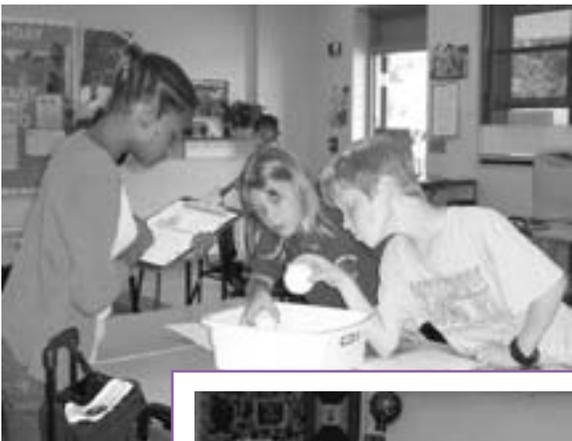
students, individual accountability for learning the material, and the use of appropriate interpersonal social skills by the students in order to be truly cooperative.² If done correctly, the cooperative group setting encourages students to help each other learn and master the material, as well as conveys to students that learning is important and fun.³

Effective cooperative learning is perhaps most important in teaching subjects that are conceptual and complex, such as science, that require critical thinking, problem solving, and decision making.² Scientific research is never done in isolation—it is a continual collaboration between people in which progress is dependent on information sharing and discussion⁷ (NAS, 1995).

Unfortunately, teachers often teach science as a process conducted by a single individual who either gets the “right” or “wrong” answer to a specific question, with right answers leading to progress and wrong answers being a waste of time. Teachers do not explain that right, wrong, and even unclear answers all play important roles in scientific research and contribute to our collective knowledge of the world and how it works. Teachers rarely teach that scientific discovery occurs by continually building on the ideas and findings of others. Progress is a result of the cooperation of many people, even across different disciplines, towards a common goal.

Incorporating cooperative learning into science teaching allows students to explore and come to their own conclusions and in doing so, strengthens their understanding of science concepts and their use of higher-level reasoning. In addition to knowledge in the sciences, students gain essential social skills, self-esteem, and positive feelings towards cooperation and group interactions. Cooperative learning helps motivate students and instills in them a greater confidence in tackling an area that they often view as difficult and boring. Use of cooperative learning in science teaching through inquiry-based and interactive group activities, sets the stage for critical thinking and honest discussion,⁵ as well as an understanding of the true scientific process as it occurs in the “real world.”

In this chapter, I discuss observations conducted during a particular inquiry-based science activity performed by fifth-graders in small groups. I focus on observed behaviors and problems, student opinions on group work, potential techniques to minimize problems, and the benefits of using cooperative groups in teaching science at the K–12 and undergraduate levels.



Students making observations and recording data from a GEMS “sink-float” activity.

Setting

I conducted these studies at Canopy Oaks Elementary School with Patty Ball’s fifth-grade science classes. At the point when I made the majority of the following observations, I had been visiting the classes as a GK–12 NSF Fellow once a week for three months.

This is a fairly new school (built in 1998) located in Northern Leon County in Florida and consists of pre-kindergarten to fifth-grade students. Each classroom is isolated from the others by walls, and the school is technologically advanced with computers and TV screens in each classroom. The number of students in each of the four fifth-grade classes ranged from 25–28 students with an almost even mix of boys and girls. These children are from either single-parent homes or two-parent homes in which at least one of the parents is

working. The ethnic make-up of the four classes is approximately 67%–75% Caucasian and 25%–33% African American with few other minorities. Desks in the classroom are arranged in groups of five or six although the children often work individually. Students are accustomed to working in groups during science experiments, and I had specifically worked with them in groups for other Great Explorations in Math and Science (GEMS—curricula developed at Lawrence Hall of Science at the University of California, Berkeley) activities such as *Ooblek: What Do Scientists Do?* The student groups consisted of students of mixed skill and achievement levels, as well as genders (although some groups were all boys or all girls) and ethnicities.



Students showing their artistic representation of the ship the Mimi from the story *Voyage of the Mimi*. Note their depictions of themselves on the boat and clouds.

Activity

Although I made similar observations during most of the interactive activities in my time in Ms. Ball's classroom, this chapter concentrates on the behaviors observed during a “sink/float” activity. Both Ms. Ball and I participated in this particular activity during a GEMS teacher workshop during the previous summer, and based on our own experience, we were excited to try it with the students. In the previous science class, we introduced the students to the concept of density through an activity in which they added salt to water until an egg floated. The sink/float activity expands on the concept of density and seeks to have the students work through the common misconception that small objects float and large objects sink. It also allows students to make predictions about what they think will sink/float and then test their predictions. Students recorded their predictions, results, and interpretations on a data sheet I created (see page 47).

After discussing what they had learned the previous day about density, the sink/float activity was described. In groups of four to six, students passed around each of the 12 objects and tried to come to a consensus on their predictions of what objects would sink or float. We used overlapping circles of yarns to enable the students to physically divide the objects into “sink,” “float,” or “unsure” categories. We encouraged the students to voice their ideas and try to convince others of their views by justifying them with clear reasoning. Ms. Ball and I circulated among the groups asking the students about their predictions and their reasoning. The students then took turns putting objects in the water to test their predictions. They recorded their results and answered some interpretive questions on their data sheet. After testing their predictions and completing the data sheet, students shared their group results with the rest of the class and Ms. Ball wrote a sink/float list on the blackboard. Students discussed and interpreted their findings together as a class. We divided the activity into three sections (i.e., predictions, testing predictions, results) with each section separated by instructions. In addition, we distributed resources during each section. We distributed the data sheets and objects in section one and the bucket of water during section two. We removed the buckets of water in section three.



GK-12 teacher Patty Ball with Katie McGhee, GK-12 Fellow, in the classroom.

Observations During Sink/Float Activity

Making Predictions

Animated discussion occurred during this stage. Students used higher-level reasoning and past experience to justify their predictions. For example, some students had

“floating candles” at home; others remembered throwing a penny into a wishing fountain and seeing it sink; and others remembered the paperclip sinking into the Ooblek during that activity. Students did not realize they were using previous experience as a justification until Ms. Ball and I prompted them, but they understood the importance of this knowledge immediately. Most students discussed their different ideas at great length and had clear justifications and reasoning for their ideas.

Most groups had a difficult time reaching a consensus about their predictions. Listening to each other’s opinions and arguments was frustrating for some students who would get impatient and interrupt. Other students were more patient and let others explain themselves. The most common objects students disagreed about were the candle and the string. Although initially and as we circulated among groups Ms. Ball and I stressed that students had to justify their predictions to one another and try to convince their group of their reasoning, some groups ignored those who disagreed with the majority stating, “Since this is a democracy, the majority rules.” Though it is easy to superficially settle disputes using “majority rules,” it does not promote learning or discussion, and students should uphold their opinion unless logically persuaded. When disagreements persisted, we gave students the opportunity to record their differing opinions.

Testing Predictions

After groups completed their predictions and students filled out that portion of the data sheet, I explained to the class the next step: testing their predictions. We distributed buckets of water, and students were able to test their predictions by gently

placing each object in the water and recording whether it sunk or floated. In order to promote participation by all students, Ms. Ball and I instructed the students to take turns testing the objects and to record their observations on their data sheets. Students were extremely excited about testing their predictions especially the highly debated objects that they had placed in the “unsure” category.

Problems with taking turns to test the predictions varied by group. All groups decided on the order and who would test which objects before testing began. After we gave permission to begin testing, many students frantically grabbed for an object as if they were afraid they would be left out. Some groups agreed on the order, and each student patiently waited for the student ahead of them to test his or her object. At the prompting of their group members, the next student tested his or her own object. Although few

groups followed this type of fair protocol for the entire group, the ones who did were usually groups of close friends.

The majority of the groups had at least one minor problem testing their predictions. Common issues included students who wanted to be the last one to go (in the few cases where this occurred, the student was female), students who wanted to test a particular object (usually the objects in the “unsure” category), students who went out of turn, or students who tested fewer than the others (there were not always two objects per student). These minor problems only slightly disrupted the group, and usually the activity resumed a minute or two later. Often, the group would get upset with a particular student for not following the agreed upon order or for “cheating” (testing more than his or her share of the objects, going out of turn, or stealing someone else’s object). These “trouble” students were often disruptive in other activities as well. In order to maintain order, which got out of hand a few times, Ms. Ball and I circulated among groups asking questions and encouraging forward progress while only staying a minute or two at any one group.

GK–12 Fellow Katie McGhee and students discussing results of a GEMS “sink-float” activity.



Disagreeing and Sharing Results

At both the prediction and experimental stages, when students had different opinions, predictions, ideas about “fairness” or the “rules,” and were unwilling to compromise, the discussion sometimes elevated to an argument. Physical grabbing of an object or shoving often occurred when there were disagreements about who was going to test which object (the objects about which students were uncertain were often the most coveted) or the order in which students were going to test their objects. There was never a case where all members of the group were arguing different points. Instead, the group would divide into two camps or one student versus the rest of the group.

When it came time to see which members of the group were “right,” there was surprisingly little gloating. Most students simply stated they were right and moved on to the next step in the experiment. The students that ended up being “wrong” usually acknowledged happily that the other student was right and that they were way off. In some ways, being surprised was a good result. For example, after testing the predictions, students were not discussing which ones they were right about but which ones they were wrong about and how surprising it was! Often groups that had wrong predictions were the ones most excited about sharing their results with the rest of the class. Students were not reluctant to talk about their right or wrong answers in any way, and this is likely due to their experience doing inquiry-based and interactive science activities.

When groups had completed their experiments and students had completed their data sheets, the groups could then share their results with the class by stating what they found to float and sink and recording it on the board. The class discussed inconsistent results (e.g., some crayons sank while some floated) as well as results that differed across the day (e.g., the string only floated for the first class of the day), and students discussed possible explanations for these results. Although it is not necessary for groups to compete against one another to increase cooperation in the group, students will often make group comparisons informally. These comparisons can be important for increasing interdependence within a group and “group-support.” In addition, these types of comparisons do not lead to low self-esteem or negative feelings since groups containing both low-achievers and high-achievers make these comparisons.

What Students Think About Cooperative Group Work

After completing the exercise, I asked two of the four classes how they felt about doing these types of activities in groups. In all the classes, there was agreement that groups were often more fun because you can talk with others, especially if you have friends in your group. In addition, all agreed that they did not like the arguing that often occurred during group work, especially when trying to reach a consensus. For example (all names have been changed):

What do you like about working in groups like this?

Paul: It’s fun. You get to talk to people and your friends. And you don’t have to be quiet.

John: You can get help if you need it.

Anne: If you don’t know the answer and need help, you can ask smart people in your group and they can help you.

Jack: You get more opinions and ideas. Sometimes people have different ideas.

Jennifer: You can test your hypothesis.

What do you not like about working in groups like this?

Anne: Arguing. There is sometimes a lot of arguing, and I don’t like that.

Dean: Sometimes people don’t listen to your opinion and ignore your ideas.



A student in Katie’s classroom.

Sara: Sometimes a person is too sensitive and pouts when they don't get their way.

Christina: Sometimes people gang up on one person. If you have a different idea and the group thinks you're wrong, they gang up on you. They won't compromise.

Theo: If the group won't compromise, they put an object in "unsure" instead of making a choice on sink or float.

Anne: You don't always like people in your group.

Sara: I don't like being bossy, but I end up being the leader in a group.

Aaron: Sometimes one person will be the boss and the rest of the group doesn't matter.

Although students had more to say on why they did not like group work than on why they did like group work, approximately 67% of the students in the surveyed classes preferred to work in groups rather than individually, and almost all preferred inquiry-based, group learning to a teacher demonstration of an activity.



In an evolution activity, students acting as birds received a "baby bird" for every five beans they collected and gave to the GK-12 Fellow.

Techniques to Reduce Problems

Group Assignments

Designating groups is often difficult, and there is no guaranteed way to assign students to a group to ensure cooperative learning. Teachers who work with small groups often find that groups formed based on friendship work better together and produce better work than groups formed based on other criteria.⁸ In the activity previously described, there was only one group formed entirely of male friends. However, it is impossible to have *all* groups formed entirely of friends. It should be noted that close friends in a larger group might form cliques from which other members of the group feel excluded or by whom they may be bullied. In some cases, peer groups may overwhelm independent thinkers and cause wrong ideas to persist.⁸ Perhaps it is best to separate *close* friends and distribute students throughout the classroom.

For effective cooperation and interactions to occur, the more difficult the concept or task, the smaller the groups should be.² In addition, groups should not consist of more than six students and all students must be able to see and reach the objects involved in the task to be able to actively participate.² These groups should consist of students of mixed abilities to promote discussion, creativity, and peer teaching.² Cooperative learning in such mixed groups allows students of all levels to feel successful by allowing low-achieving students to contribute while challenging bright students to explain the concepts to others.⁵

Differences of Opinion

Teaching students the difference between "not listening to your opinion" and "disagreeing with your opinion" is difficult but an essential concept. In the activity described here, one particular student, "Dean," got very agitated that the group did not agree with him and interpreted it as the

group ignoring or not listening to him. Most other students who could not convince their group of their opinions wrote down their own independent predictions; "Dean," however, pouted and refused to participate for a few minutes, convinced that the group was not changing their predictions because they did not like him. He took their disagreement with his predictions personally. Some of the other group members attempted to coax him into participating by encouraging him to test a prediction or even volunteering one of their own objects for him to test. Perhaps these particular students were attempting to placate Dean in order for everyone to be included and the activity to continue. It is possible that these students had younger siblings who have behaved in a similar manner when they did not get their way.



Girl observing fossils.

Perhaps one of the more difficult concepts for teachers to convey to students is that listening to someone's idea does not mean you have to agree with it⁶ and that the converse is true. It is important for all students to have a non-judgmental environment in which to voice their opinions and accept those of others.⁶ It is also important that students understand that it is okay to criticize and disagree with an idea, but that it is not okay to criticize a person for their ideas. Teachers are in a position to provide ways that group members can maintain their individuality and improve their role as a member of the group.⁹ If the teacher stresses a no-risk environment and respect within a group, meeting the needs of individuals can be done in a cooperative learning setting when all students work together.⁹

Distribution of Resources and Labor

Having enough objects or "jobs" so that students can take turns and all can participate is essential for cooperative learning in a small group setting. This alleviates much tension, especially that directed towards the most domineering students who the others often regard as bossy. Encouraging student collaboration by distributing resources and equipment among students (resource interdependence) or dividing the labor of a common project among students (goal interdependence) results in positive interdependence and gives students the impression that they will get better results by working together.^{6, 1, 9} This division of resources and labor works well in today's classroom in which there is limited time and teacher resources.

Activity Parts

Breaking up the activity into smaller chunks (e.g., predictions, testing, results) separated by teacher instructions or material distribution so that the teacher can restore quiet in the classroom, helps calm students down and allows them to "start over" at each part of the activity. Some students, who were bossy in the first section, became subdued in the next section, perhaps because the others in their group got upset with their bossiness in the previous section. Other overlooked students often spoke up or participated more in the next section, perhaps because they didn't want to be excluded.

Cooperative Groups and Science Learning

My observations lead me to conclude that working in groups is extremely important for students not only in learning concepts but also in learning social skills. It teaches them sharing, patience, tolerance, and respect for others. Although many children work well in groups and sincerely try to help others, others do not seem to know how to compromise, make their opinion known without pouting, or follow directions. It would be interesting to investigate whether having siblings plays a role in learning how to compromise and work with others.

Cooperative learning promotes positive interaction, and these strategies should continue to be incorporated in early childhood classes to encourage sharing, taking turns, and enhancing children's relationships with peers of different genders, races, and social groups.¹⁰ Instilling the feeling that more can be accomplished when you contribute as part of a group can help students in many of their school subjects, in addition to their "real-life" experiences. Cooperation is essential in almost any career, and students will be better equipped in their future the earlier they learn these skills.

In terms of science and mathematics, students learn best when they can construct understandings based on their own experiences, when they can examine and solve, and when they can discover, prove, and communicate their own theories.¹¹ In other



Students watching freshwater fish behavior.



Students recording behavioral observations of freshwater shrimp.



Students showing GK-12 Fellow Katie McGhee local fish they had identified from a field guide.

words, cooperative learning aids science learning. Without the ability to work with others, science does not progress at all. Communicating ideas, sharing results, and listening to different perspectives are crucial and part of what makes science so exciting. As the students in this activity acknowledged, sometimes it is better to work in groups because you get new ideas and you can get help when you do not know the answer. I think that activities that encourage students to work together and cooperate, perhaps in planning an experiment as well as executing it, help students get excited about science, learning, and discovery. In addition, group inquiry-based activities keep all students engaged throughout the entire learning process.



Girl recording data from a fish behavior experiment.

