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Article

Graduate Experience in Science Education: The Development of a Science Education Course for Biomedical Science Graduate Students

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The University of Rochester's Graduate Experience in Science Education (GESE) course familiarizes biomedical science graduate students interested in pursuing academic career tracks with a fundamental understanding of some of the theory, principles, and concepts of science education. This one-semester elective course provides graduate students with practical teaching and communication skills to help them better relate science content to, and increase their confidence in, their own teaching abilities. The 2-h weekly sessions include an introduction to cognitive hierarchies, learning styles, and multiple intelligences; modeling and coaching some practical aspects of science education pedagogy; lesson-planning skills; an introduction to instructional methods such as case studies and problem-based learning; and use of computer-based instructional technologies. It is hoped that the early development of knowledge and skills about teaching and learning will encourage graduate students to continue their growth as educators throughout their careers. This article summarizes the GESE course and presents evidence on the effectiveness of this course in providing graduate students with information about teaching and learning that they will use throughout their careers.

INTRODUCTION

In his essay "Scientists and Science Education Reform," neurobiologist James M. Bower of the California Institute of Technology states:

> "Scientific training often includes little or no focus on science education itself. Instead, it is simply assumed that a Ph.D. in experimental science is adequate preparation for ones eventual educational responsibilities. . . . The most important personal consequence of my involvement with science education reform has been a growing awareness of how poorly I have taught my own students. . . . I have become profoundly aware of the negative effect the poor teaching of science in colleges and universities has on the rest of the educational system."

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One way to counter the "negative effects" that Bower describes is to train college and university faculty to be "teachers" not "tellers," ones who know about and also apply the vast body of research about effective science teaching and learning.

Biomedical scientists are trained during graduate school and postdoctoral studies to be researchers. Many of those who pursue academic career tracks are also expected to teach, especially if they assume faculty appointments at smaller colleges. Ph.D. graduates often find that they are not well prepared for this faculty role (Golde and Dore, 2001; Austin, 2002). Many graduate school programs do have a teaching requirement, but this is often limited to being a teaching assistant (TA) in a lecture-based course or in an introductory laboratory course. TAs seldom have full course-planning responsibility. Other opportunities for teaching such as leading discussions and assisting with lab investigations are aspects of science teaching that TAs may be involved in, but they rarely have opportunities to create and lead their own lessons. Often, the only "teaching" experiences that graduate students have are the occasional, interdepartmental seminars (using lecture format) that they are required to give to fellow graduate students and faculty.

Graduate students who want to learn more about teaching and, more importantly, learning, have few role models to turn to. Faculty in basic science departments are unlikely to also be involved in science education, particularly at a large research-based university where their primary function is to produce and publish research data that advance the goals of their laboratories. Research faculty are often completely grant funded, and even when scientists themselves are interested in teaching or participating in science outreach programs, they may be discouraged because their interest in teaching and learning does not contribute to their research goals.

A large percentage of graduate students will end up in academic careers that require them to teach. Data from a 2003 National Science Foundation (NSF) survey of 593,300 doctoral scientists and engineers in the United States indicate that 259,380 of them are employed at universities and 4-yr colleges (NSF, 2006). Thirty-one percent (183,650) of all respondents to this survey indicate that teaching is their primary work activity. Forty percent of the doctoral scientists employed at universities or 4-yr colleges indicate that teaching is their primary work activity, whereas 21% indicate that teaching is their secondary work activity. According to the 2005 Survey of Earned Doctorates, conducted for the NSF, 24.2% of the 29,246 science and engineering doctoral recipients in 2005 indicated that they will be employed by an educational institution after receiving their doctorate (Hoffer *et al.*, 2006).

These percentages provide evidence that a critical need exists to provide graduate students with information on educational skills needed by faculty members who teach at the undergraduate, graduate, or professional level, including instructional skills and strategies and knowledge of theories and principles of learning and teaching. Graduate students also need to be introduced to a variety of curricular designs, instructional strategies, and differentiated assessment methodologies that could be used in their future courses.

One approach to broadening the exposure of graduate students to teaching and learning would be to institute a mandatory teaching course coupled with a mandatory teaching internship. However, few basic science departments would be in favor of adding time and effort required "away from the bench" for their graduate students in order to complete such a course. In contrast, a one-semester science education elective course would be quite useful for students who might be interested in pursuing an academic career but who have little time to devote to extra coursework. Such a course could be followed by additional opportunities for graduate students who are interested in teaching and learning.