In this day of rapid technological and biological advancements, it is important that students feel excited about science and remain interested in the subject area as they progress through school. Cooperative learning helps students promote a positive attitude towards the subject area as well as continued motivation to learn about the subject in the future.²

The teacher is in a unique position to provide guidance and cooperatively designed science activities so that the students' experiences with science, cooperation, and group work are ones that they will want to repeat again in the future.⁹

Cooperative Learning at the Undergraduate Level

Undergraduate teaching in universities rarely utilizes effective cooperative learning in the sciences. Although students may have a laboratory partner or group with whom they must work, it is primarily because of limited resources. The professor assesses work individually, and slower students are often left behind when faster group members rush through the experiments, dissections, and other activities in order to get out of the laboratory quickly. Using cooperative learning in exploration and learning of concepts, and especially in revealing common misconceptions, could be extremely helpful. It is perhaps at the undergraduate level when most misconceptions could be remedied and where this approach could be extremely rewarding. When students hear from the professor that things are a certain way, they may memorize it for a test but may not believe or truly understand it because of previous teachings in high school or earlier. Inquiry-based activities in a small group setting help expose these deep-rooted misconceptions and enable students to reconstruct on their own what is important. As with younger students, encouraging undergraduate students to work together positively rather than competing against one another could help students of all abilities by allowing low-achievers to contribute in being creative and voicing ideas and challenging high-achievers to explain difficult concepts to others. At an age when most students feel they are smarter than everyone else, using interactive groups to explore difficult concepts, design an experiment, gather data, and explain results to others could capitalize on this attitude by using it to help motivate students to learn and help each other. Although lesson and activity design can be challenging, allowing students to explore rather than support the information the teacher has just explained would be the most valuable for undergraduates.

After working with elementary-school students, I think students of all ages would benefit from incorporating cooperative learning into inquiry-based science activities with small groups. After a little nudging in the correct direction, students often progress at a faster pace and gain a more thorough understanding and mastery of the material in a cooperative group setting than in a lecture setting. It takes practice and thoughtful execution for the teacher or professor to develop science lessons that result in truly cooperative learning. However, the teacher can nurture the skills used in cooperative learning, and once students and teachers have experience in this type of learning, the teacher can hone these skills so that the students can build upon them for the rest of their lives, resulting in a lifelong appreciation for science, exploration, and teamwork.

Boy excited about marine invertebrate activity.



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The sink/float activity expands on the concept of density and seeks to have the students work through the common misconception that small objects float and large objects sink. It also allows students to make predictions about what they think will sink/float and then test their predictions. Students recorded their predictions, results, and interpretations on a data sheet Katie McGhee, the GK–12 Fellow, created.

Sinkers and Floaters

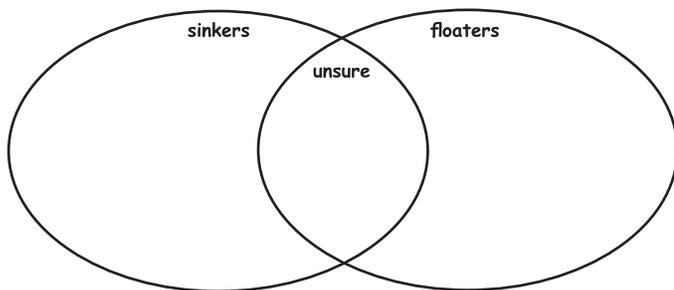
Name: _____ Date: _____

Predictions

Which objects do you predict will sink?

Which objects do you predict will float?

List the objects based on your predictions:



What things were important when you made your predictions?
(e.g., size, material, shape...)

Experiment

Taking turns, gently place one object at a time in the water.

Does it float?

Record your observations.

	Sink	Float	Other
Plastic spoon			
Crayon			
Wood clothespin			
Foam			
Candle			
Penny			
String			
Button			
Paperclip			
Piece of glass			
Vial of water			
Elastic band			

What surprised you? Why?

Did all the heavy items sink?

Did all the small items float?

Why did some large, heavy objects float and some small, light objects sink?



The **Learning Cycle** of **Classroom Management:** A **Design** for **Producing** an **Effective Teacher**

By Jocelyn Dudley

Biographical information:

Jocelyn Dudley
M.S. in Chemistry and Biochemistry, August 2005 from
Florida State University

Why I chose my field:

My science teacher from high school, Mrs. Weida, and my father inspired me. Mrs. Weida made science so fun and engaging. I never had a dull moment in her class. As a child, all the toys that I received from my father were educational and mostly related to science and mathematics. He prepared me for my journey ahead in the science field. He made sure that I had the best and the latest technology in order to do well in school.

Why I applied for the GK-12 program:

I wanted the opportunity to help my community and increase the interest in science by aiding the science teachers.

What I gained from the GK-12 program:

I have realized that I would make a wonderful professor. I have gained the experience, the patience, and the tolerance to handle anything.



GK-12 Fellow Jocelyn Dudley.



GK-12 Fellow,
Jocelyn Dudley, at
graduation.

Ready to Teach

On the first day of class I was ready to teach. I had all of my lesson plans and assignments designed for three weeks, and the enthusiasm that I felt would last me a hundred years. Much to my chagrin, I soon learned that it takes more than just having lesson plans and activities to teach. It takes patience, adaptability, good communication skills appropriate for that particular audience, and the ability to control the mood of my students in the classroom. In the beginning, it was very difficult to try to teach science to my students when there was very little order in the classroom. I found that the major problem with me trying to be a good teacher was not that I was ill prepared, uncommunicative, impatient, or unable to adapt, but rather that I had a problem with classroom management. I had to find some way to take control of my classroom in order for me to teach. To do so, I had to implement careful planning of the procedures, routines, and school policy for appropriate behavior. I had great mentors and teachers who taught me how to gain the experience needed in managing a classroom. I observed and critiqued their management skills and personalized my own techniques. Most importantly, I learned that an effective teacher is one who has great classroom management skills. By maintaining control over the classroom, this decreased chaos and optimized the environment for learning.



Jocelyn Dudley, GK-12 Fellow,
sharing the fun of science.



A future scientist!

My Role as a Scientist/Para-Educator

I participated in the National Science Foundation-funded GK–12 Program in which the GK–12 Fellows went into the educational community and aided the science teachers. Our goal was to improve the quality of science that we taught with the teacher through use of alternative teaching styles and inquiry. It was my pleasure to make science as exciting and interesting as possible. The ultimate goal was to try to capture the students' attention and to encourage them to learn more science, and perhaps, pursue a career in the sciences. To show them that science was fun and attainable and that there are so many things to be discovered, I always tried to treat my students like little scientists in the making. I valued their thoughts and ideas and encouraged them to pursue the answers to their own questions.

Good Teacher Versus Effective Teacher

As an educator, I learned that we wear many hats. We are classroom managers, communicators, counselors, role models, disciplinarians, conveyors of information, and other roles. Since we influence our students in so many ways, it is our job to vary our presentations and create a learning environment that addresses the individual learners. I have found that there are some great and wonderful teachers, and there are some teachers who lack the passion and capability to teach.

What are the characteristics of a good teacher? A good teacher is very good at explaining information to the students at a level that the majority fully understands. She takes the time to willingly and patiently help those who do not understand the information. A good teacher has a wonderful sense of humor. She can make any room light up and ease the tension in the classroom. A good teacher likes people and is comfortable with the age group that she teaches. A good teacher is fair-minded, has common sense, and can make good decisions quickly and fairly. She is very knowledgeable in her field and is constantly learning new ideas that will vary the classroom environment so that the students can learn through inquiry. She sets high standards and expectations for her students and accepts nothing less than the best from them. She keeps the class focused and on task and manages her time wisely.

How is an effective teacher different? I knew I had all the qualities of being a good teacher, but it takes more than good teaching and being knowledgeable in my field to be an effective teacher. It takes great management skills to make sure that the class stays on task, to decrease chaos, to have more time to engage in activities, and to increase the amount of learning in the classroom.¹ It takes an effective teacher. An effective teacher will spend more time in the beginning of the year managing the classroom in order to prevent classroom discipline problems later in the year. By taking control early in the school year and teaching the students procedures, routines, and the school policy, the students will know appropriate behavior and will maintain structure and order. Thus, more time can be spent on teaching,

activities, and learning. This is where the problems lie with some teachers; they do not spend enough time going over procedures, routines, and school policies. Teachers are sometimes inconsistent with their methods of correcting behavior. Teachers need to realize that the majority of the bad behavior can be corrected very easily by practicing good classroom management.



GK–12 Fellow Jocelyn guiding the student in her own discovery.

Role of a Teacher

Classroom management is a process that should be considered in advance and constantly emphasized to the students. The role of the teacher is to manage the classroom. It is her job to enforce the routines and procedures and to avoid the problems before they start. It is very difficult for para-educators to teach students when there is no order in the classroom, no control, no structure, and, therefore, no learning takes place. The teacher must know what she wants and expects from her students. She must precisely convey her expectations to her students and communicate that clearly to her students. In order to reinforce her expectations, she can have the student sign a contract with her and forward a letter home for the parents to sign as well. The letter should consist of expectations and school policy and the consequences for not following them. Rewards for adherence to the guidelines should also be outlined. For more information about techniques and guidelines for classroom management, you can visit *The Really Big List of Classroom Management Resources*² for an invaluable list of resources available.



Girl recording data from the experiment, Analyzing Physical Properties.

Ideal Class Under Good Classroom Management

An example of a class with good management would be one that has the procedures, routines, school policy, and consequences for everything posted visibly for all students to see and read.³ There would be a student center that would contain a pencil sharpener, a homework collection drop box, a box for returned graded assignments, and an assignment folder listing all homework or in-class assignments for those who were absent. This way, if the student had been absent, all the student would have to do is go to the folder and see what work s/he had missed. The teacher should write the homework due for the next day in a consistent, visible place so that after the students arrive in class they can write down that day's assignment in their agenda books. In order to control the beginning of class, a bell-work assignment, which is to be finished before the bell rings, should be available as the students enter the classroom. The quicker they come in, the more time they will have to complete the bell-work that will be graded. The objectives for the day should be written on the board. So, the first five minutes of class should consist of students coming in, placing homework in the homework drop box, the student helper passing out any graded work, the students writing their assignment in their agenda books, students completing their bell work, and students starting to review the day's objectives while the teacher takes roll. If done properly, this saves a tremendous amount of time, maximizes the amount of learning, and minimizes the frequency of behavioral problems. The bell-work must be graded or the students will not do it and may spend their time talking.

Working in groups also calls for procedures and routines.⁴ As a scientist, I try to teach the students the process of investigation. The scientific method consists of first observing and noting these observations, forming a hypothesis to explain what they think is happening, performing experiments to test their hypothesis, collecting data, analyzing their results, and perhaps formulating new questions or developing a hypothesis based on the new data. The students will never fully conquer this task in one period nor gain the concept of that particular laboratory unless they are extremely focused and structured. For the laboratory, the teacher should place a container full of the materials needed to perform the



Jocelyn was a role model for young girls like this one to pursue a career in science.



Boy exploring and discovering endless possibilities.

laboratory in the center of the table. At first the students should not touch anything; the first step of the scientific method is to observe with their senses of sight, sound, smell, but never taste. Once this has been done and with the teacher's permission, the students may touch the items and then must write down their observations and continue the steps of the scientific method. There should be someone to record, to collect the materials, to test the materials, and to return the materials and clean the area. The students will learn by inquiry and cooperative learning. They will learn to work together quietly and efficiently and to practice following directions, staying focused, presenting and communicating with peers, taking notes, and solving challenges together. At the end of the laboratory, the students should write a summary of what they have learned and, if time permits, share their results with the class for an open discussion.

Learning Cycle of Classroom Management

The five Es of the learning cycle are to engage, explore, explain, extend, and evaluate.⁵ The learning cycle can be applied to any learning environment. The first

step of the cycle is engaging the learners. I will give you examples of what we did in our program when the GK–12 Fellows took a graduate-level course for credit on the *Teaching and Learning of Science*. During the engaging process, our class prepared us for what we might be faced with as scientists entering a classroom. We learned about such things as children's mentality, learning styles, teaching styles, Florida Comprehensive Assessment Test (FCAT), assessments, classroom management, and other objectives.



Girl engaging in the scientific process of observation.

During the exploration stage of the class, we learned how to assess and to teach for different learning styles through watching a video of Harry Wong on classroom management, listening to guest speakers who provided inquiry activities, and having in-class discussions. Once we were teaching in the K–8 classrooms and aiding the

teachers, the Fellows met to discuss our experiences and what we had learned, what we liked and disliked, and how we could try to improve those situations. We reflected on what we learned in the class and how we could influence the teachers on what we grasped from our class without confrontations. With every class I taught, I was able to improve my techniques of managing the classroom. This led to the extension and evaluation steps of the learning cycle. We modified different techniques to suit our managing styles while making class as fun, exciting, and enthusiastic as possible. We reflected on what happened each day in our K–8 classrooms as part of the evaluation step in the learning cycle.

We brought this model of the learning cycle into our K–8 classrooms to enhance student understanding and interest in science.



Children discussing their findings cooperatively in an inquiry experiment.

Observations of Teachers and Classroom Management

My first assignment was at Sealey Elementary School working with Mrs. O'Meara's fourth-grade class. She was a wonderful, effective teacher. The students followed every

routine and procedure flawlessly, even when she was not there. For every laboratory we always finished on time, had time to summarize and discuss what was learned, and discussed other approaches that could have been done. She had great management skills from the beginning of class to the very end.

My second assignment was working in a sixth-grade class. This was my teacher's second year of teaching. She had not quite developed efficient management skills and therefore lacked control over her class. It was extremely difficult to plan activities and perform laboratories when there was little structure.

Next, I had the pleasure of working with Mrs. Roberson's sixth-grade class at Fairview Middle School. She was a very efficient teacher. I learned from her about structuring a classroom from A through Z and how to help the students take control of their own learning experiences. She was very good at making the students feel that they had a voice in what activities she implemented and asked for feedback from the students about the quality of new activities.

From the three teachers with whom I worked, the mentors within the GK–12 program, and the guidance of Harry Wong, I strongly feel that I have fully traveled the path of the learning cycle of classroom management and have grasped the skills needed to be an effective teacher. The GK–12 program was a wonderful experience that allowed me to expand my horizons and to aid the scientific community by preparing the young minds of today for the future tasks of tomorrow.

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Girl reading directions in order to follow the procedure correctly.



Mrs. O'Meara, Jocelyn's GK–12 Teacher, looking over her student's work.



Girl collecting data and analyzing her results.



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Better Lessons Through Topic Research

By Heaya Summy

Biographical information:

Heaya Summy
Ph. D. candidate in the Department of Physics at Florida State University

Dissertation Topic:
Shell Model and Nuclear Structure

Why I chose my field:
The nucleus is the heart of the atom, and by solving some mysteries associated with it, new and useful science may be produced.

Why I applied for the GK-12 program:
Having attended many public schools in the nation, I saw a need for some improvement in the teaching of science and math. Also, there have been some good examples of teaching styles that I felt should be perpetuated.

What I gained from the GK-12 program:
By participating in the GK-12 program, I gained a deeper understanding of teacher-student dynamics and effective teaching methods.



GK-12 Fellow Heaya Summy at one of the GK-12 monthly meetings.

Introduction

As a product of America's public school system, I am very interested in learning about the science education reform movement and contributing to possible improvements in science teaching and learning. There are many fine teachers at all grade levels, but the very best are the teachers who retain their inquisitive nature and try to continue to learn regardless of how long they have been teaching. During my time as a GK-12 Fellow, I have encountered many of these fabulous teachers and know how the teachers value the opportunity to show children that learning can be both fun and interesting. Since the teaching profession is such a critical one, I would like to provide some assistance and confidence to those who are teaching science outside of their fields of expertise.

There are a plethora of studies raising the alarm for the need to improve science education in the U.S.^{1,2,3}; however, imposing new standards from classroom outsiders alone cannot extinguish the deficiency. The classroom element with the greatest influence is the teacher, thus definitive progress can only be made with his/her help.

All high-performing countries show student gains between grades 3 and 4, and again between 7 and 8. The U.S. does not. Even in fourth grade, where the U.S. students do well relative to those in other countries, their performance in physical science areas is weak, foreshadowing their average performance at eighth grade and their unacceptably poor showing at twelfth grade. When we compare our GK-12 schools and curricula in light of the TIMSS¹ results, we find many teachers lacking good content preparation and, in the aggregate, a muddled and superficial curriculum.²



GK-12 Fellow Heaya Summy showing student how to read the thermometer.

Based on my two years as a GK–12 Fellow, I perceive that what is needed most is something that has to be implemented by teachers themselves. Perhaps you have heard the expression “physician, heal thyself.” Along similar lines (but without the cynicism), I propose, “instructor, teach thyself.” When a teacher is unfamiliar or uncomfortable with a subject, it is easy to gloss over it, cover it poorly, or even eliminate it from the curriculum. Even with the time constraints of today’s classrooms, this does not have to be the case with the application of a little organized research on the part of the teacher.

Cooperative teaching with Heaya Summy, GK–12 Fellow, and Teresa Anderson, GK–12 Teacher.