Despite the obvious need for graduate students to develop skills in teaching and curriculum design, few universities offer their graduate students the opportunity to enroll in a science education course, and if they do, the course is usually coupled to a "teaching minor" or is limited to students who are already participating in science education programs. Some quality programs do exist, however, and have grown out of the Preparing Future Faculty (PFF) initiative, a joint undertaking of the Association of American Colleges and Universities and the Council of Graduate Schools. PFF was supported from 1993 to 2001 by the NSF, the Pew Charitable Trusts, and the Atlantic Philanthropies (http://www.preparing-faculty.org). PFF programs provide doctoral students (and some postdoctoral fellows) with opportunities to observe and experience a variety of faculty responsibilities including teaching, research, and service. These opportunities usually occur through mentoring and partnerships developed with liberal arts and community colleges. PFF programs have been implemented at more than 45 doctoral degree–granting institutions and nearly 300 partner institutions.

For example, the Department of Biological Sciences at the University of Pittsburgh recently instituted a Teaching Minor program. The requirements of this program include at least two semesters of teaching, participation in a monthly teaching club, enrollment in a Teaching Practicum Course, and maintenance of a Teaching Dossier (http://www.pitt.edu/~biohome/Dept/Frame/teachingminor.htm). University of Minnesota's Center for Teaching and Learning has a PFF program for graduate students and postdoctoral fellows. In their Teaching in Higher Education course, students "model a variety of active learning strategies (e.g., cooperative learning, collaborative learning, problem-posing, case study, interactive lecture, discussion, critical thinking, role-playing) and facilitate discussions addressing educational theory and practice" (http://www1.umn.edu/ohr/teachlearn/pff/courses/8101.html). This course is followed by several other courses that offer opportunities to teach and also a course that prepares students for entering the job market in academia. North Carolina State University has several education courses in which graduate students may enroll, including Teaching in College, which focuses on some of the "fundamental tasks of a college teacher," and Teaching Mathematics and Science in Higher Education, which examines "design of courses and curricula, innovative programs and facilities, and methods and materials for instruction." The University of Florida offers a Fundamentals of Biomedical Science Education course (http://www.med.ufl.edu/IDP/courses/Syllabus/GMS5905Education.html) that is focused on providing skills for teaching medical student courses.

Universities and funding agencies are working together in numerous ways in an attempt to address the need to prepare graduate students for academic teaching careers. A prime example of this is the Center for the Integration of Research, Teaching, and Learning (CIRTL), an NSF-funded partnership among seven universities that "work together to promote professional development in teaching and learning for faculty and future faculty" (http://www.cirtl.net). CIRTL initiatives at the seven partner institutions focus on three foundational concepts (known as "CIRTL pillars"): Teaching-as-Research, Learning Communities, and Learning-through-Diversity.

The University of Rochester (UR) has approximately 950 graduate students enrolled in doctoral degree–granting programs in science and engineering. Opportunities for UR science and engineering graduate students to gain teaching experience or to learn about teaching and learning include working as TAs in laboratory or lecture-based courses and working as team leaders in peer-led, cooperative learning–based workshop courses. Graduate students and postdoc-

Table 1. Students attending the GESE course, 2005–2007

Year	Enrolled	Auditing	Total
2005	9	0	9
2006	14	2	16
2007	16	7	23
Total	39	9	48

toral candidates can also volunteer their time to assist with science outreach programs for local K–12 students and teachers. A group of several dozen UR graduate students and faculty members meet monthly as an informal Cluster for Leadership in Education. This group discusses a variety of topics in teaching and learning and hosts occasional guest speakers. The UR's Department of Electrical Engineering offers a one-semester elective course called "Preparation for Academic Careers in Engineering and Science." This course covers a variety of topics of interest for students who may pursue an academic career, such as how to interview and negotiate for a faculty position; how to juggle teaching, research, and service; grant writing; and achieving tenure.

In 2004, faculty from UR's School of Medicine and Dentistry submitted a proposal for a two-credit elective course in order to familiarize science graduate students interested in pursuing academic career tracks with a fundamental understanding of some of the theory, principles, and concepts of science teaching and learning. Despite initial reluctance (and an underlying attitude of concern) from several of the graduate training program directors that such a course would take graduate students' efforts away from their laboratory research, the course was given unanimous approval by the university's Committee on Graduate Education. The Graduate Experience in Science Education (GESE) course was initiated in Spring 2005. This one-semester elective course provides graduate students with practical teaching and communication skills to help them better relate science content and to increase their confidence in their own teaching abilities. The GESE course is designed to make graduate students more aware of educational research and application about learning and research-based pedagogy. The GESE course focuses on general aspects of teaching and learning, foundations on which the PFF programs are designed. GESE also includes an introduction to some methods that are specific to science teaching, such as inquiry-based and problem-based learning, emerging technology, and communicating about science research.

This article summarizes the GESE course and presents preliminary data from the 2006 cohort to evaluate the effectiveness of this course in providing graduate students with information on instructional methods that they can use throughout their careers.

COURSE DESIGN

Educational Environment

GESE is a one-semester, two-credit, 15-wk course offered through UR's School of Medicine and Dentistry during the spring semester (mid-January through early May). The course meets for one 2-h session each week. This interdepartmental course is open to all UR graduate students and has attracted graduate students from almost every biomedical Ph.D. training program at the university as well as from the Chemistry and Physics departments. Nine students enrolled in GESE during 2005, which was the first year that this course was offered (Table 1). Fourteen students enrolled (and two audited) this course during 2006. Sixteen students enrolled (and seven audited) this course during 2007. Table 2 shows the gender and departmental affiliation of the students who have enrolled (or audited) the GESE courses during 2005–2007. The GESE course attracts mostly upper-level graduate students who have already completed most or all of their required coursework (see Table 3). It is interesting to note that 19 of the 48 students who have attended GESE (40%) are fourth-year graduate students. This may be a time in their graduate student years that they have more time to devote to thinking about their future beyond graduate school. They have completed their required coursework and passed their qualifying exams and are not yet in a rush to finish their thesis projects. One postdoctoral fellow and one faculty member also audited the 2007 GESE course.

The GESE course director (D.G.M.) is a Ph.D. molecular biologist who has spent the past 16 years directing science education and outreach programs, primarily for secondary school students and teachers. The course codirector is a

Table 2. Department affiliation and gender of students attending the GESE course, 2005–2007

Department	Male	Female	Total	Auditing
Biochemistry and Biophysics	5	6	11	1 post-doc (female)
Biomedical Engineering	2	3	5	4 (2 male, 2 female)
Biomedical Genetics	1	1	2	
Biostatistics	0	1	1	
Chemistry	0	1	1	
Community and Preventive Medicine	1	0	1	
Microbiology and Immunology	5	6	11	1 (female)
Neurobiology and Anatomy	2	0	2	1 faculty (male)
Pathology	1	4	5	1 (female)
Physics and Astronomy	1	1	2	
Toxicology	4	3	7	1 (male)
Total students attending	22	26	48	

Table 3. Year in graduate school of students attending the GESE course

Year in graduate school	No. of students
1	6
2	7
3	7
4	19
5	2
6	4
7	0
8	1

The enrolled students and auditing students are included, but postdoctoral fellows and a faculty member who audited the GESE course are not. The student in year 8 of graduate school had switched laboratories midway through graduate school.

retired secondary school science teacher and K–12 science supervisor (M.J.D.) who has expertise in curriculum development, student assessment, preservice teacher education, and inservice professional development. GESE guest instructors include faculty from UR's Center for Science Education and Outreach (http://cseo.envmed.rochester.edu/) and the Life Sciences Learning Center (LSLC), a hands-on science education outreach center located at UR Medical Center (http://lifesciences.envmed.rochester.edu/). Faculty from UR's Margaret Warner Graduate School of Education and Human Development, as well as education and science faculty from several other Rochester-area colleges, also participate as guest instructors in the GESE course.

Expected Outcomes

The goal of the GESE course is to provide graduate students with a fundamental understanding of the theories of education and the principles and concepts of differentiated instruction, curriculum design, and assessment so that they will be able to use this knowledge in their future role as educators. This goal is accomplished through 2-h weekly course sessions that include the following:

- an introduction to cognitive hierarchies, learning styles, and multiple intelligences
- modeling and coaching some practical aspects of science education pedagogy
- lesson planning using several different models
- an introduction to instructional methods such as case studies and problem-based learning
- use of computer-based instructional technologies

To meet the goals of the GESE course, students provide evidence toward meeting a variety of expected outcomes, including the following:

- applying theory, principles and concepts of learning and teaching in the design and implementation of effective lessons
- generating questions and becoming informed about some of the practical aspects of college science teaching
- developing skills in planning and implementing science lessons that:
  - assess learners' prior knowledge
  - stimulate and sustain learners' interest, engagement, and achievement
  - use instructional strategies and assessment approaches to meet the needs of learners of varying abilities
- observing science teaching in a variety of field experiences (secondary and undergraduate)
- designing a lesson based on their own laboratory research, for a target audience of their choice, and presenting their lesson to the class
- reflecting on what they have learned by participating in an online discussion board and through classroom discussions

Summary of Course Syllabus

The 15-wk GESE course is divided into the following major themes. Some of these themes are covered in several class sessions, held over consecutive weeks, or spread through the semester. Each 2-h session provides models for instructional methods that students can use in their own teaching.

How Students Learn. The first 4 weeks of the course provide an overview of some well-accepted learning theories, with a focus on differentiated instruction. Presentations and class discussions cover general aspects of constructivism, cognition, and inquiry.