Lesson Preparation

Another contributing factor to the widening gap between the U.S. and other countries in their students’ performance in mathematics and science³ may be the small amount of time being spent preparing to teach. In the U.S., most science teachers teach five to six periods of classes each day, have laboratory materials to get ready and put away themselves, meet with individual students and sometimes their parents, and have grading to do as well as lesson preparation. In other countries that are doing well in terms of their students’ performance in mathematics and science, their teachers have fewer classes to teach each day and have planning periods to work together to improve the lesson.³

In part due to this time and responsibility crunch, even specialized U.S. science teachers sometimes use activity sheets with their students without reading over the material beforehand to make

sure that they are clear on the objectives and principles of the lesson. Thus, a teacher can at times introduce major ideas without a full understanding of the lesson, thereby presenting vague and/or incorrect fundamentals to the students. Although teaching

students incorrect information is a key issue, the main point I want to make is the lack of careful, thoughtful preparation of the lesson. Furthermore, this presentation is probably repeated to several classes during the day.

Today’s teachers have a myriad of administrative responsibilities in addition to their teaching duties. Most have an array of standards to cover to ensure students succeed in the high-stakes testing environment found in many states. This causes serious time constraints for many teachers. What I suggest may appear unattainable; however, I believe that if a teacher takes the time necessary to review the material and curricula available on the topics to be presented, he or she will end up saving time in the long run.



Heaya teaching how to take temperature measurements.

Topic Research Explained

Since knowledge is the difference between a teacher and a pupil, foremost to becoming a brilliant teacher is gaining familiarity with a lesson topic. Understanding the lesson can seem confusing at first because we may not initially have a feel for how much we need to know or where to even start in the search for knowledge. Hopefully, this chapter can serve as a reference source for those who feel overwhelmed by the prospect of researching science subject matter on their own. Topic research does not have to be a looming monolith waiting to fall and crush the unwary. The following are some guidelines that may help alleviate some of the anxiety attributable to preparing for a difficult science lesson.

Know Your Sources

We need to discuss how to approach topics that are unfamiliar or uncomfortable for the reader. With this in mind, it is useful to start with some basic material, whether it be an activity out of a laboratory manual, a worksheet obtained at a teachers' conference, or a guide to already researched and prepared activities (e.g., GEMS—Great Explorations in Math and Science⁴). Additionally, any quality material that contains the target subject makes our task of laying a foundation easier.

The textbook to be used with the students plus some additional comprehensive texts should be the first source of reference. Choosing a supplemental reference textbook is not problematic but should be done carefully before the school year begins. It could be the college textbook that the teacher used (for example, in my field, the freshman physics text or a text from the science area being taught). I found my college textbooks to be particularly useful even when I was teaching elementary-school science during the GK–12 program. Other teachers or professors can be helpful in recommending a fundamental textbook if you are not sure what is available or useful. It is important to remember that you are not teaching from this text but learning enough to make yourself comfortable enough with the content material to prepare a good and accurate lesson appropriate for the grade level. Look in the index for the topic (e.g., energy, work, waves, lenses), and read as much as necessary to understand basic ideas. Develop questions on the subject matter as the reading progresses, and try to predict what sort of questions your students might ask. It may be necessary to look up additional terms and subjects in order to understand the main topic. Don't go overboard here—only some background information is needed at this point. If the questions are not answered to your satisfaction with further reading, do not worry. There are plenty of other sources of information.

Take advantage of the golden age of the Internet in which we live. This may turn out to be one of your favorite sources of information. First, test out the various search engines in order to find the one that suits your needs.

Table 1: Search Engines on the Internet

Google	www.google.com
Netscape	www.netscape.com
Lycos	www.lycos.com
Altavista	www.altavista.com
Yahoo	www.yahoo.com
Excite	www.excite.com

In Table 1 are some suggestions of search engines that you may utilize. Searching the Internet successfully is an acquired skill that may take a little practice. If good results are not obtained with the initial topic for which you searched, try transposing words or rewording the search. One caveat: be wary of the websites visited. Keep in mind that anyone with a computer can post material on the Internet; only gather information from reputable sites (e.g., universities, government, professional organizations, etc.).



Students composing a rap about heat energy. Heaya Summy, the GK–12 Fellow, and her GK–12 Teacher allowed the students to do this after the class was completed and just before the bell rang. The students paid attention, as they knew they had the opportunity to apply the science vocabulary to their song.



Student examining his data chart.

The Web can do more than just detail content background for your topic. It may provide lesson or activity ideas, post good test/quiz questions or other assessments, or provide interactive sites that your students can use (some of these are especially well developed). It can be an invaluable tool in learning details of various things not easily found anywhere else. Some examples of useful physics related websites are listed in Table 2. Included at the end is my GK–12 Web page that is still under construction.

Table 2: Physics Resource Websites

States of Matter	<ul style="list-style-type: none"> • www.chem4kids.com/files/matter_states.html • www.harcourtschool.com/activity/states_of_matter (interactive) • www.chem.purdue.edu/gchelp/atoms/states.html
Forces, Vectors, and Newton's Laws of Motion	<ul style="list-style-type: none"> • http://sciencespot.net/Pages/kdzphysics.html • www.physicsclassroom.com/Class/vectors/vectoc.html • www.glenbrook.k12.il.us/gbssci/phys/Class/newtlaws/newtltoc.html
Work, Energy, and Power	<ul style="list-style-type: none"> • www.glenbrook.k12.il.us/gbssci/phys/Class/energy/energtoc.html • http://hyperphysics.phy-astr.gsu.edu/hbase/work.html
Heaya Summy's GK–12 Web page	<ul style="list-style-type: none"> • http://comphy.fsu.edu/~hsummy/GK12/index.html

Students engaged by teacher's explanation.



For additional information, as a final step, ask other teachers and scientists for any needed clarifications. If you do not have rapport with a knowledgeable scientist or science educator, why not send an e-mail to an appropriately positioned professor at your local college or university detailing your question? I recommend directing questions to more than one professor, in case the first is extremely busy at the time of your inquiry. Make sure to let the professors know who you are in case their own children attended, are attending, or will attend your school, then who knows how much help you will get! Many are very willing to aid teachers. After a couple of e-mails, a useful new relationship may become established. If you cannot find someone to help you after this, type, “ask a scientist” into your Internet search engine and access online assistance from sites maintained by practicing scientists.

Using the finished product of activities, lesson plans, and curricula of your colleagues that are published on public school sites on the Internet can save a considerable amount of time. There are numerous already prepared items ready for immediate use. Your colleagues in the public school system have already time-tested most of these ideas, and it would be to your great advantage to utilize these resources.

Get It Together!

Most likely, it will not be necessary to go through every step outlined above. Also, since each teacher has individual strengths and weaknesses, you will probably find that you have preferences in regards to the order of the steps and the

amount of time to spend on each step. Tailoring these ideas to your personal style optimizes the benefit of this guide. The section entitled “Application in Practice” lists some GK–12 teachers with whom I have worked and their talents that most impressed me.

Students taking temperature measurements.



Another requirement for successful implementation of this guideline is early preparation. It is not clear from the beginning how many days it will take to get your questions answered, so it is better to start sooner rather than later. This does not mean that it will take you a long time to actually prepare the lesson, but for instance, you may have to wait longer than you expected for an e-mail reply.

The first time you research a subject will take the most time. After going through it once, you will bring that information with you in the next school year. The best time to begin your research might be during the summer or breaks (like winter or spring break). Consider too, that simply listening to students' questions or noticing their points of confusion can often help to re-evaluate the lesson and improve it. Also encourage your students to find the answers through inquiry, either in the laboratory or through the Internet. After teaching the lesson once, it is much easier to revise, improve, and re-use in subsequent years. Select a few lessons to develop each year until you have a full toolbox of strong science lessons and confidence in their content.

Application in Practice

As mentioned in the previous section, every teacher has natural strengths. In this section, I mention some of the strengths of the teachers with whom I have worked. Developing similar strengths could be useful for you in helping to produce good lessons.

I had the pleasure of working with two wonderful teachers at W.T. Moore Elementary School. My first assignment was with a third-grade class working with a highly talented and remarkable teacher, Roberta Hudgins. Her most unique and rare strengths are her ability to utilize many resources to the maximum advantage and to deliver a potent lesson. Even as a teacher with expert experience, she spends much of her own time perusing bookstores for fresh ideas to make lessons more fun and interesting for her students, and she is eager to learn new things to share with her students. Roberta practices critical thinking during class discussions and often asks insightful and thought-provoking questions. Sometimes she would ask me questions that I would have to go home and think about overnight before attempting to answer in any sensible manner.

My second assignment took me to Fairview Middle School where I worked with Theresa Anderson and her eighth-grade classes. Even though her physical science classes are filled with difficult preteens who do not necessarily want to be in school, Theresa is able to hold order in her classroom and successfully reach out to the students. She attends many workshops, staying alert for laboratory and other materials to interest the students in science. Her position requires a delicate balance of challenging the students to learn while keeping attrition to a minimum.

The next assignment was again at W.T. Moore with Nancy Long's fifth-grade class. Nancy knows the value of science laboratory materials, which is a big benefit for her students. She is very organized with her equipment and keeps good supplies so that we could do practically any experiment or laboratory exercise desirable. It was enjoyable to develop activities and curriculum with a positive and cooperative teacher such as Nancy.

Students taking timed data.





Students working together in chemistry/physics laboratory to generate their data.

Currently, I am finishing my last assignment with Teresa Callahan at Raa Middle School. One of Teresa's eighth-grade classes is for advanced or "gifted" students, so there is an added challenge of planning lessons at two different levels. Teresa is amazingly resourceful and committed to conveying meaningful science to her students. She is well known for holding yard sales in order to raise money for science laboratory supplies. She scopes many sources for information and helpful teaching aids and approaches her lessons from multiple directions for effectiveness and thoroughness.

Skills and talents among teachers are ideally multifaceted and can be honed to encompass more and more methods of teaching. Increasing our skills should ultimately have the effect of perfecting our teaching styles.

Final Remarks

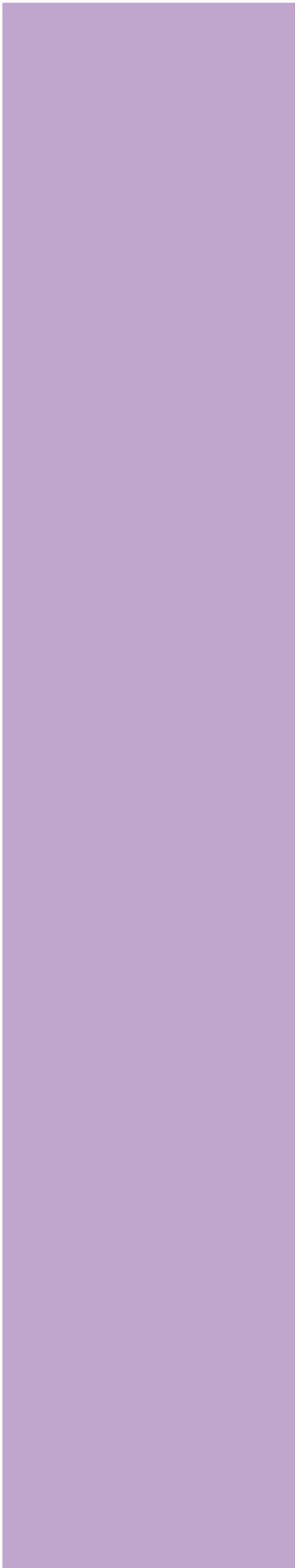
Even as teachers, we remain students. Learning is a lifelong process that always holds possibilities of excitement and reward. It is uplifting to see the wonderful attitudes of the public school teachers with whom I have worked in the GK-12 Program. These teachers were delightful and open-

mined. They were willing both to share their skills with me and to learn from me new ideas and techniques for communicating science to their students. I owe them a debt of gratitude that I hope to repay by continuing my work with other teachers as I proceed through my science career.

I also hope this guide will prove helpful not only to the teachers who have had the assistance of GK-12 fellows but also to the teachers who have not had any extra help in their classrooms. My public school teachers have made all the difference in my career choices. To all teachers, I want to again emphasize how important your work is and to ask that you never give up the quest for knowledge and/or desire to pass it on to your students.

Notes and References

1. For details on TIMSS methodology and findings, see Schmidt W. H. et al. (1996). *Characterizing pedagogical flow: An investigation of mathematics and science teaching in six countries*. Dordrecht, the Netherlands: Kluwer Academic. See also, National Center for Education Statistics. (1997, June). *Pursuing excellence: A study of U.S. fourth-grade mathematics and science achievement in international context*. Washington, DC: U.S. Department of Education (NCES 97255). See also, Mullis, I.V.S. et al. (1998, February). *Mathematics and science achievement in the final year of secondary school: IEA's third international mathematics and science study*. Chestnut Hill, MA: TIMSS International Study Center. The Commissioner of Education Statistics has also responded to criticisms of the TIMSS methodology and interpretation of findings. See, Center for Education Reform and Empower America. (1998). *Achievement in the United States: Progress since a nation at risk?* Washington, DC: National Center for Education Statistics, U.S. Department of Education, also online at <http://nces.ed.gov>.
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Lessons Learned From the Partnership of a GK–12 Fellow and a Third-Grade Teacher

By Wendy J. Walton and Roberta Trowbridge

Biographical information:

Wendy Walton
Ph. D. candidate in the interdisciplinary program in Molecular Biophysics at Florida State University

Dissertation Topic:

I study glycoprotein biochemistry. Glycoproteins are proteins that contain carbohydrates, and I am interested in the function of carbohydrates on glycoproteins.

What I gained from the GK–12 program:

I really enjoyed the GK–12 program. Even though it was a lot of extra work, I learned so much about so many disciplines of science. I have a new appreciation for space science, and I also feel like I relearned everything I had forgotten from elementary school science. I hope that I will be able to work with K–5 schools sometime again. It was a gratifying experience, and I hope it helps spawn more scientists from America, because American scientists are truly needed.



Wendy is a Ph.D. candidate in Molecular Biophysics and has been a GK–12 Fellow for three years.

Biographical information:

Roberta Trowbridge

Area of expertise:

I am a third-grade teacher at W.T. Moore Elementary School in Tallahassee, Florida.

Why I chose my field:

I have always been a compassionate person and a person who wanted to help others. I became interested in teaching students with disabilities after meeting my first college roommate who was blind. It amazed me how she was able to function in a sighted world and how difficult even daily living could be. After I made the decision to major in the Visual Disabilities area of Special Education, my father advised me to earn a degree in Elementary Education as well. While teaching, I decided to take advantage of living near a university and spent the next several years working on my Masters Degree in Early Childhood Education before the birth of my daughter.

Why I applied for the GK–12 program:

I became interested in the GK–12 program while attending a GEMS workshop. I was hoping that someone could assist me in narrowing down what I needed to present about science to the students. I also wanted to learn motivating ways to teach science.

What I gained from the GK–12 program:

Team teaching with Ms. Walton and participating in the GK–12 program afforded me the opportunity to provide a high-quality, effective science experience for all students in my classroom.



Roberta Trowbridge is a third-grade teacher who supervised GK–12 Fellow Wendy Walton. The two co-taught together in a very productive way.

As described in the first chapter of this monograph by Dr. Granger, the GK–12 fellowship at Florida State University is an NSF-sponsored program that places the science graduate students in public school classrooms at elementary or middle schools. Most of the GK–12 Fellows aid the teachers with activity- and inquiry-based lessons in science. This chapter describes the cooperative learning of science and



Wendy Walton, GK-12 Fellow for three years.

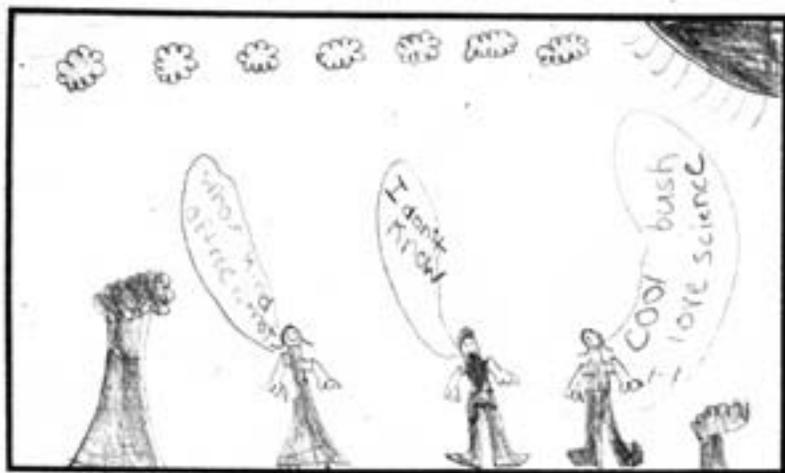
"I love science." A student remembers our trip to identify the schoolyard trees.

science teaching between one of the authors, Roberta Trowbridge (a teacher), and the other, Wendy Walton (a GK-12 Fellow). The information presented in this chapter comes from written questionnaires, and the chapter describes our interactions and lessons learned during one semester.