Students learn about Benjamin Bloom's three domains of learning, focusing on the six-part hierarchy of the Cognitive Domain (Bloom and Krathwohl, 1956). They also learn about Williams' taxonomy of creative thinking skills (Williams, 1980) and what types of learner behaviors are associated with each of Williams' eight skill levels. Students complete their own Learning Style Inventory (Silver *et al.*, 2000), which is based on Carl Jung's theories of psychological types (Jung, 1971). In completing the Learning Style Inventory, students create a visual representation of their learning style profile and discover how their own learning profile is characterized by particular learning behaviors and abilities within each style. It is interesting to note that graduate students in the class discover that most of them have a dominant "Understanding (Intuitive-Thinker) Style," characterized by learners "who prefer to be challenged intellectually. . . . are curious about ideas. . . and have a high tolerance for theory and abstraction [and], a taste for complex [academic, scientific, and intellectually stimulating] problems." (Silver *et al.*, 2000).

Students also complete a Multiple Intelligence (MI) Indicator (Silver *et al.*, 2000) while learning about Gardner's theory of multiple intelligences (Gardner, 1983, 1996). Although students' dispositions in this class show expected tendencies toward Verbal-Linguistic and Logical-Mathematical Intelligences, students are surprised to find that the results of their MI Indicator reveal a "unique combination of intelligence strengths and weaknesses" (Silver *et al.*, 2000). They learn that "Learning styles are concerned with differences in the process of learning, whereas multiple intelligences center on the content and products of learning." (Silver *et al.*, 1997).

As students become exposed to different ideas about cognition, learning styles, and intelligences, they begin to change their conception of teaching from one of "professing" content knowledge to one focused on their own (and on others') learning. Students learn methods of how to use differentiated instruction tools to create lessons and assessments to meet the needs of different types of learners. Students create a Task Rotation assignment by picking a topic that they know something about (for example, their area of research or a sport or hobby that they enjoy) and then creating questions and tasks in each of four Learning Styles: Mastery, Understanding, Interpersonal, and Self-Expressive. They learn that effective teaching focuses on creatively applying an understanding of learning profiles (not just styles) in the development of lessons. Students are also challenged to think about matrixing profile tasks to integrate learning styles with Gardner's multiple intelligences and create more complex and integrated examples of differentiated instruction.

Instructional Methods. Students are introduced to a variety of instructional strategies that focus on active, student-centered learning. These include instructional methods for peer review and cooperative learning and working with both small and large groups of learners. One visiting instructor's GESE class session models the use of case studies as a teaching technique and introduces students to the wide array of case studies that have been published online through the National Center for Case Study Teaching in Science (http://ublib.buffalo.edu/libraries/projects/cases/case.html). During this session, students engage in a pharmacology case that involves the toxicology and chemistry of tetrodotoxin, a neurotoxin found in puffer fish. In another session students learn about the peer-led team learning (PLTL) workshop method (PLTL, 2006). The PLTL instructional method is used in several undergraduate science courses at UR and utilizes trained, graduate student peer facilitators to help small groups of students work though assigned problems on a weekly basis. Another GESE class session on computer-based instructional tools introduces a variety of Web-based learning methods such as using webquests (http://webquest.org/) and modeling programs to support active, inquiry-based learning.

Assessment of Student Learning. A session on assessment of student learning introduces students to assessment strategies that can be used to collect evidence of student learning. These include assessment of prior knowledge (how to assess what students come into class already knowing), formative assessment (how to assess students' levels of understanding as a lesson is being taught), and summative assessment (how to assess lesson objectives and concept attainment, i.e., what have students learned). Students are provided with examples of various types of assessments, including objective tests (multiple choice or short answer), authentic and performance assessments (such as developing a method to purify river water as part of a unit on water purification), and alternative assessments (such as using long-term inquiry projects, concept maps, exhibitions and demonstrations, and portfolios). Students learn about designing assessments that reflect what they learned about learning styles and multiple intelligences, and then they compare and contrast these forms of assessment to more traditional standardized tests.

Lesson Planning. A session on lesson planning introduces students to several models of lesson formats. These include Silver and Strong's ROPE model of Review, Orientation, Process (Presenting, Processing, Practicing, Producing), and Evaluation (Silver *et al.*, 2000); Madeline Hunter's Effective Teaching model based on teacher behaviors and decision-making (Hunter, 1982), and the 5E instructional model of Engage, Explore, Explain, Elaborate, and Evaluate for developing a constructivist lesson (NRC, 1996; Biological Sciences Curriculum Series, 2003). Students are provided with overviews and sample lessons using each of these formats and asked to compare common elements and contrast unique features among the models. For their final project, students must select one of the models or design a hybrid one that best fits their content and audience.