Roberta Trowbridge is currently a third-grade teacher. She has a B.S. in elementary education and visual disabilities (K-12) and a M.A. in early childhood education. She has taught in several areas in her 24 years of teaching: special education (i.e., visually impaired, hearing impaired, as well as the multi-handicapped), first grade, second grade, and third grade. Roberta learned about the NSF GK-12 program during her participation in a *Great Explorations in Math and Science* (GEMS) workshop during the summer of 2003. Dr. Granger mentioned the program in passing, and by the end of the day, Roberta was volunteering. Initially, she did not know what to expect and was just thrilled to have a willing individual come into her classroom and be an extra set of hands. She was hoping that someone could assist her in narrowing down what she needed to present about science to the students. She also wanted to learn motivating ways to teach science.

Wendy Walton is currently a fifth-year graduate student working on her Ph.D. in molecular biophysics. She has a B.S. and M.S. in biology. She started her research

career with aquatic toxicology as an undergraduate, and after her B.S., she worked as an environmental chemist for one year. Afterwards, she spent three years working on her M.S. where her research focused on glycoprotein hormone biochemistry. Her current research focuses on a neuronal glycoprotein. Wendy's teaching experience consisted of two undergraduate cell biology laboratories and one undergraduate microbiology laboratory during her time working on her M.S. thesis. During the GK-12 Fellowship, Wendy helped teach third- and fifth-grade science, as well as seventh-grade life science. The semester with Roberta Trowbridge was Wendy's second GK-12, semester-long assignment. Wendy originally found out about the GK-12 program from her research advisor, Dr. Timothy Logan, who encouraged her to apply. She was hoping to make an impact on children by increasing their interest in science and by making science fun for them. As she progressed through the program, she focused more on enabling the teachers to create engaging ways to present science.



Name Sade E B Date 12-2-05
Dear Mrs. Walton, you are great at helping us with science. It was cool when the test tube popped the balloon. I really liked it when you showed us the prism. The colors were really pretty. You're a great scientist because you are good at helping people learn. I wish you could stay with us all year.
Your friend
Sade

Constructing Lessons

We worked closely with another teacher and another GK-12 fellow in

the third-grade classroom next door. We met for planning approximately one week before we taught a new unit. Roberta and the other teacher were ready with lesson

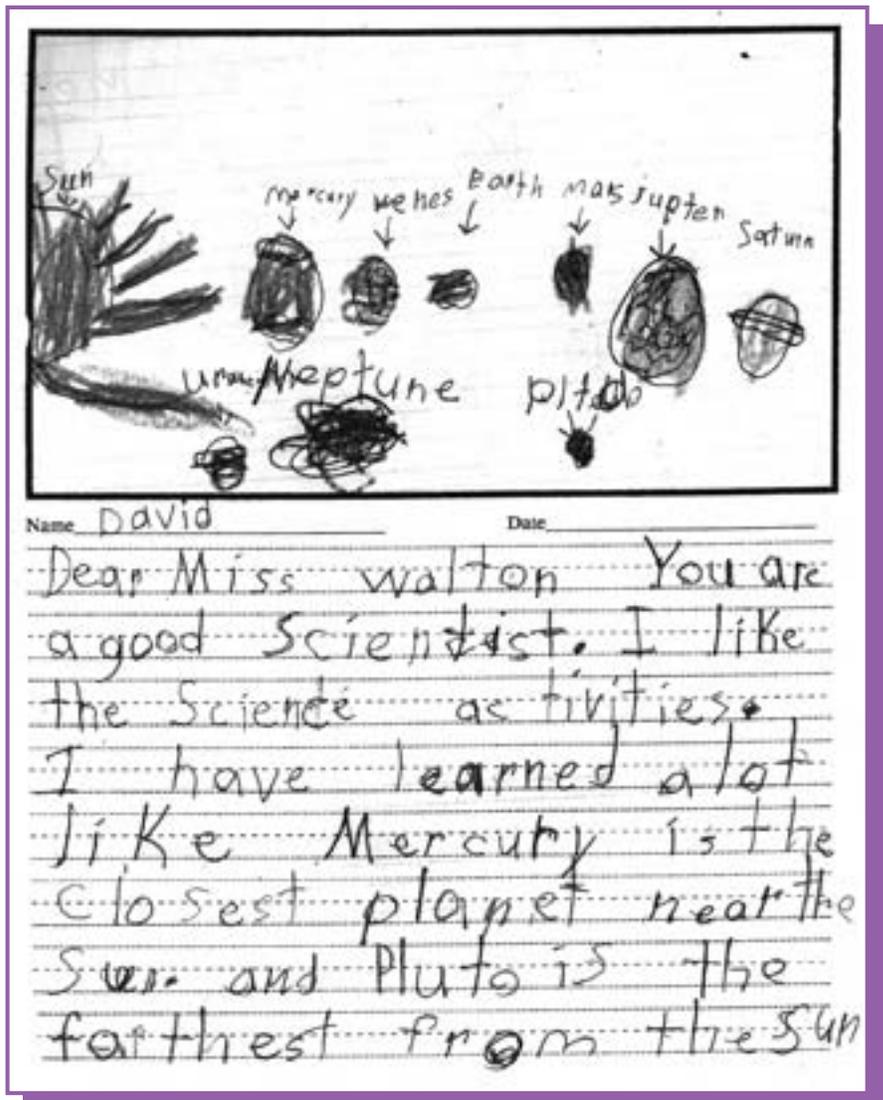
suggestions during these planning sessions, which moved things along quickly. We planned most lessons to include Florida's teaching standards, the Sunshine State Standards (which are not unlike those in many U.S. states). The two teachers listed available activities appropriate for third-graders from several sources: their text,¹ *Great Explorations in Math and Science* (GEMS) guides, *Activities Integrating Math and Science* (AIMS) guides, other commercially available lesson books, and the Internet. The other Fellow, Heaya Summy, and Wendy looked over the activities and decided which ones to pursue, based on whether or not the materials needed were available and the activity clearly illustrated the standard of interest. Fortunately, the school science laboratory had many supplies available. Roberta provided most of the disposable items such as cups, spoons, and starch. We also asked the students to bring in materials from home when appropriate.

We used a variety of methods to convey information such as reading, writing, and hands-on inquiry activities. When possible we incorporated mathematics and art into the science lesson. We also reinforced material with movies on a few occasions. Roberta and Wendy both agreed that there is not one way of teaching science that works best in all instances. Roberta added:

Every approach has its place in the teaching of science. In the early stages of learning about a new topic, exploration and hands-on seem to be the best approach. Demonstration and lectures also have a place in the process. Science does not have to be taught from a textbook or in a classroom lecture setting. Science is everywhere, and we should be aware of our surroundings and be able to relate what we see in our environment back to things we may have learned in units previously taught. I also think that we should not end a unit, never to discuss it again for the entire year if a natural learning situation should occur related to the topic.

Roberta, a constructivist teacher, believes that learning is a complex process that develops from previous knowledge.²

We covered the standards on life science, space science, matter, and energy in our semester together. The next semester, Roberta finished force and motion, earth science, and ecology by herself. Table 1 is a list of the activities used in one semester of third-grade science. For each activity, we list the Sunshine State Standard (e.g., SC.F.1.2.3) and the reference but do not include the pre-tests, tests, lectures, worksheets, movies, and reading materials also used in the science lessons.



Learning about planets.

Wendy is showing Roberta's students some neat websites on space.



Two of Roberta's students are playing with a GEMS treasure box activity.



One of Roberta's students is drawing a picture of a Protist that she is observing under the microscope.

A student shows Wendy her space travel brochure.



Table 1. Calendar of activities

Sunshine State Standards

Table 1. Calendar of activities		Sunshine State Standards
Weeks 1–2:	GEMS: <i>Treasure Boxes</i>³	
Weeks 3–7:	Life science and ecology	
	Family/species matching game	SC.F.1.2.3
	Protists and microscopes	SC.F.1.2.4
	Worming their way home	SC.G.1.2.2 ¹
	Exploring schoolyard trees with tree field guides	SC.F.1.2.3
Weeks 8–11:	Space science	
	Day, night, and seasons demonstration with a globe ⁴	SC.F.1.2.3
	Solar eclipse demonstration with sun, earth, and moon model	
	Star box construction	SC.E.2.2.1 ⁴
	Solar system picture (art)	SC.E.1.2.5
	Star book	SC.E.1.2.3 ⁴
	Lunar eclipse demonstration with model	
	Moonlight demonstration with foam ball and a flashlight	
	Making moon craters using a sandbox, ruler, and rocks ⁴	
	Space camp (paper plane races, balloon rocket races, marshmallow toss)	
Weeks 12–15:	Matter and energy	
	Measuring with balances	SC.A.1.2.1 ¹
	What is matter? (grouping) ¹	
	GEMS: <i>Dry Ice</i> investigations; Activity 2, Session 1	SC.A.1.2.2 ⁵
	GEMS: <i>Oobleck</i> Sessions 1 & 3	SC.A.1.2.4 & SC.A.1.2.5 ⁶
	Melting crayons into cupcake pans with heat	SC.A.1.2.2
	Hot air balloon (demonstration that gas takes up more space using a candle, test tube, and balloon) ⁷	SC.A.1.2.2
	AIMS: Heat energy moves	SC.B.1.2.6 ⁸
	AIMS: Sound energy [Paper cup telephones; musical bottles; sound is vibration (pluck rulers hanging off side of desks, Popsicle sticks in mouths, and rubber bands on rulers)]	SC.B.1.2.2 ⁸
	AIMS: Light energy [Prism power; I love color]	SC.B.1.2.2 ⁸

Roberta's Activities Assessment

Roberta thought that the GEMS activity *Treasure Boxes*,³ a unit in which children use collections of small “treasures” to acquire many mathematical and scientific skills, was the perfect way to start a school year. She recalled that the children became excited by the investigations and that it was a wonderful situation in which to observe her new



students as they classified and sorted items. She said, “It was interesting to watch the thinking of different students as they worked.” Roberta’s favorite activity of those we did together was the *Oobleck: What Do Scientists Do?* activity⁶ (by GEMS), a unit in which we actively engaged students in learning about the nature of science, because the students were so enthralled with the properties of the Oobleck. She enjoyed watching the students explore the Oobleck (i.e., a slimy green goo that is a solid when exposed to rapid pressure and a liquid without). She thought it was a great way to teach the properties of matter. Roberta liked using the GEMS guides because they are so well thought out and easy to follow. When using the GEMS guides, the teacher can quickly read over the lesson and know what materials are needed. Many of them also match well with the standards that we needed to teach.

Roberta’s favorite activity in life science was looking at microscopic Protists. Had it not been for her involvement in the GK–12 program, she would not have known how to get access to the slides or live Protists. Furthermore, she would not have been able to provide the background and the knowledge that Wendy shared with the children as they looked at the different Protists. Roberta thought the experience was terrific and that students felt as if they were “really doing science.”

The solar eclipse demonstration with the model was Roberta’s favorite space science activity. She said that she had a horrible time explaining a solar eclipse and thought, “Wendy made it very clear and the children really understood the concept. Some of the students asked particularly good questions and I was impressed!” When asked what her favorite physical science activity was, Roberta replied, “The light energy demonstration with the prism was so astonishing to the students. They were so amazed! Light was magic to them, and it was a true teaching moment when Wendy explained why we saw the colors of the rainbow.”

Roberta began the next school year doing the GEMS *Treasure Box*³ unit again this time without a GK–12 Fellow partner. She spent four weeks on it and did all 12 of the activities. She also did the “Worming Their Way Home” activity again. In addition, Roberta repeated the microscope activity, borrowing Protist slides once again from the Department of Biological Science at Florida State University (FSU) through

Phases of the moon. In this picture a student recalls our demonstration of the phases of the moon. There were two GK–12 Fellows for this lesson.



Wendy demonstrates that bottles of the same size containing different volumes of water make different pitches of sound.

Wendy, who was in another classroom at Roberta's school. Roberta did not have live Protists available that time since the biology laboratory classes at FSU did not include a unit on Protists until much later in the semester. To do the Protist activity again after Wendy graduates, Roberta will have to arrange to get the materials directly from FSU herself. It would be great if there was a program that could transport materials readily available in universities, such as dry ice and biological specimens, to K–12 classes to use, keep, or temporarily borrow like the program that FSU has that loans physical science equipment to schools.

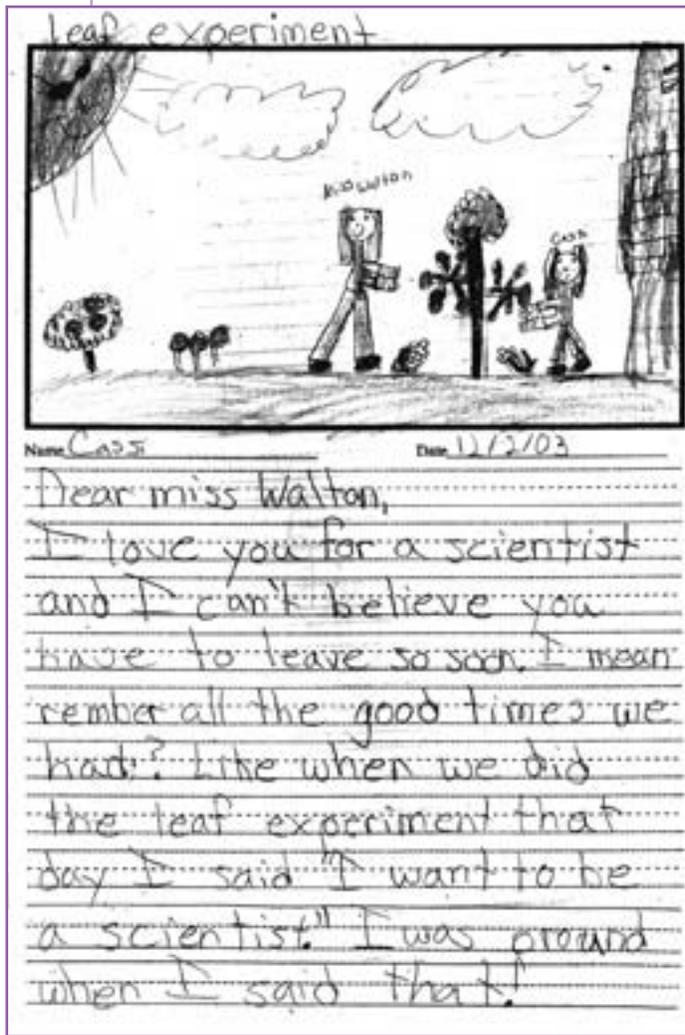
Co-Teaching

Wendy tried several different roles in the classroom before finding effective ones. At first, Roberta led the class through the GEMS activity *Treasure Boxes*.³ Wendy's schedule allowed her to be there on Monday, Wednesday, and Friday mornings during science, and she helped Roberta by answering questions from the children working with their treasure boxes. This was a good beginning role for Wendy until she became more familiar with the class, but she was anxious to participate more in the future.

We spent the next few weeks on life science since that was one of Roberta's favorite subjects and one of Wendy's strengths. On the days when Wendy was in the classroom, she sometimes directed games or short activities for small groups of students that were pulled from the classroom one group at a time. At other times,

Roberta and Wendy would direct activities for the entire class, when students watched while volunteers from the class performed experiments. There were also activity days where small groups of two or three each performed their own experiments with their own supplies. The first method, in which we pulled students from the main classroom to do quick games or activities with Wendy, proved to be disruptive: students waiting to be called were so eager with anticipation that they were unable to give Roberta their undivided attention. Wendy was also learning how to manage students and, at times, had difficulty getting a few of them to behave. Another issue was that when they were in Wendy's group activity, students missed material presented by Roberta to the rest of the class. The methods in which Roberta

"I want to be a scientist."



and Wendy directed demonstrations or small group activities together worked much better.

Roberta led all of the classes on space science. Aside from the usual worksheets and short lectures, the students also used creativity when constructing star books, star boxes, and drawings of stars and solar systems. During this unit, Wendy would often lead a short activity for small groups of students pulled from the class; these were less disruptive during the art projects. Wendy also gave several short demonstrations to the class using a model of the Earth, Sun, and Moon.

When the class started physical science, Wendy assumed a more centralized role, as she felt more comfortable with the material. When Wendy led lessons on matter and energy, Roberta managed the classroom, assuring that the children were on task. This proved to be an excellent union between Roberta and Wendy. Roberta was especially skilled at clarifying ideas or concepts for the students if they became confused about something Wendy had said. Roberta observed Wendy's lectures and helped with the activities. She plans to repeat some of the lessons on her own, especially those in matter and energy.

It was difficult to co-teach in a continuous fashion when one of the teachers was part-time. It worked best when Roberta continued the teaching on the days when Wendy was not there. This saved a lot of time, added continuity to the lessons, and gave Roberta the chance to teach the material upon which we had agreed. Roberta also included science words from the Sunshine State Standards during her spelling lessons. This kind of reinforcement was beneficial to the students' learning and understanding of science.

What Was Learned

When asked what she learned from the time she spent with Wendy, Roberta replied that she found that teaching science required a broad knowledge base and substantial time to plan lessons and gather materials. Roberta noted that she already knew this, but it seemed more apparent when it was time to plan together or gather materials. In addition, Roberta said she had learned to really listen to students' questions and take them more seriously. Roberta noticed that Wendy explained the answers to student questions in very grown-up terms, and they respected her for that. Roberta also felt that she learned a great deal about science. For example, Roberta had never heard of a *Moneran* or a *Protist* before co-teaching with Wendy. Here are some of Roberta's comments about co-teaching: "Co-teaching is the way that classrooms should be all day, everyday. There are too many subject areas to cover in an elementary classroom and too many different children's needs to meet (even in small classes). Co-teaching with an expert in the field, makes the learning so much more natural. I did not have to concentrate on making sure all the facts I had were correctly presented. I had an expert in the room to either confirm or negate what I said."

Wendy also learned much during that semester in Roberta's class. Each time they went over a new subject, it was a chance for Wendy to brush up on her knowledge and understanding about it. Roberta also introduced her to many activities and creative lessons appropriate for third-graders. The most valuable training for Wendy was learning how to be in better control of a classroom after watching Roberta with her class. This has been very helpful in her subsequent work with three additional classes during her GK-12 fellowship.



Wendy is teaching about atoms and compounds in Roberta Trowbridge's third-grade classroom.

What Changed

Roberta felt most comfortable teaching reading and mathematics before Wendy spent time in her classroom. For Roberta, each subject has positive aspects, but teaching students to read and appreciate books was one thing that she particularly enjoyed. Roberta now looks forward to and feels more comfortable with teaching science lessons. She was optimistic about what the next school year would be like, as she would be teaching some of the topics that they had taught together by herself.

Before working with Roberta, Wendy felt most capable teaching life science to older students. After working with Roberta, Wendy felt prepared to teach space, life, and physical science to elementary-school students. Notably she was also more enthusiastic about teaching physical science after their experience. Wendy now realized the importance of this subject and how difficult it was to understand and communicate to such young students. She was pleased to find that there are numerous physical science activities available to convey difficult topics, such as energy, in an engaging and comprehensible way.

Effects on Students

Roberta observed that the students were more at ease about asking questions after Wendy spent a semester in her classroom. Science had become more meaningful and fun to them. The girls looked up to Wendy as a role model and were not self-conscious about asking questions. The girls seemed to be more confident that their answers were going to be considered as valuable as the answers given by the boys. Wendy was

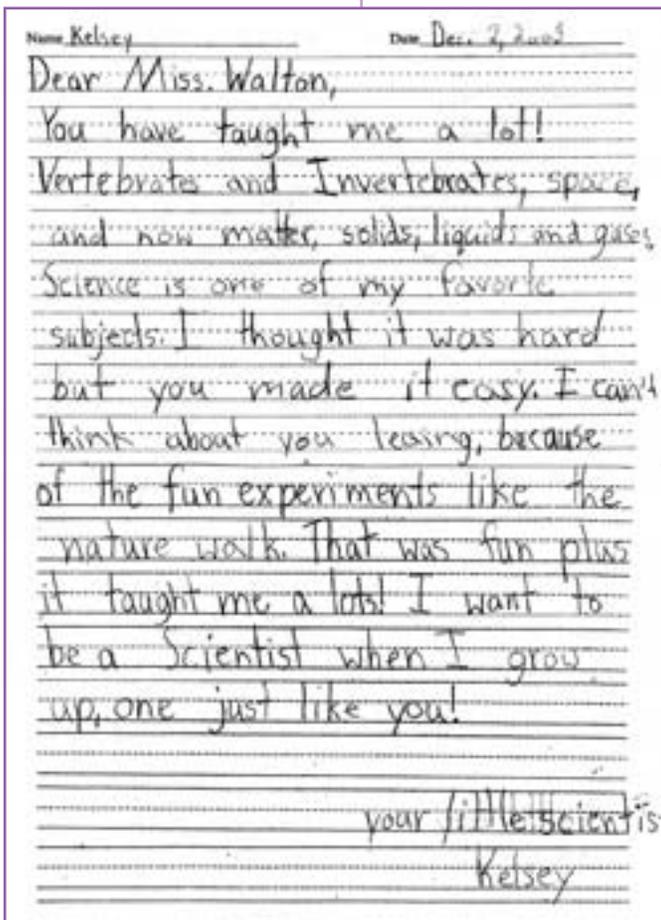
especially gratified to hear many of the girls say that they wanted to become scientists toward the end of her semester in their classroom. Roberta thinks that before the students worked with Wendy their perception of a scientist was a person in a white laboratory coat unable to relate to people, especially kids.

Challenges

One challenge Roberta faced was scheduling. As she was in a contained classroom, teaching all subjects, she had to rearrange her teaching schedule for several subjects to accommodate Wendy's availability based on her university schedule. Usually Roberta taught the same subjects at the same time as the other third-grade teachers, which is often done to facilitate the teamwork among elementary-school grade levels. Another complication was incorporating a third person into their lessons. Roberta was assigned an intern from FSU at the time and did not want her to feel that she was any less important because she was an intern. Fortunately, all of these situations worked out well. Everyone was flexible, and they worked well together.

The most difficult challenge for Wendy was balancing her time between her dissertation research and her GK-12 responsibilities. Since Roberta's class had science every morning, Wendy came three mornings per week. The school was far from her home and the university so she spent quite a bit of time in transit. She also spent appreciable time preparing and would often stay up late reading. Wendy liked getting ready for lessons by reading-up on the subject that she was presenting the next day.

All things to learn about science.



Even though she felt she was learning important things for herself and her students, the significant preparation time consequently took time away from her research.

Conclusions

The experience between Roberta and Wendy was successful on many levels. It was important that Roberta was eager to work with and to learn beside Wendy the entire semester. They had separate responsibilities of equal value in planning and teaching. This cooperative relationship allowed them to efficiently learn from each other. Information that either one knew or learned was spread to the other when they watched and listened to each other. Both learned more about science and teaching, Roberta came to value the student's questions, Wendy learned classroom management, and the children learned science and came to appreciate and love it.

Acknowledgments

Roberta and Wendy want to thank the other teacher, Roberta Hudgins, and the other GK–12 Fellow, Heaya Summy, for all the time and effort they put into planning lessons, writing tests, and gathering materials with us. We also thank Jean Hancock and Barbara Shoplock from the Biology Department at FSU for providing *Protist* slides and live *Protists* for the students.

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Science Graduate Students Enhancing K–8 Education

By Penny J. Gilmer and Martin Balinsky

Biographical information:

Penny J. Gilmer

Ph.D. (Biochemistry)
D.Sc.Ed. (Science Education)
Professor of Chemistry and Biochemistry at Florida State University



2nd doctoral dissertation title:

Transforming University Biochemistry Teaching Through Action Research: Utilizing Collaborative Learning and Technology (Curtin University of Technology, 2004)

Why I chose my second field of science teaching:

I chose my field of science education to improve college science teaching, to bring into teaching what we are learning about improving learning environments and to enhance my own life and teaching.

Why I became the GK–12 program evaluator:

Since I was doing an evaluation project for my own second doctorate on my own teaching and since I am a practicing biochemist, it seemed like a natural to become the internal evaluator on our GK–12 program. What I learned on one project helped with the other.

What I gained from the GK–12 program:

I gained a renewed interest in what happens to graduate students in the sciences as they progress through a graduate program, whether they are in the GK–12 program or in our comparison group. I'm interested in what they think of the nature of knowledge, or epistemology, especially knowledge in the sciences and if this changes as they proceed through graduate school.

Penny J. Gilmer, GK–12 internal evaluator, graduating from Curtin University of Technology in Western Australia with her second doctorate—this one in Science Education. Her first doctorate was in Biochemistry from the University of California, Berkeley. Dr. Gilmer worked on the GK–12 evaluation while she was finishing the writing for her own doctorate.

Biographical information:

Martin Balinsky

Doctoral candidate in Science Education in Middle and Secondary Education at Florida State University

Doctoral dissertation topic:

The Confluence of Cultures in a Collaborative Partnership Between Science Doctoral Students and K–8 Science Teachers

Why I chose my research topic:

I have a dual background in both science and education, with M.S. degrees in both geology and science education. I have always been interested in how these two cultures view and inform each other. By having experienced both, I feel that my mental landscape has been enriched. Of particular interest to me is the dual existence and interplay of objective fact and subjective interpretation. Also, having taught earth science at both community college and middle school, I am interested in the ways that experiences teaching K–12 science can inform an individual's ability to teach college science more effectively.



What I gained from participating in the evaluation of the GK–12 program?

I gained a tremendous appreciation for the difficulties that science doctoral students in such programs face when attempting to negotiate between two worlds: the world of scientific research within their home departments and the world of K–12 science education. The demands on their time and the challenges to their thinking have been many. But I believe that the experience will expand their breadth of understanding in marvelous and immeasurable ways. Their range of understanding will surpass that of their peers, and their time-balancing skills will serve them well. It has allowed me to understand better my own challenges involved in splitting my time between a science doctoral program and a full-time job at a state department of education.

Martin Balinsky, a GK–12 Fellow, is a Science Education graduate student who is doing a qualitative study of several of the GK–12 Fellows in collaboration with Dr. Penny J. Gilmer.



A third-grader pretending she is a butterfly.

Introduction

In 1999 the U.S. federal government started a grant program called the GK–12 program with the idea to involve graduate students in science, mathematics, technology, and engineering in K–12 school education on a nationwide basis. These graduate students are young, idealistic, and knowledgeable individuals who have much to contribute to the K–12 teachers and students. Also the GK–12 Fellows have much that they can learn about teaching and learning and about science content, especially because they often must teach in areas beyond their area of expertise. In addition, the Fellows learn about the culture of K–12 so that in the future they will understand better how to interact with the K–12 system as a service to the community, whether it is directly with the schools that their children will attend or in their professional careers.

Florida State University received its NSF funding for our GK–12 grant in August 2002, and we started with a cohort of nine graduate students in their second through fourth year of graduate school in the sciences with the plan that they would remain in the program for the entire three years. We still have

seven of the original GK–12 Fellows. We replaced one who left after one year and another who left after two years. In addition, we had one undergraduate senior who participated in the first year. Therefore, a total of 12 Fellows have been part of our program, and currently there are nine.

The focus for the evaluation of our program is to determine how our GK–12 Fellows' ideas of what makes a good environment for teaching and their ideas on the nature of science have changed or are changing during their three-year program.¹ These GK–12 Fellows immerse themselves in the culture of K–8 and learn from the GK–12 Teachers about teaching and learning and the strengths and constraints of the system. It is a true partnership among tertiary education, K–8 schools, and the federal government. It is also a collaboration of scientists, mathematicians, engineers, students, teachers, principals, and the community. We expect that our GK–12 Fellows would have learned about teaching and learning within the culture of K–8 schools and about the nature and content of science while immersed in the planning and execution of science lessons with the GK–12 Teachers.

Theoretical Frameworks

Our theoretical referents include *social constructivism*,² *cultural-historical activity theory* (CHAT),^{3,4} and the *theory of structure*.^{5,6} Through social constructivism we understand that people learn based on their prior constructs and experiences (such as the Fellows' experiences in science and in learning in the classroom). By providing new experiences and social interactions, we influence people's thinking and what they learn.

Through CHAT (FIGURE 1), we understand that we live within certain constraints and opportunities that influence the contradictions and coherences that influence what activities happen and how and why they happen as they do. According to CHAT, there are several interacting factors involved: *Subjects*, *Objects*, *Tools*, *Communities*, *Division of Labor*, and *Rules or Schemas*. All of these influence the *Subjects*, *Objects*, and *Outcomes*.

Various elements influence the flow of the *Subjects* (i.e., the GK–12 Fellows, in this case) toward their *Objects* (learning about teaching and learning and about science) and on to their *Outcomes* (becoming professional scientists with an evolving

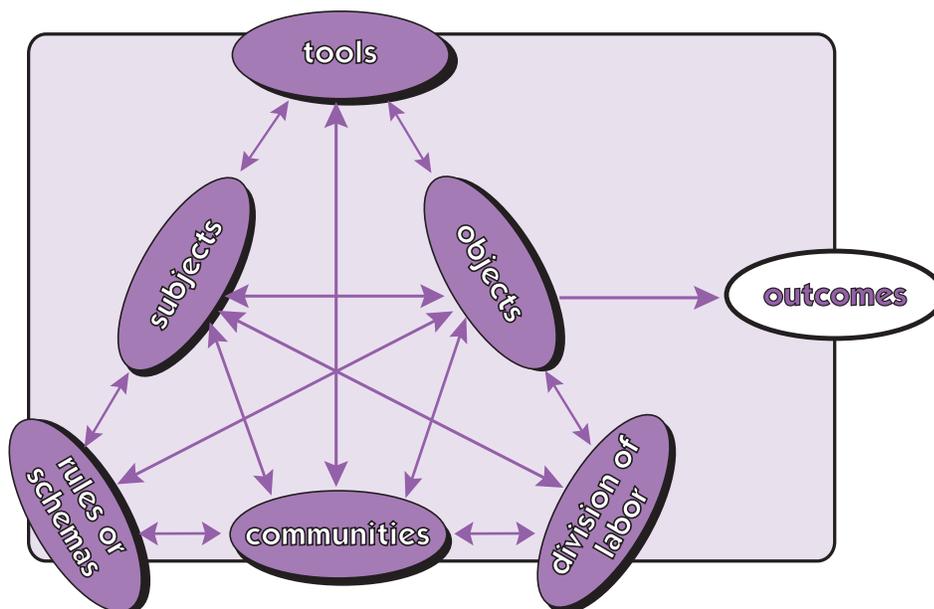


FIGURE 1. Using the cultural-historical activity theory (CHAT) diagram is a way to think about how the **Subjects**, in our case the GK–12 Fellows, move within activities toward their **Objects** and to their **Outcomes**. The **Tools, Rules or Schemas, Communities, and Division of Labor** can inhibit the flow with contradictions (or challenges) or add to the flow with coherences. This theory informs our understanding of what and how activities happen or not.

understanding of teaching and learning and of science). The influential factors include *Tools* (i.e., GEMS lesson plans,⁷ the Internet, resources within their science departments, their own lesson plans), *Communities* (i.e., other GK–12 Fellows, GK–12 Teachers, GK–12 grant faculty and staff, fellow science graduate students, science faculty), *Division of Labor* (i.e., between the GK–12 Teacher and GK–12 Fellow, and among GK–12 Fellows), and *Rules or Schemas* (i.e., state-mandated testing of students, Florida Comprehensive Assessment Test (FCAT) for testing of K–8 students, the Sunshine State Standards, organization of K–12 schools, constraints within graduate programs). By focusing on the progression of the Fellows toward becoming professionals and on how the various elements influence this flow, we better understand how to make the system more productive in both a formative and summative fashion.

Sewell’s ideas on *structure* and *agency* fit well with CHAT. Through the theory of structure we understand that there is a dialectical tension between structure and agency, in which one influences the other. There are three components to structure: *human* (includes social networks, practices, communities, and division of labor), *material* (includes technology and other “tools” from activity theory), and *symbolic* (includes a person’s status and “rules and schemas” from activity theory). There are two components to agency: *access* (includes gender, underrepresented populations, and technology) and *appropriation of resources* (includes what individuals know and can do from their culture and use of resources to meet their own goals—goals include relevance, interests, and the “objects” from activity theory). When the structure changes, it influences one’s agency, and vice versa.

Research/Evaluation Design

We adhere to the quality criteria of trustworthiness and authenticity.⁸ This is a formative study that started with the beginning of the program and is ongoing during the third year of the program.

Currently, there are over 1,000 Fellows within the United States.⁹ GK–12 programs vary considerably from one location to another, with some programs enrolling new Fellows for each academic year, and without any special training in teaching and learning in advance. Other programs enroll Fellows for two years, and perhaps some others for three. Some of the programs concentrate on science, some mathematics, some on engineering, and some on technology. Some concentrate on a particular

specialization within science. Our program involves students in science but not in a particular specialization. Our Fellows come from a variety of science departments: biochemistry, biological science, geological sciences, physics, and molecular biophysics. In addition to the 11 graduate students, for two semesters we had an undergraduate Fellow. Of the 12 GK–12 Fellows that have been part of our program, we have had a rich ethnic mixture of Fellows, with three African Americans, one Hispanic American, an Asian American, and seven Caucasian Americans. Nine of our Fellows are now assisting in K–8 classrooms. Of the 12 individuals who have participated in our program, 10 are female and two are male.

One special feature of our program was described in detail in the introductory chapter: a four-credit, one-semester, graduate-level course, *Teaching and Learning of Science*, designed for the Fellows for their first semester in the program (Fall 2002). We also have a BlackBoard website where the GK–12 Fellows can download PowerPoint presentations and other files made available to them and can have discourse on a posting forum.