Teaching within a Social Context. Discussions and readings in several class sessions focus on equity issues related to teaching a population of students who are diverse in race, social class, gender, and ethnicity. Graduate students are also made aware of instructional and assessment accommodations that are suggested and/or mandated for postsecondary students with learning disabilities or physical disabilities.

Undergraduate Science Education: Panel Discussion. One session involves a panel discussion with current science faculty representing three different types of undergraduate teaching venues: a research-based university; a small, liberal arts college; and a 2-yr community college. One of the panelists is a veteran teacher with several decades of undergraduate classroom teaching experience, and another panelist is a novice teacher who recently left a biomedical research position at a large university to assume a faculty position teaching biology at a small liberal arts college. The panelists share information with students about how they came to be in their current faculty positions, the types of instructional and assessment methods they use, and the various duties and job responsibilities associated with their faculty positions. Specific questions are asked that relate to learning styles and differentiated instruction and what changes these instructors have to make in their teaching, curriculum, or assessment systems to meet the needs of their students. These and other questions posed to the panelists provide a background and context for students to understand how their education and career pathways might be similar to and different from each of the panelists.

Online Discussion Board for Reflection and Formative Assessment

Student reflection on their learning is facilitated through classroom discussion and the use of Blackboard, an Internet-based "discussion board" (www.blackboard.com). Students use the discussion board to reflect on class presentations and their readings during that week. Students are assigned one or more specific focus questions each week about which they direct their postings. For example, in the discussion board posting completed as a follow-up to a class session on Silver and Strong's four learning styles (Mastery, Understanding, Interpersonal, and Self-Expressive), students are asked to complete two of the following four tasks and post their responses onto Blackboard. Each task is created with a different learning style in mind (noted in parentheses):

- Name the four Learning Styles, their abbreviations, and a minimum of three characteristic and identifiable traits for each style. (Mastery)
- In what ways do your thoughts about Learning Style theory reinforce or "muddy the waters" from your previous notions about learning? (Understanding)
- Describe your feelings about your own Learning Profile and speculate on how it may have positively and negatively affected your personal and professional life. (Interpersonal)
- Choose one of these: (Self-Expressive)
  - Write a poem or song using Learning Style concepts.
  - Write the dialog of an interview between your dominant learning style and your learning style "shadow."
  - Create (and be ready to explain) a 3D representation of your Learning Profile.

Final Project: Lesson Plan

As a final project, GESE students create a lesson plan for a 1- to 2-h lesson based on their own laboratory research or on a topic that their lab or department is investigating. Each student decides what content area/topic to focus on, what level of learner their lesson is meant for, how to accommodate different learning styles, how to make use of technology, and how to assess "student" learning. The lesson must not solely be a lecture-type format. The final project requires inclusion of an active-learning component such as a hands-on lab activity, a case study scenario activity, a computer activity, a game, or any other type of activity that would get their "learners" actively engaged.

Students are expected to use one of the three lesson plan models (the 5E model, Madeline Hunter's model, or the ROPE model), or a hybrid of the models based on the student's choice of content and audience. The students are also required to incorporate material covered during the sessions on differentiated instruction and learning styles, assessment, and social and diversity issues. Students are also encouraged to include, as appropriate, what they learned from their sessions on teaching undergraduates, case study teaching, and computer-based instructional tools.

Short, weekly assignments provide students with a structured framework for applying what they learned each week to the creation of their lessons. The weekly assignments are designed to help students focus on the following aspects of their projects:

- Assessment: How will you assess what your students already know? What do you want your students to learn and at what level of learning? What different kinds of evidence will you collect to show that learning occurred?
- Lesson planning: How do you plan an effective lesson? What lesson plan model will work best for you?
- Computer-based instructional tools: How could computer software and the Internet be incorporated into your lesson?
- Diversity, inclusion, and teaching within a social context: How will you differentiate your lesson to create learning opportunities so that all learners will be successful?

Students are provided with a "checklist" that they use to self-assess their progress in completing their project. The checklist asks students to answer focus questions that guide them through the project. Examples of these questions range from: "To what extent have you identified the major conceptual understandings that you will assess as a result of this lesson?" to "To what extent have you included instructional methods that allow for diversity for students with learning and/or physical disabilities?"

At the end of the semester, students submit a project write-up containing the following:

- A lesson plan outline with a timeline
- Detailed descriptions of the lesson and activities (for students and the teacher)
- A list of materials and instructional resources needed
- Suggestions for modifying activities and instructional methods for different learning styles
- Student handouts
- Plans for assessment of student learning

The project write-up also includes a reflections section in which students answer the following questions:

- Why did you decide to select this topic for your lesson?
- Why did you select this "student audience"?
- What were the reasons that you chose to design the lesson this way?
- Why did you choose to use certain aspects of this course, but not others?
- What part(s) of this assignment were easy for you, and what part(s) were more difficult?