While enrolled in the class, the Fellows had opportunities to design science lessons while using the learning cycle,^{10,11} now proposed with either four steps: invitation, exploration, concept introduction, and application (e.g., as described in a Geologic Education Outreach¹² program) or as the five E's: engagement, exploration, explanation, elaboration, and evaluation.¹³ For instance, the Fellows divided into collaborative groups and designed a lesson on substances dissolving in water. One group set a goal for what the students should learn: what a solution is, what dissolving is, and what is the meaning of concentration. The Fellows in that group devised ways

to invite the students into the discussion to explore meanings, discuss these meanings, and introduce applications of them. Groups made presentations to each other of their suggested ways of teaching this topic, and we compared and contrasted them in a group discussion afterwards.

To measure how these GK–12 Fellows' views on the nature of science might be changing, we used the VNOS-C (Views on the Nature of Science) survey^{14,15} at the beginning of the program (August 2002), again in April 2003 after they finished the course and one semester of teaching, and once again in April 2005 during the last month of their fifth and final semester of teaching in the schools. The main audiences who have taken the VNOS-C in other studies are students and K–12 teachers. Few have used it to study graduate students in the sciences. Schwartz and Lederman report preliminary results on a study of senior faculty in the sciences.¹⁶ In April 2005, we asked the GK–12 Fellows to respond, in paragraph form, to a "final questionnaire," a four-question survey about how the experience had influenced their ideas about science and teaching.

In addition to the GK–12 Fellows, we have a comparison group of seven science graduate students not working with the GK–12 Teachers to see how their ideas on the nature of science change during their time in graduate school, as compared with the GK–12 Fellows. However, since we are focusing on the experiences and reflections of the GK–12 Fellows, we have chosen not to include the reflections of the comparison group in this chapter (but it will be part of the NSF report).

Children exploring density with an educator.

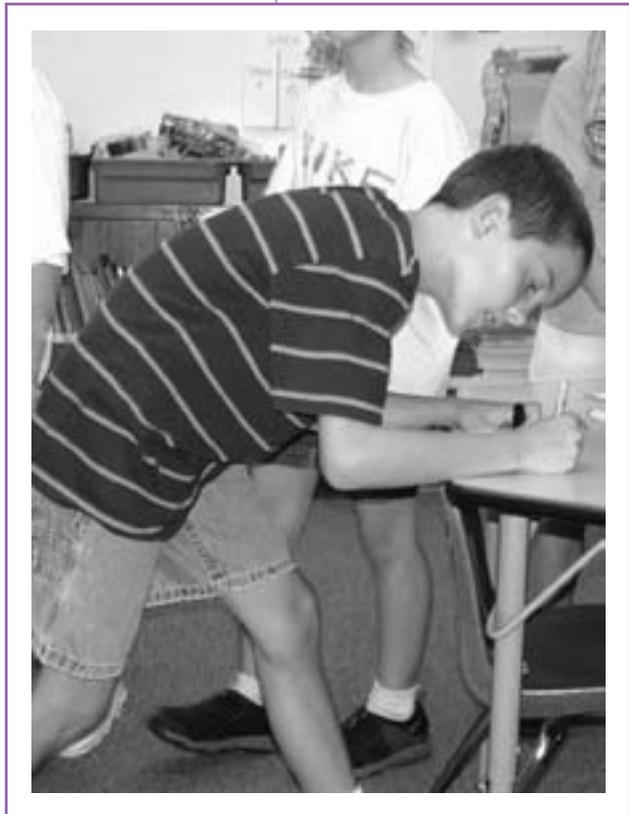


In addition to the two types of surveys, we gathered qualitative data in the form of interviews with a number of the Fellows, visitations to all but the newest Fellow in their classrooms, and videotapes of many of them teaching a lesson. We also met with the GK–12 Fellows monthly as a group to talk about problematic issues in teaching and learning and reviewed and posted some of their lesson plans on our GK–12 website. Below is a list of various data sources that we used in the analysis:

1. Videos of the *Teaching and Learning of Science* course taken by the GK–12 Fellows, notes from the class activities, summary day of Fellows’ ideas on teaching and learning, Fellows’ responses to assignment #2
2. VNOS-C questionnaire data (9/02, 5/03, and 5/05) for GK–12 Fellows
3. “Teaching Survey” data (12/02 and 5/05)
4. Visitation of GK–12 Fellows in their classrooms:

# of Fellows	Time span	Type of classroom
4	May 2003	Elementary
1	May 2003	Middle
1	January 2004	Elementary
2	February 2004	Middle
1	April 2004	Middle
1	September 2004	Elementary
1	March 2005	Elementary
2	February–May 2005	Middle

5. Feedback from GK–12 Teachers on GK–12 Fellows (by e-mail)
6. Interviews of seven of the nine GK–12 Fellows who completed the program and twelve participating GK–12 Teachers
7. Transcripts of GK–12 Fellows monthly meetings
8. GK–12 comparison group: VNOS, April/June 2003 and March/April 2005 (seven responses at the beginning and four at the end)
9. Interviews of two from the comparison group
10. Constructed GK–12 website at <http://gk12.bio.fsu.edu>
11. Lessons constructed by GK–12 Fellows and uploaded on GK–12 website
12. Chapters written by seven of the present GK–12 Fellows for SERVE monograph on their experiences



Child recording some notes.

Data Analyses and Findings

Using the qualitative software research (QSR) program,¹⁷ we sorted the GK–12 Fellows’ responses to VNOS-C, the teaching surveys, and our own set of questions obtained from the transcribed interviews. We use pseudonyms for all Fellow responses throughout this chapter. There were five main categories of responses, which we refer to as “nodes:”

- ▷ Early Experiences in Science and in Teaching
- ▷ Ideas on Teaching
- ▷ Ideas on Assessment
- ▷ Ideas on Learning
- ▷ Ideas on the Nature of Science

GK–12 Fellows' Early Experiences

Early Experiences in Life in Science

The GK–12 Fellows commented about their *early experiences* in life in science or teaching. Tamara commented, “I strongly disliked science in K–12,” and “I hated coming up with science projects because I never felt I had good guidance as to how to come up with a question(s).” Rebecca mentioned how she had grown up in a “family of teachers and had always believed that you simply either do or do not have a personality for teaching,” that it was “in your blood.” Rebecca’s grandmother thought that Rebecca had a “big dose of it [personality for teaching].” Wanda, Nathan, and Rebecca commented on their participation in science fairs in their childhood. Rebecca participated every year between fourth and eighth grades, and she mentioned, “I probably had to be helped with an idea the first year, but I can remember coming up with ideas every year after that.” Nathan participated but does not remember how he arrived at his topic. Wanda said, “I got my ideas from my experiences and my resources, including other people.”

Early Experiences in Teaching Science

When the GK–12 Fellows first started to teach in the program, Nathan’s levels of self-efficacy were low when compared to later in his teaching. As he relates, comparing himself to two other Fellows in the program:

I think they (the other two Fellows) were confident in front of a class right from the get-go. For me it took a few years to develop in front of any age group, feeling ready to get up and give a presentation and keep them engaged. (Nathan interview, 2/15/05)

Thus, Nathan reveals his view that some of his peers were more naturally confident in front of a K–12 classroom, and it took him a long time to adjust. Yet he grew a great deal during the course of the program and now feels at ease teaching K–12.

Some of the Fellows initially experienced problems in negotiating their role in the classroom. In one case, Rebecca did a significant amount of work preparing projects for the teacher, only to have the projects cut or not included in the class. Another, Jose, had interpreted his role to be that of a mentor to the teachers, a role that excited him, and that was the reason he joined the program. As he stated, “What I understood was we were to be mentoring the teachers, so I said, ‘Okay, this is okay.’” Later he learned that this was only his interpretation of the program; he was to observe and learn from the teacher, which he found disappointing. Jose revealed this interpretation when he related, “You were supposed to only follow the teacher and supposedly try to learn what they did.” He had hoped that he would be the source of knowledge from which the teacher would draw, but instead he found that he was supposed to learn from her. Nathan reported that he experienced one teacher who worked very well in tandem with him as an equal and another who wanted him more in the background. He had been expected to be more involved, the way he had with the first teacher. As he stated,

She’s been there 30–35 years, and I came in the classroom, and I said, “I’ve done this and I’ve done that,” but right from the start it was like, “Okay, I’m gonna be the magician and you’re gonna be the lovely assistant. That’s the impression I got, although she never said it. (Nathan interview, 2/15/05)

In this instance, Nathan entered the classroom of an already well-established, experienced teacher, and one who probably felt that she did not need much assistance in the classroom. In an interview, the GK–12 teacher admitted finding difficulty relinquishing control:

I think sometimes he has to push me away because I enjoy teaching and I’m not real good about just leaving him to take over, so he’s

had to be a little forceful with me to give up my kids. But I think he's doing a nice job.

In the last part of this passage, we see Nathan's teacher's belief that she feels that he is doing well. So her difficulty in relinquishing control to Nathan has nothing to do with his ability. This is part of the Fellows' learning as well, that teachers feel ownership over their own classrooms.

By contrast, Nathan worked so well with the first teacher that he asked to return to her in his fifth (and final) semester of teaching. She was very pleased to have him return to her classroom. As he reported,

I wanted to go back there because (the teacher) is the best co-teacher I've worked with. And she—whether she's doing it consciously or not—co-teaches. I'll be teaching and she'll interrupt and say, "oh and by the way", and she'll throw something in. And that's what I need someone to do co-teaching. We work together. Yesterday we worked on a lab. Today we are backing it up with this. She has been great to work with. Not every teacher is like that. She is very good at that kind of stuff. (Nathan interview, 3/28/05)

This quote clearly shows that Nathan and this teacher work very well together, and they complement each other in a natural way. One of us visited his classroom in May 2005 and observed the good atmosphere that existed when they were in the class together. The other of us visited Nathan in his classroom with a different teacher in April 2004, and there was a similar complementarity between them as well.

GK-12 Fellows' Ideas on Teaching

The GK-12 Fellows' ideas on teaching have changed considerably in three phases: the first was during the graduate-level course that we offered on the *Teaching and Learning of Science* during their first semester in the program (for more details see Granger's Chapter 1 in this monograph), the second was during the first semester of teaching, and the final was throughout the rest of the program. Before entering the program, most of the Fellows had not thought much about how people learn (they seemed to assume that most people learned like they did) nor about how to promote science learning through teaching. Most science graduate students had been a teaching assistant for at least one undergraduate laboratory but had not needed to formulate the lessons to go with the laboratory experiments or to devise their own experiments.

After the Fellows took the course, there were differences for the Fellows in their teaching philosophies and their ideas on teaching and learning (except for one graduate student in the comparison group who was about equal in her thinking in comparison to the Fellows). For instance, Jose stated:

Well, through the classes that we took in science education it did [change my ideas]. It did change somehow, especially as we saw the information from psychologists about how students are able to see things. I see that some things in kindergarten and elementary will need to be changed about science. [It's] the methodology that we have to change. It shouldn't just be at the blackboard and talk to them. It should be more interactive, and they should have to do things on their own too. (Jose interview, 1/21/05)



Student conscientiously studying.



Collection of fifth-grade students' reports on various planets.

The two girls in the center hold hands while enacting the sun and the three boys circle them while representing the inner planets Mercury, Venus, and Earth. The boy further away from the "sun" in the background was Mars.



Student sharing poems she's written on comets:

*You know if I was flying
with a comet,
I think when I'm up high
I will vomit,
Hopefully I will quickly
get down
Or else the vomit will be all
on the town."*

*The comet looks like a bluish
and yellow firework,
It smells like a large chunk
of dirty ice,
And feels like a bunch of air
flowing through your hair.*



Additionally, immediately after the course on teaching and learning, Jessica wrote:

I have been aware that understanding is the key to learning, but I was not aware of the importance of two fundamental concepts of understanding: learning the whole picture puts everything into perspective and hands-on experience gives students a visual understanding....Once students truly understand a concept, at multiple levels, it is more likely that they will remember it, compared to merely memorizing concepts.

These statements demonstrate how the ideas of the GK-12 Fellows were changing once they had started to learn how people learn and how one assesses one's students' learning.

One of us visited Jessica while she was teaching in her fifth-grade classroom near the end of her first semester of teaching. Jessica had mentioned beforehand to one of us that she was not looking forward to teaching space science and the planets (as her own area of scientific expertise was different), but, nonetheless, that topic was coming up in the curriculum close to the time one of us was to visit. One of us shared some presentations she had prepared for another course on exploring our universe, and Jessica opened to it, embracing it. Space science quickly became one of her favorite science subjects to teach. She realized that what she had written about the children—"It is important that children realize learning is a gift and not a chore"—also applied to herself in learning space science. Her fifth-grade students came to love space science too, and each wrote a report on a planet, with some

students including either a lovely picture they had drawn or poems they had written about their planets. They also enacted the movement and scaled distribution of the planets around our sun in their school playground.

At the end of the program Jessica said that one of the ways that she has changed since starting the GK-12 program is in coming to learn that "there are numerous methods [to teach], but using a variety seems to be important since there are a variety of different kinds of learners in a given classroom." We saw multiple modalities of teaching enacted in her classroom. The other way that Jessica reported having changed was, "I realize the importance of student inquiry. When students ask questions the students are truly interested in [the] material, and their questions

should be answered as completely as possible to keep them interested and to help them learn effectively.” Student inquiry was another theme that we saw enacted in the GK–12 Fellows’ classrooms.

In her teaching, Wanda learned different ways to connect to students. She found discussion to be particularly useful but also found that using a variety of strategies is important in order to connect to different types of learners. As she stated:

The discussion sections are where a lot of the learning takes place. The only thing is that some students are going to be left out of the discussion. There are some students who don’t learn that way [discussion], and you can see the ones that are making connections while you are talking and discussing. And I have the students answering a lot and telling a lot of information, and some others don’t believe or listen, as they are waiting for the teacher to answer. That’s a problem—a lot of the information is coming out of students’ mouths, and some other students aren’t going to pay as much attention to that. (Wanda interview, 2/4/05)

So, through her experiences, Wanda came to recognize different types of learners. Her mind is often on how to connect to students, and this is reflected in classroom observations we made of her teaching.

At the end of the program, Kisha mentioned, “My participation in the program has changed the way I plan to teach undergraduate classes [when I become a faculty member myself], and I feel like I can do a lot of good through teaching science.” Interestingly, she also said that with her research in biology she needed to learn much physics and chemistry to teach basic concepts, and “it has really made me realize how broad science is and that there is so much known and I know so little of it.”

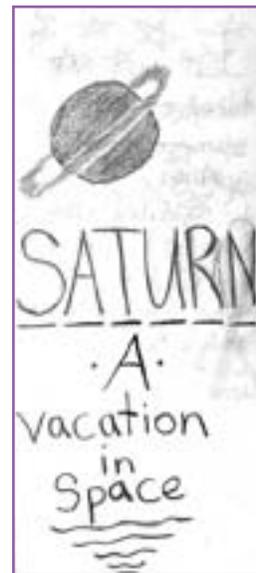
Nathan mentioned something similar to Kisha, saying, “One thing that has changed is I am slowly learning to appreciate more disciplines of science.” In the beginning, he was most comfortable helping to teach physics, his area of specialization. By the end of the program he found himself

looking forward to working on subject matter I normally wouldn’t study. For example, I recently worked with my co-teacher to explore adaptations and mutations in coral reef organisms by showing students clips from Finding Nemo. It was fun for them and us, and I was interested in studying the topics we were discussing so I would be better prepared for the class. (End of year VNOS-C survey, April 2005)

The experience in the program is having such powerful effects on our Fellows in the area of teaching to diverse styles of learning and in learning science content beyond what each knows through scientific research. This experience should serve them well in their future careers, particularly when it comes to teaching college courses and potential involvement in K–12 science classrooms.

GK–12 Fellows’ Ideas on Assessment

The third node from the analysis was on the topic of *assessment*. Prior to their course on teaching and learning, the Fellows had not been aware of the importance of assessment. As one of the GK–12 Fellows, Tamara, said, “I have learned new ideas on assessment and that there are a variety of creative ways to determine what students have learned.” She also noted that different



A student's report on Saturn: "Saturn, A Vacation in Space: If you are tired of warm summers and springs then come to Saturn where it is at least -185°F (-175°C) in its clouds. The atmosphere is thick and cloudy with winds up to 1,000 mph. This makes Saturn a good place to hang glide!"

A GK–12 Teacher showing one of her student's earlier bird books, which she is still using in her elementary school classroom.



students learn in different ways, so we need to enact different methods of assessment. This is a big step in growth when a graduate student in the sciences has been assessed in traditional ways, to see that there are alternative ways to assess students' learning and knowledge. Similarly, Jessica noted, "Assessment should occur before, during, and after a lesson." She realized that she needed to use both formative and summative assessment.

The only one of the GK–12 Fellows who brought up assessment on our teaching survey (it was not asked explicitly) was Jessica. What she said early in the program was, "Assessment is more difficult than I thought prior to this class." By the end of the teaching and learning course, she realized and clearly stated, "I have learned the importance of assessing what students know when they come into the classroom."

GK–12 Fellows' Ideas on Learning

The fourth node from the analysis was on the topic of *learning*. One concept that Fellows learned was children of different ages have different cognitive abilities. As Rebecca pointed out, "The same goals of exploration and learning are there [between different age groups], but younger students may need simpler, more directed exercises than older students."

The Fellows also learned that learning builds upon prior knowledge. As Nathan reported, "We concluded that students already have viewpoints about most topics before they hear a lecture of explanation." Nathan also reported that it was sometimes a challenge not aiming the material at too high a level (not unlike the challenge we see among many science faculty teaching undergraduate courses). Sometimes he was uncertain as to what they had and had not already learned in school. As he related:

There are textbooks, and I'll flip through and say, do they know that yet? And I'll see—oh, they haven't had this yet, and it's not even required for their grade, because I went in my first time at [his school], and I would check their textbooks, but sometimes I would miss stuff and it would be way over their head, and [his participating teacher] would say, "Hold back, we should revise this, and be careful not to use all these terms." (Nathan interview, 2/15/05)

This indicated that Nathan was not aware, prior to this experience, of either what content was taught at what level in the K–12 system or what developmental level students were at different ages. Yet he gained all of this knowledge because he was open to learning about it. Nathan not only had a good working relationship with a number of his GK–12 Teachers, as we mentioned above, but he also learned considerably from them.

In addition, the Fellows learned that conceptual learning is more meaningful than rote recall of facts. As Rebecca stated, "Conformity and memorization are much less important than creativity and understanding." This demonstrates her understanding of the value of such conceptual learning, something that she came to understand through her work with an alternative K–8 school where the students learned conceptually and through using themes.

Especially common among the Fellows' learning was their recognition of the importance of creativity. Sandra summed up the views of her colleagues with her comment, "Imagination and creativity are key in all aspects of experimentation." Other Fellows echoed this view.

Rebecca learned the importance of relating material to students. She realizes that the material she is teaching should be applied to students' everyday lives. Without these connections, the material will not be meaningful to students. As she stated:

You can teach geology in a very dry way, which is the way most people teach it. Or you can teach them [geology students] in an interesting way, including Milankovich Cycles, or the way the plates move, and how that affects our lives, and I don't think a lot of them [professors] are applying it to the students' lives at all. If the students don't see how it relates to them, they're not interested.
(Rebecca interview, 2/10/05)

This comment by Rebecca demonstrates a bridge that she is making between the K–12 classroom and the university geological sciences department in which she has been a teaching assistant in the past and will be again in the future. It is probable that the GK–12 Fellows will become college faculty in the future and they will bring such ideas to their own teaching of undergraduates and graduate students in the sciences.

Near the end of the program, Crystal commented, “Well, the idea of teaching science to be exciting for the kids is new to me since teaching in K–8 classrooms.” This probably represents a change for Crystal since it must have been boring when she was a K–8 student herself.

GK–12 Fellows' Ideas on the Nature of Science

For the fifth node, the Fellows' beliefs about the nature of science appeared to reflect the dominant paradigms of science found in science and science textbooks, at least in some of the early interviews and our VNOS-C results (September 2002, June 2003, and April 2005). Their beliefs reflected probably what would be found among most individuals with a science background, at least in the early stages of their tenure as GK–12 Fellows. We found this to be true with regard to the GK–12 Fellows' ideas about the nature of knowledge, the nature of scientific investigation, ideas about theories versus laws, creativity in science, and social and cultural influences on scientific knowledge. In the following sections, we address each in turn.

Nature of Knowledge

On the nature of knowledge or epistemology, in the first month of the program (at the beginning of the course), Crystal addressed this topic by writing, “Scientific knowledge is based on observations that are concrete and can be taken to be factual.” Beth, at the start of her program, wrote, “Unlike other disciplines, science does not allow for multiple interpretations.” These are positivistic views of the nature of knowledge.

When asked whether science is always true, Beth responded that it was and gave the reason: “Nature holds those answers not humans,” meaning that the human instrument as a measuring device was not relevant to the “truth” of science. Instead, truth is “out there” to be discovered and not to be interpreted or constructed using our prior experiences. She too saw subjectivity as a limitation and objectivity a virtue, stating it as a positive criterion, “Nature is not bound by beliefs or values.” In this vein, Wanda stated that science differed from other disciplines because opinions and untestable theories are the basis of some other disciplines, implying that predisposed beliefs do not play a factor in scientists' interpretation of results.

Nature of Scientific Investigation

Relative to the nature of investigation, Sandra wrote at the beginning of the program, “Science is the enactment of the scientific method; that is, the formulation of hypothesis, experimentation, and finally interpretation of data.” Tamara came from the perspective of using a null hypothesis, commenting, “An experiment is a



A third-grade student.

controlled way of collecting data in order to reject hypotheses that explain a natural phenomena.” Beth’s idea indicated that creativity can be influential in the approach taken: “The invention of a better design for an experiment and/or using a novel approach when analyzing data could lead to vast improvements or the discovery of new ideas.” Therefore, at the beginning, the Fellows’ ideas varied from some traditional to some more creative.

Four months into the program, the teaching survey indicated that their ideas on the nature of science had started to shift. For example, Tamara commented, “From my experience, I think it is very important to teach the process of science by actually conducting science.” Tamara wanted students to experience science first-hand. She commented further, “The process of science is a description of how science is carried out, how information is gained through asking questions and discovering the answers.” Wanda’s view was more open-ended than the others, asserting, “The process of science is identifying something that is intriguing and then investigating it.”

By one year into the program, Wanda’s view on the nature of investigation was even more open-ended, writing, “To me, observation is preliminary to experimentation; after observation, questions arise that may be answered by experimental design.” Wanda went further, stating, “In other words, simply taking what is already known and reanalyzing it from a different perspective is a way to develop scientific knowledge.” However, Nathan’s ideas are more traditional: “An experiment is the instrument used to gain further understanding.” Crystal’s ideas were similar to Nathan’s: “I think that experiments are necessary for the development of science because science is about asking questions, and the only way to find the answer to a specific question is to do an experiment, no matter how simple.” To be fair, we should also mention that by this time the Fellows were a year further into their graduate programs. Therefore, their more advanced understandings of the nature of science may possibly be due (in part, in full, or not at all) to their work in their laboratories. A detailed analysis of the responses of the comparison group may help differentiate the possibilities.

By the end of the program, Wanda commented in the VNOS-C survey, “Science is a discipline based on inquiry that is addressed in a process that involves hypotheses that are useful for mathematical interpretation of observation (with or without manipulations) and are useful for identifying possible explanations.” This is more in depth from what Wanda said after the first four months, and it takes into account the use of mathematics to understand processes and that there can be more than one explanation for the data.

Wanda felt that the process of teaching connected her well with the world of scientific research. We had expected that the Fellows would all report some alienation from their discipline because of being isolated physically from the people in their departments. While this was true in some cases, it was not true in Wanda’s case. In particular, she learned considerably about areas of her discipline, biology, that were not directly related to her subfield, botany. As she related:

I learned microbiology, like I said, I learned so much! I had never taken a microbiology class, so here I was with a microbiology textbook. We learned different colonies and morphologies, so it was good. It’s great for learning. (Wanda interview, 2/4/05)

Just as importantly, she expressed the idea that in some ways it connected her more with scientific research because of this increase in content knowledge.

Wanda saw schools as a place where real scientific research can take place. In the following passage, she talked of her idea to have scientists’ laboratories extend into a classroom. As she stated:

I could see with certain sets of students if you just turn the classroom into a laboratory, you could see how that could happen. You can have your courses melding with what you're (as a scientist) doing in the laboratory, or investigate some of the wider scale—the things that you're doing with the class—investigate them even further. (Wanda interview, 4/18/05)

So Wanda saw science classes (in college or K–12) as potential places to connect students with scientists and scientific experiments.

Rebecca reported that her teaching connected her more with her research by making her more holistically focused. Her topic related to climatological cycles in East Asian sediments. Although she originally had been focused solely on the sediment cycles, she came to recognize, through her teaching, that different factors influence each scientific phenomenon. As she related:

I never would have gotten the connection with the loess [an airborne dust particle] sequence and with the Milankovich Cycles, and human evolution, and so many different areas if I hadn't been interested enough to look in all those different areas, I would have never got the connection. (Rebecca interview, 2/10/05)

She saw science more in terms of connections, and it influenced her to view her own research topic in a broader sense and to learn more about different topics that relate to it. Her experiences teaching a variety of subjects motivated her to research in depth a variety of topics that related to her dissertation. She researched such topics as monsoon cycles and archeological studies because they informed her study in a broader manner.

Ideas About Theories Versus Laws

The distinction between theories and laws is one of the most commonly confused aspects about the nature of science. Schwartz et al. define the difference between theories and laws:

Theories and laws are different kinds of scientific knowledge. Laws describe relationships, observed or perceived, of phenomena in nature. Theories are inferred explanations for natural phenomena and mechanisms for relationships among natural phenomena. Hypotheses in science may lead to either theories or laws with the accumulation of substantial supporting evidence and acceptance in the scientific community. Theories and laws do not progress into one and another, in the hierarchical sense, for they are distinctly and functionally different types of knowledge (p. 613).

In other words, laws describe a relationship, while theories provide an explanation for that relationship. For example, if we drop a pen on the Earth, it will always fall to the ground. This could be referred to as the law of gravitation. But if we want to explain why the pen falls to the ground, we must invoke a theory. This does not imply that for every theory there is a corresponding law. For example, the theory that dinosaurs became extinct because of a meteorite impact does not have a corollary law that says, “Dinosaurs will always die out when there is a meteorite impact.”

Most of the Fellows held the view that laws were simply no more than widely accepted and solidified forms of theories. At the start of the program Sandra wrote, “The difference between scientific theory and law is simply a function of the number of times a theory has been tested.” Similarly, Nathan wrote, “A law is a well-established theory that can be taken as a fact,” and Wanda wrote, “If theories were more defined and proven or observed, they would become laws.” Their idea was that laws were simply

outgrowths of theories, with laws being theories that had stood the test of time and were now known to be definitely true.

Among some Fellows at the beginning of the program, however, there did appear to be some understanding of differences in nature between theories and laws. Beth, for example, wrote, “Although scientific theories and scientific laws are closely related, there may be a subtle difference between them.” In a second statement, although she identified laws and theories as being accepted as “true,” she appeared to understand some of their differences: “Both theories and laws are well-tested ideas accepted as true by the scientific community; however, scientific laws are usually more concise than theories.” At the end of the program, Beth said:

In order to develop scientific knowledge, we must be able to rely on some guiding principles. In my opinion, [there is] very little [difference between a scientific theory and a scientific law]. However, the term scientific law may imply some stronger mathematical development of principles that can be used to calculate quantities.

One can see the development during the program of Beth’s ideas on the differences between laws and theories. Her last sentence in the above quote about a “stronger mathematical development” is on the right track.

Some of the Fellows recognized that scientists use theories to inform working experiments and hypotheses on an ongoing basis through time. For example, Tamara wrote, “Theories are useful tools for explaining occurrences, for developing experiments to test the theories, and for understanding the history of a particular area of research.”

Most of the Fellows appeared to recognize that theories change with new information. Beth understood the recursive nature of theories in that experiments can influence the theories upon which they are based, as revealed in this passage: “There exists a two-way road between experimentation and theory formulation.” Jessica, too, noted, “I think scientific theories change over time.”

At the beginning of the program Crystal wrote, “The laws don’t change, and they are factual,” while Wanda added, “Theories are more fluid, more changing, than laws,” which is not what distinguishes them. However, Wanda did seem to grasp that theories could change with new constructions over time, when she recognized, “Changing theories reveal the history of science.”

Even at the end of the program, however, some Fellows’ ideas did not change and others did on the difference between a law and a theory. For instance, for these same two Fellows, Crystal said, “[Newton’s law] cannot be disputed, and there is only one set of laws to describe one phenomenon.” Wanda’s ideas were changing but still had some contradictions within them: “Laws are not debated as much as theories. Theories are less accepted as truth than laws.” Wanda still saw laws as “truth,” not as our best construction of a relationship of what we observe or perceive about nature. Other Fellows were mid-way along the continuum from thinking of laws as unchanging truths to thinking of them as “relationships, observed or perceived, of phenomenon in nature.”

Social and Cultural Influences on Scientific Knowledge

Since scientists from different cultures have differing experiences and perspectives, they will bring in different interpretations to scientific data. At the beginning of the program, most of the Fellows did not believe that knowledge was socially constructed but instead accepted it as a “testable truth” that is the same for all individuals and that does not change between different cultures or societies. Sandra exemplified this when she wrote, “The social sciences...entail the study of behavior and thought through

history and geographical settings [and] are unable to exact the scientific method in its purest form.” In other words, to her, social and cultural phenomena only contaminate the pureness and objectiveness of science and objectiveness is a virtue.

Jose gave particularly strong views about how culture and societal influences are not a part of science when he wrote, “Science transcends national and cultural boundaries; it is independent of social, political, philosophical, or religious values, as well as intellectual norms of any culture.” He went on to confirm his endorsement of science’s objectivity by asserting, “Science, by itself, is just a body of knowledge, hopefully as objective as can possibly be attained, about the universe, reality, the world around us, etc.” Jose saw socially and culturally based influences and differences in human opinion and experiences as factors that do not play a role in science and that are to be avoided.

There were, however, some notable exceptions to those views. Rebecca understood that science is not independent of such influences. She revealed this when she wrote, “Science has historically reflected social and cultural values and still does today.” Wanda wrote in response to one of the questions, “I don’t feel that I am able to answer this question without bias since I am under the influence of culture, but I do believe that our thoughts influence our interpretations.”

As is common among those grounded in the science culture, most of the Fellows described science in the language of objectivity, testability, and provability, indicating that there was one set answer for each question and that there must be “right” and “wrong” answers to scientific questions. Nathan stated, “They [his students] already have an idea how these things work out. So you kind of have to erase the incorrect knowledge and hopefully replace it with the correct knowledge” (Nathan interview, 2/15/05). He recognized that students had preconceived ideas about knowledge, but he did not necessarily recognize that there might be partial truths in these ideas that can be used, rather than replaced.

Crystal on the other hand recognized the possibility of alternate, supportable constructions of the same phenomenon. She wrote, “What goes for the general public also goes for scientists in that two people can look at the exact same thing and see something totally different (sic).” Wanda recognized that there could be several equally valid approaches to a problem. She wrote, “Every question may be approached from different directions with some approaches having different conclusions than others.”

At the end of the program, there were not as many statements on social and cultural effects on science from the final VNOS questionnaire. Nathan stated, “Different conclusions can be derived from the same set of data in this example because different scientists have different previous experiences and contexts in which to put new information.” Therefore, Nathan could see that scientists might interpret data differently. Elsewhere in the same VNOS questionnaire, Nathan wrote, “Experiments carried out in different cultures should produce the same result.” This is an apparent contradiction that signifies that both types of ideas are present in their minds at the same time and that they have not had a chance for discourse and time to resolve them. Interestingly, no one mentioned that scientists might ask different research questions depending on their gender or culture.

Creativity

During the first month of the project, ideas on creativity varied considerably from one GK–12 Fellow to another. For instance, Tamara acknowledged, “Scientists must use their creativity and imagination at every stage of the process.” Tamara also gave a practical metaphor for science: “Science is like cooking—there are guidelines and accepted ways of conducting research but there is always room for creativity and change.” In contrast, Wanda thought scientists “are encouraged to use their imaginations during the planning and design of experiments and during the analysis of the data but not during the collection of the data.”

Four months into the grant, at the end of the teaching and learning course, Rebecca commented as follows in our teaching questionnaire: “I think the process of science is explorative and creative in nature and can best be taught in a ‘hands-on’ manner when possible and always in a ‘minds-on’ fashion.” By the end of the program Rebecca commented:

*Scientists must use creativity at ALL stages of experimentation and investigation. When I am designing an experiment I try to imagine every potential variable and outcome so that I can control for as many things as possible. During data collection, things can break or not work as I had planned. I then have to be creative to discover the problem and fix or work around it. Finally, interpretation is all about creativity. If you can't imagine possibilities, you can't really do meaningful science (and I imagine it wouldn't be much fun).
(VNOS, April 2005)*

It's obvious that Rebecca has experienced these issues in her research. When one visits her classroom, one can see her self-confidence because she knows the science and wants to share that understanding of both the process and content of science.

One year into the project, some other Fellows mentioned creativity in their writing. For instance, Crystal wrote, “Every graduate student has to be creative in their own research projects to find innovative ways to answer the question that they have put forth.” Jessica addressed creativity when she wrote, “Method development is a very creative process that can be imagined spontaneously, in dreams, or as epiphanies.” Nathan agreed with the others: “Imagination is apparent in all stages of experiments.... If scientists cannot use their imaginations, then how will new theories and ideas be offered and then developed?” These Fellows may have had creativity in mind since the beginning of the project.

By the end of the program, every GK–12 Fellow wrote about the importance of creativity in science. For instance, Nathan wrote, “All the fundamental ideas we know in science were once someone's ‘crazy ideas’ (creative thoughts).”