The project write-up is worth 25% of the final grade and is scored using a point system (100 points total), with each part of the project assigned a specific point value.

During the last two classes of the semester, each student presents a summary of the design of their lesson in a brief (15 min) PowerPoint presentation. The presentation does not "teach" the lesson, but rather provides an overview of the lesson's learning objectives, instructional methods, and assessments to be used. The presentations require students to share their reflections on what they learned about being a prospective teacher as a result of doing the project, as well as what they found easy and difficult about the project.

Students rate each other's presentations using a rubric to assess 1) the organization of the presentation, 2) inclusion of relevant information about the lesson, and 3) the visual appeal of the presentation. The rubrics are collected and the "reviewers'" scores are averaged. The student presentations are worth 20% of the final grade.

Observations of Classroom Teaching

The graduate students are required to observe practicing teachers leading three different types of science classes: a high school class taught in a Rochester-area public school, a class taught to high school students visiting UR's LSLC, and a college science class. To encourage graduate students to make effective use of their classroom observation experience, they use a template for keeping their observation notes and for reflecting on what they experienced in each classroom. Students record information about the class make-up (age, gender, and ethnicity) and how the classroom was organized (seating in rows or in groups at tables). They summarize how the teacher taught the lesson, including how the teacher assessed prior knowledge, communicated expectations, checked for understanding, made transitions, asked questions, and interacted with the students. They note what the teacher did to promote students' enthusiasm for science and what classroom management techniques the teacher used to ensure attentive involvement of all students. The observation notes also include a reflection section that asks the graduate students to share what they learned about teaching and learning as a result of the observation and how these experiences can be applied to their teaching. The graduate students use this reflection section to offer any questions or concerns that they have about what they observe. The teaching observations are worth 10% of the final grade.

COURSE OUTCOMES, 2006

Description of Graduate Students Enrolled

Sixteen students attended the GESE course during the Spring 2006 semester. This was the second year that the course has been offered. (Nine students attended the GESE course in Spring 2005.) Fourteen students were officially enrolled in the 2006 course, and two graduate students audited the course.

As part of a career path introduction activity done during the first class session, students discussed why they decided to enroll in the GESE course. Student responses varied from those who wanted to gain teaching experience "without actually getting a teaching job" to others who wanted to develop their communication skills to "help express thoughts better." Students also described the most influential teachers in their lives. Most often these teachers were described as energetic and enthusiastic educators with a "passion for learning and teaching."

Final Projects

The final projects for the 14 students enrolled in the 2006 GESE course are summarized in Table 4. The graduate students created lessons for a wide range of student audiences, including visitors at a science museum, high school students, graduate students, and pharmaceutical company research managers. The learning objectives of the lessons reflected the diversity of the graduate students' research areas and ranged from very specific concepts in molecular genetics (for example, a case study on the *Drosophila* GAL4 sys-

Table 4. Final projects of the students enrolled in the GESE course during 2006

Department	Lesson title	Target audience for lesson	Instructional methods	Lesson plan model(s)
Physics	Introduction to color vision for a museum audience	General public	Demonstrations and discussion	5E
Pathology	Supersize me: mechanisms of obesity-associated insulin dependence	High school science class	Incomplete notes (lecture), case study research and presentation	ROPE
Biochemistry	Exploring microorganisms in the everyday environment	High school life sciences class	Case study, lab activity	Hunter
Biochemistry	Ecology	Undergraduate science or nonscience majors	Observation of natural world	5E
Biochemistry	Introduction to RNA secondary structure	Physics/engineering graduate students	Individual and group hands-on activities and discussions	ROPE, Hunter
Physics	The infrared and infrared astronomy	High school science class	Hands-on activities, lecture	5E
Toxicology	Cancer: biology, cause and treatment	Undergraduate biology majors	Case study, computer lab activity	ROPE
Biochemistry	Ketogenesis and the role of mitochondria	Undergraduate biochemistry class	Case study	5E
Biomedical Genetics	A case study in the *Drosophila* GAL4 system	Undergrad biology majors	Case study	5E
Microbiology and Immunology	Roles of TNFα in liver disease	Pharmaceutical company research and development managers	Small groups design hypothetical experiments	ROPE
Biochemistry	DNA structure and function	High school biology class	Case study, lab activity	5E, ROPE, Hunter
Neurobiology and Anatomy	Action potentials: origins and conduction	Undergraduate biology majors	Lecture, hands-on lab	ROPE
Biochemistry	HIV and drug design	Undergraduate biology majors	Lecture, group activity	Hunter
Biomedical Genetics	Using genomics to identify drug targets for cancer therapy	Undergraduate biology majors	Lecture, lab activity, PubMed Literature search	5E

ROPE, Review, Orientation, Process (Presenting, Processing, Practicing, Producing), and Evaluation; Hunter, Madeline Hunter's Effective Teaching model; 5E, Engage, Explore, Explain, Elaborate, and Evaluate.

tem) to very general understandings of the natural world (for example, an ecology lesson). All of the projects incorporated one or more student-centered instructional methods, with case studies being the most popular of the approaches. Only a few of the projects used lectures in the lessons. One project (Super-size me: mechanisms of obesity-associated insulin dependence) used an "incomplete notes" lecture format, in which the lecture notes are provided in an incomplete form that the students fill in as the lecture progresses. Students made use of all three types of lesson plan formats. One of the projects (Introduction to RNA Secondary Structure) used a hybrid of two lesson plan formats, whereas another project (DNA structure and function) merged three different lesson plan formats.

Student Evaluation of the GESE Course

Course evaluation surveys were administered to students on the last day of class. Fourteen students completed the surveys in class and turned them in anonymously. Two students were absent that day, and one of these students completed the survey later that week and submitted it via intercampus mail. The following are summaries of student answers to some of the survey questions.

What part(s) of the course did you like best and why? This question drew a wide variety of responses. Students liked the sessions on differentiated instruction and learning styles, as stated by one student, "I think it is very important as a foundation for developing lessons and class activities that really facilitate multiple ways to learn." Students appreciated learning about different instructional techniques, such as case studies and the use of computer-based tools. "I felt like I assembled a teacher's 'toolbox,' " stated one student. Class observations were mentioned by five of the students as being their favorite part of the course, because it allowed them to see real-life examples of teachers using the same instructional methods that they learned about in the classroom. "I enjoyed interacting with teachers and getting many different types of input on education/lesson planning." "The classroom observations were very revealing. I really enjoyed doing the observations because it gave authenticity to what we learned in class." Students liked the interactive format of the class discussions, especially the panel discussion on undergraduate teaching. They also noted how Blackboard was used as an assessment tool, so that it was "nice to be able to come in and absorb without an exam looming every week or so."

In What Way(s) Did This Course Meet Your Expectations? Most of the responses to this question indicated that this course provided the graduate students with a good overview of the teaching process, including lesson planning and instructional techniques about which most of them had been unaware. As stated by one student, "I have a much better understanding of the education process. It was an excellent overview of everything!" "It opened my eyes to a lot of the aspects of teaching and what would be required" was another comment. Students indicated that the course provided students with tools that they can use to go beyond lectures. For example, one student stated "If you asked me to design a lesson before this class, I'd have probably just come up with a lecture. That I now think in terms of activities and learning styles is a big plus," whereas another student stated, "I gained insight in how I as a teacher can really teach in a way that facilitates learning." Several students mentioned that this course has now made them feel more confident about teaching. "I feel that I could walk into a classroom and at least have a fair shot at being a successful teacher," stated one student, whereas another declared, "I expected that this would help me decide how I feel about teaching science—it did—I love it!"

In What Way(s) Did You Find This Course Relevant to Your Development as a Graduate Student? Answers to this question revealed the frustration that many students felt about their prior experience in undergraduate and graduate courses, which are often lecture-based and unengaging. As stated by one student, this course "sadly embittered me further on the low quality graduate lectures I've had." Students overwhelmingly agreed that this course was very relevant to their future, despite the lack of importance that some faculty place on preparing graduate students to be future science educators, and "My PI [principal investigator] told me this class was 'self-indulgent' and would be of no use to my career. I feel the opposite. I feel like I am better prepared to become an instructor. I am more aware of the learning styles of my audience." Nine students commented on the need for scientists to develop effective communication skills. "Regardless of whether I decide to teach, I will still need to communicate effectively," commented one student, whereas another student wrote, "Whether speaking to peers or to students, it is important to communicate well in a way that is engaging to one's audiences." As summed up by one student, "We are not trained to think this way when research communication is essential."

Suppose Other Graduate Students Ask You for Information about This Course. What Will You Share with Them? Students indicated that they would share with others the relevance that this course has, especially for graduate students who cannot spend much time away from their research to pursue additional coursework. "It is an excellent opportunity to get their feet wet in education while still maintaining research. It was nice not to have to get a degree in education to gain an understanding." Several students indicated that they thought this course should be taken by all graduate students: "Even if they don't see teaching in their future, it will help them." "I think this should be a required course," said one student, "The course will give [students] exposure to teaching that they otherwise will not get as grad students." "Anyone who wants to be an effective teacher should take this course. It makes you consider things you have never thought of that will make you a better teacher." As aptly stated by another student, "TAKE IT! It will change the way you think about learning and education."