Challenges

Using the CHAT as a theoretical frame, we searched for contradictions or challenges in what the Fellows stated. We searched for contradictions because we can learn from them how to improve the flow of the *subjects* (the GK–12 Fellows) to their *objects* (to learn about teaching and learning and about science) and toward their *outcomes* (becoming professional scientists with an evolving understanding of teaching and learning and of science).

The two strongest sets of contradictions or challenges were concerning the ideas on the nature of science and epistemology and on the interactions between the teachers and the Fellows. We will discuss each of them in turn, with evidence to support our claim of the presence of contradictions.

Nature of Science and Epistemology

The strongest challenge or contradiction of the Fellows was that they espoused the ideas that science is a series of facts and that truth can be achieved through science. Rebecca, from the beginning, did not do this, and Nathan tended to change in this direction. This goes beyond our Fellows and those in the comparison group, as most people, including scientists, tend to talk this way. At least scientists, however, know that science does change as we learn more. As we gather more data, we continue to reanalyze and develop new hypotheses and test them. It is as if we want others to think science is fact so that science will have a higher authority of knowledge. Also, even though scientists within their research groups tend to discuss science tentatively,

in oral presentations they can present their findings more forcefully as the “truth.” Scientists also may feel that they need to defend their conclusions as “fact” because some groups may assault science on the basis of its perceived weaknesses (i.e., that science is open-minded on the nature of truth).

In an attempt to understand these contradictions or challenges, we compared Fellows’ views on the nature of science at three different stages: at the beginning of the program, midway through the program, and near the end of the program. Their views are presented in the following charts:

Quotes on the Nature of Science From the Start of the Program

GK–12 Fellow	Representative Quote (source)
Crystal	The scientific knowledge is based on observations that are concrete and can be taken to be factual. (VNOS)
Jessica	The process of science is the process of coming to conclusions with repeatable results. (Teaching survey)
Latoya	Learning is a process. One can find science in everything. (Teaching survey)
Nathan	Science is defined as a study to obtain systematic knowledge. I believe science is exploring or attempting to explain something unknown using a governing set of rules. (VNOS)
Rebecca	Science is a method of thought in which ideas may be disproved but never truly proven.... Creativity and observation are very important, and the hypothesis, experiment, data, results’ model is not really an effective definition of science. (VNOS)
Tamara	Science is a study of the natural world. (VNOS)
Wanda	Physics and biology are more based on tangible, observable, and quantifiable events or objects, whereas philosophy and religion are based on conscious and subconscious thought. (VNOS)

Quotes on the Nature of Science After the Course on Teaching and Learning or Midway During the Program

K–12 Fellow	Representative Quote (source)
Beth	I believe that science is universal, but I also believe that the pursuit of scientific knowledge can be restricted by social and cultural values.... [Science is always true because] nature holds those answers not humans.... Since science answers solely to nature, the only way to test the accuracy of scientific ideas is to test them in nature. (VNOS)
Crystal	Science has to do with inquiry and experimentation.... What makes science different is that it is factual with few discrepancies once the facts have been proven. (VNOS)
Jessica	The process of science is the...coming to conclusions with repeatable results. (Teaching survey)
Latoya	Science is different because it is mostly based on physical proof and can be quantitatively tested. (VNOS)
Nathan	Science is the attempt to gain understanding of the unknown.... An experiment is the instrument used to gain further understanding. (VNOS)
Rebecca	Science differs from other disciplines of inquiry in that it requires a hypothesis to be repeatedly tested and these tests to produce alike results. (VNOS)

Quotes on the Nature of Science After the Course on Teaching and Learning or Midway During the Program (continued)

K–12 Fellow Representative Quote (source)

Tamara Science is, in theory, different from other disciplines of inquiry in that it is based on repeatable experiments and falsifiable hypotheses. (VNOS)

Wanda The science I describe is different from other disciplines of inquiry in that scientific disciplines seek the observable and measurable truth under stated conditions whereas other disciplines of inquiry focus on questions to which answers are often opinions or un-testable theories. (VNOS)

Quotes on the Nature of Science from the End of the Program

GK–12 Fellow Representative Quote (source)

Beth Theories can be modified as we learn more and more. If continued experimental results contradict a theory, then the theory must be thrown out. (VNOS)

Crystal Science differs from other disciplines in its requirement for observable proof. (VNOS)

Jessica Science is different than other disciplines because experiments are used to verify ideas. (VNOS)

Kisha Science also has the potential to get a definitive answer supported by data (VNOS)

Latoya Science is the process of observing one's surroundings, asking a question about why certain things occur, and trying to conduct experiments to resolve the question and later explain one's findings of the pros and cons of that finding. (VNOS)

Nathan Science is the attempt to learn or better understand something that is not yet understood. Rather than relying on faith or opinions, science creates laws using facts found through experiments. Science also contains opinions and theories, but they are based on the current knowledge available to us, and I think the opinions in science are more readily changed than those in religion... Science creates laws using facts found through experiments. Science also contains opinions and theories, but they are based on the current knowledge available to us, and I think the opinions in science are more readily changed than those in religion. (VNOS)

Rebecca Science is a process of inquiry in which ideas are (usually) testable and results are (or should be) repeatable. Science differs from other disciplines in that there is not an absolute "truth" and matters are not taken on faith. (VNOS)

Tamara Science is different from other disciplines in that hypotheses can be specifically tested and compared to alternative hypotheses... Science is not a static discipline. (VNOS)

Wanda Science is a discipline based on inquiry that is addressed in a process that involves hypotheses that are useful for mathematical interpretation of observations (with or without manipulations) and are useful for identifying possible explanations. (VNOS)

There are various types of contradictions addressed in these three tables: (1) Sometimes there is a contradiction between what a Fellow says at one point and what the Fellow says at another point in the same questionnaire, (2) sometimes there is a contradiction between what different Fellows express, (3) sometimes the Fellows' ideas change with time or ideas are not fully resolved within the Fellows (they are still pondering them), and (4) sometimes there is a contradiction between what scientists and social scientists think about science and what the Fellows think.

Interactions Between GK–12 Fellows and GK–12 Teachers

During their three-year tenure in the program, the Fellows had differing experiences in working with teachers. There were always some teachers with whom they worked very well and others with whom they did not work as well. In the previous part of this chapter and much of the monograph we have described much of the positive interactions. Here we discuss some of the challenges.

In some ways, the challenges were part of the learning for the Fellows, as they came to understand that there are different types of teachers in K–12 schools. At the same time, it may work better in the future to have a more select group of teachers and have the Fellows remain with each teacher for an entire year.

Some of the Fellows noticed that their participating GK–12 Teachers were not industrious, while others were first- or second-year teachers too overwhelmed with work to be able to work well with the Fellow. In the latter case, the situations were not truly in the teachers' control but were more a reflection of the difficulties that they were facing. There were some first- and second-year teachers, however, who worked out very well. One thing that this indicates is that there is a great need for better instruments to assess which teachers would benefit the most from professional development.

Another major issue was control of the classroom. In some cases, the Fellows were not permitted the time to do much teaching. As Rebecca reported about one of her teachers, "I felt like it was no partnership at all, and I brought nothing to the picture because I wasn't allowed to do anything." She would work very hard on lessons for this participating teacher, but the teacher did not value these lessons and would cut or cancel her lesson at the last minute.

In other cases, the exact opposite problem occurred—the teachers left the Fellows to fend for themselves teaching alone in the classroom. As Nathan reported:

More than half of the teachers I have worked with have left the classroom at one point or another (beyond just using the restroom). They should be involved in every activity or lesson. On the days when the Fellow has prepared a lesson or activity, the co-teachers sometimes feel like they are on vacation. (Nathan's end-of-year questionnaire, 4/22/05)

Here, Nathan revealed a problem that Fellows sometimes faced: that the teachers saw this as an opportunity to give up the classroom instead of co-teaching. It was easier for these teachers to turn over the classroom to the Fellows and simply vacate the premises or have their minds on something else.

Wanda added that there were some teachers who understood and embraced the concept of co-teaching, while there were others who did not. She stated:

The first teacher I worked with, she loved the co-teaching. I could talk about something, and she could come in and talk about something, and that would make me think about this, and I would talk about it. So that worked—but some teachers don't work that way. (Wanda interview 2/4/05)

In her statement, she explained that while some teachers worked well with Fellows and enjoyed the co-teaching, others did not. It depended on the individual and on the personality matches.

Despite doing our best at matching GK–12 Fellows with GK–12 Teachers, it was hard to predict what matches would work out well. There really is an element of art, skill, and luck to the matching process. Instruments developed by researchers to assess teachers' readiness to learn from professional development will be very useful for situations like matching practicing teachers with GK–12 Fellows. It would also be useful to have instruments to know which GK–12 Fellows are ready to learn from the experience of teaching.

Even though one of us interviewed 9 of the 25 GK–12 Teachers in the first and second years of the program, the topic of co-teaching only came up once. In that instance, the teacher was trying to work with the Fellow so that there would be productive co-teaching. We should note that in these nine interviews we did not specifically ask the GK–12 Teachers about co-teaching, as it did not really surface as a strong concern with the GK–12 Fellows until the end of the program. It may have been that the teachers would be able to legitimately tell another side to the story had we asked them.

Later, in the third year of the program, we specifically and directly asked four of the Fellows and four of the GK–12 Teachers supervising three of them about co-teaching, so our answers were more extensive. In some cases, GK–12 Teachers reported frustration with not knowing exactly what role the Fellows were expected to take. As one of them said, "The one thing I would like to mention is I was unsure of how much [the Fellow] was supposed to actually do." This teacher was uncertain what role the Fellow should have in the classroom. Therefore, better communication between the directors of the GK–12 program who make the placements with the teachers and the school system in advance might help. One Fellow suggested having the applicants for the GK–12 Teachers write short essays to answer questions such as:

1. What would you like to contribute to your K–8 classroom?
2. What do you feel that you can bring to the partnership with the GK–12 Fellow?
3. What and how would you want the Fellow to teach in your classroom?
4. How do you feel about the Fellow teaching some of your classes?

Besides doing science workshops in the summer for the GK–12 Teachers, we could include workshops on co-teaching^{18,19} as well. This might prove helpful in other GK–12 programs.

Some of the Fellows expressed a preference for having teacher assignments be for an entire school year, especially provided there is careful matching. This would allow for the program to be more selective in choosing teachers, as fewer teachers would be required. Nathan stated, "I would actually increase the screening process at both the Teacher and Fellow level." Here, he recommended screening not only GK–12 Teachers but also GK–12 Fellows in order to be fair and improve matching. In our program for the third year, three of our nine Fellows did get to work with one teacher for an entire year, and it was very productive.

GK–12 Fellows' Learning From Writing This Monograph

In the process of writing and reflecting on their experiences in the K–8 schools, it should help the GK–12 Fellows to move along the continuum towards understanding the nature of teaching and the nature of science. Mary Budd Rowe reminded us that John Dewey did not say that we learn by doing but that "we learn by doing and by *thinking* about what we're doing."²⁰ That is what we want to encourage in our GK–12 Fellows. This monograph should help other GK–12 Fellows here and elsewhere learn

the ropes of teaching in K–12 and how their ideas on the nature of science and on the teaching and learning of science may change through the experience. Some of the Fellows may be able to use their SERVE chapter as a chapter in their doctoral dissertations. Their major professors recognize that there has been scholarly work that they have done in the K–8 schools and that this should be part of the doctoral record.

Reflections by a Pre-Service Science Teacher

A pre-service science teacher and pre-intern, Giselle Marsh, worked on coding the GK–12 Fellows’ initial and midway comments for the analysis of the data from this evaluation. She noted that some of the Fellows’ ideas on science had changed from their initial entries to their mid-way writings. After Giselle sorted the data using the QSR software program, she wrote in her summary:

At the beginning of the project when each Fellow wrote about his/her views on science, the classroom and teaching, each response seemed so “stuffy.” It was as if they were writing a term paper for Albert Einstein. It was not until later assignments that I could see the Fellows making connections between science, education, and the students. The Fellows have really developed and become more open to the educational aspect of science.

Giselle found that reading the Fellows’ ideas on teaching, assessment, discipline, and the nature of science helped her get ready for her teaching internship. She reflected on her own ideas while she read the ideas of the Fellows and discussed contrasting ideas with one of us. It helped her as a pre-service teacher prepare herself for teaching.

Fellows’ Learning Through Participating in Research

Another advantage of our evaluation was the learning that the Fellows gained from participating in our research. By having a chance to reflect on their practice and by being able to think about their GK–12 experiences, they were able to deepen their understandings about science teaching. Wanda revealed this learning when she noted:

The types of questions that were asked during the study gave me insight about the kind of assessment that is done in the [science education] field and also enriched my GK–12 experience by causing me to analyze and reflect on the GK–12 experiences and how the GK–12 experiences influenced my thinking. Writing the monograph and reading the chapters of others was also important for reflection. I found reading my responses from the beginning of the program and comparing them to my responses and thoughts at the end of the program to be helpful in my understanding of what I have gained from the program. (Wanda, personal communication, 6/23/05)

In the above passage, she notes how it was advantageous to see how she had developed as a result of the program. By having her initial thoughts recorded, she could have a reference point with which to compare her current understandings. She also indicates that she has learned about the type of research conducted in science education and the types of questions asked. Other Fellows expressed similar sentiments. When one of us asked Rebecca if she felt that she had benefited from the research that we did, she replied “Yeah! I feel like I’ve learned a lot. I’ve gotten a much better feel—I’ve gotten a lot more confident in my research.” She went on to explain how talking about her teaching and research allowed her to understand how her teaching was informing her research. Without this study, she says she would not have thought about and come to understand this connection.

Summary of Final Evaluation

We have seen progress on our GK–12 Fellows’ ideas on teaching, learning, and assessment. The Fellows learned how difficult assessment is, how children of different ages learn differently, how to focus on the big picture rather than small details, and how one can learn even when one needs to teach out of field. They also learned generally about the nature of children and schools so that they can be better informed in the future should they become involved in outreach to K–12 education from their science professions.

Having the special course for them in their first semester in the program was critical for getting them to think differently about teaching and learning. Most GK–12 programs do not offer such a course as this, and we think it is crucial.

Where there was less progress was on the Fellows’ ideas on the nature of science. It is not too surprising, however, because that was not a primary focus of our program, but determining what factors influence science graduate students to change their ideas about the nature of science has become an area of research. Bell, Blair, Crawford, and Lederman (2003) point out that practicing scientists think that their junior research associates will pick up the nature of science “by osmosis” and that it does not need to be addressed.²¹ However, Bell et al. believe osmosis alone is not sufficient to teach people about the nature of science.²¹

Bell et al. note that by providing “forced dissonance as epistemic demand” or the “demands that a project makes on a student to draw on his or her views about the relationship between data and knowledge to make progress on the project,” we might be able to assist learners through this dissonance that they may feel.²¹

As our program comes close to the end, a number of our Fellows have spoken about the desire to stay involved in education once they finish their doctoral degrees, whether it is through becoming a university faculty member or other approaches. Wanda spoke with one of us about her change in career goal. Originally she had planned to pursue a career as an industrial scientist but now was considering a career as an academic scientist because of her desire to stay more involved in teaching. One thing that is certain is that they will influence the culture of teaching wherever they go. We think of them as seed crystals, spreading the knowledge that they have learned about teaching and learning as they move forward in their careers.

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Martin Balinsky, GK–12 Fellow Danielle Sherdan, and Penny J. Gilmer at the GK–12 Annual Meeting in Arlington, VA in 2005. Martin is a Science Education graduate student who is doing a qualitative study of several of the GK–12 Fellows in collaboration with Dr. Penny J. Gilmer, the internal evaluator.



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Science Graduate Students in K–8 Classrooms:

Experiences and Reflections

From the **Foreword** by Kenneth Tobin:

This monograph is timely. For many years university scholars have participated in outreach activities with the goal of improving K–12 education. With the advent of a National Science Foundation program to fund collaborative projects between K–12 and university scientists, there was a clear need for a scholarly publication that described how a project was planned and enacted, explored the successes and contradictions, and considered what improvements were necessary. This monograph does just that by using a variety of data resources and sociocultural theoretical frames to highlight the benefits, contradictions, and directions for the future based on research and evaluation of a NSF-funded project from the Graduate Teaching Fellows in K–12 Education program....

The uses of coteaching in this project open the door for each coteacher to learn from the other... What caught my eye in this monograph was the possibility that the coteachers' goals progressed from personal growth and change to collective growth and change in the context of cotaught classes.

A feature of the monograph is its inclusion of practitioner research from a Graduate Teaching Fellows in K–12 Education program that made a conscious effort to ascertain what was happening and why it was happening. There is considerable merit in participants undertaking research on their own practices and, on the basis of what is learned, effecting changes so as to improve the quality of enactment....

— Kenneth Tobin, Presidential Professor of Urban Education
NSF, Distinguished Teaching Scholar
The Graduate Center of the City University of New York