CONCLUSIONS AND PLANS FOR THE FUTURE

The goal of the GESE course is to provide graduate students with a fundamental understanding of the theories of education and the principles and concepts of differentiated instruction that will be relevant to their future careers as educators. We have successfully met this goal by designing and implementing class sessions that include an overview of how students learn, as well as modeling and coaching some practical aspects of science education pedagogy and lesson planning. Through students' final projects and their classroom discussions, online reflections, and written surveys we have collected evidence that this course has been successful in that students have attained an increased knowledge base, they have developed skills in curriculum design, instruction and assessment strategies, and they have developed positive attitudes toward their teaching abilities.

Students' increased knowledge base is evident in their incorporation of vocabulary and concepts presented to them in the course sessions. Students' skill development is apparent in their application and use of these concepts in their final projects. Students are able to apply what they learned in the GESE classroom sessions to designing lessons that use effective, engaging instructional strategies and assessment approaches to meet the needs of learners of varying abilities. Student's use of "assessing prior knowledge" and formative assessments within their lessons provides powerful evidence for change of thinking (and skills). Before this course, we could predict that none of the students would show evidence of either knowing about applying learning theory or differentiated instruction and incorporating these strategies into lessons that reflected these ideas. Now, all of our students understand and can make use of these instructional and assessment strategies.

The increase in students' confidence in their teaching abilities is an unanticipated positive outcome of this course. This attitude change is something that emerged from the classroom and online discussions and surveys and was not part of our original goals when we developed this course. Students' attitude changes are documented in the online discussions and the comments included in the course evaluation surveys. Students indicated that they gained confidence in their abilities to teach because we prepared them with a "toolbox" of skills, from curriculum development to instruction to assessment.

The year-end course evaluation surveys ask students questions that have helped to guide our program's improvement. This formative feedback has been used to shape course changes as the course has been modified from 2005 through 2007. For example, the initial 2005 course had more of a focus on secondary education (because the expertise of many of the 2005 course presenters is in secondary education) and in preparing graduate students to participate in science outreach programs. On the basis of formative feedback from the surveys and informal discussions with individual students, we began to shift our focus in 2006 to include undergraduate teaching. The 2007 GESE course focused even more of the course sessions and assignments on undergraduate teaching.

On the basis of student feedback, we will make slight modifications to the GESE course to give students more opportunities for practicing their teaching at various time points during the semester. We will also provide students with more experience in writing short lessons using several different instructional methods. Students requested that more time be devoted to lesson planning and other "skills of the trade." Additional changes in the GESE course will include a session about course planning, and students will be provided with more time to practice mini-teaching in small groups in class. We also plan to evaluate one impact of the course by investigating whether final project lessons more reflect students' own precourse ideas and concepts about what constitutes a "good" lesson or whether there is a correlation between our students' learning profiles and the level of the skills that they develop in creating lessons that reflect differentiated instruction.

Several students suggested in their course evaluation surveys that less time be devoted to covering social issues in education (such as diversity and accommodations). We will accomplish this by weaving these topics throughout the semester, rather than devoting three separate 2-h sessions to social issues as we have done in previous years. We will examine areas of disparity in the classroom and introduce students to research-based instructional strategies and resources that they can use to address equity issues and to support student achievement.

Graduate students who want to gain more experience in teaching can participate in semester-long, part-time internships at UR's LSLC. Here they work with LSLC staff to coteach a variety of hands-on learning experiences for secondary students, including laboratory activities in molecular biology, genetics, and microbiology. Each LSLC intern also gains additional experience in lesson planning by creating a "Case Studies in Science" lesson based on her/his own laboratory research and then teaching the lesson at an LSLC workshop for local science teachers. Graduate students participate in LSLC teaching internships with the approval of their faculty research advisor, and this experience requires additional time spent over and above the graduate student's laboratory research. The five LSLC interns during the 2006–2007 school year completed the GESE course, either in 2005 or 2006 (one LSLC intern is a postdoctoral fellow who attended the GESE course when he was a graduate student). Graduates of the GESE course who are currently participating in LSLC internships will colead a future GESE class session that features the case studies they create.

It is hoped that the early development of knowledge and skills about teaching and learning will encourage graduate students to continue their growth as educators throughout their careers. Of the 23 students who enrolled in the GESE course in 2005 and 2006, five have participated in the LSLC teaching internship, and one is currently pursuing a master's degree in education at UR. We are developing a plan to track our students through their graduate school years and after they graduate in order to study the long-term value of the GESE course and whether this course has an effect on graduate students' future career choices.

In the report *Evaluating and Improving Undergraduate Teaching in Science, Technology, Engineering, and Mathematics* (NRC, 2003), the NRC made recommendations about improving undergraduate education in our nation's colleges and universities:

> Teaching effectiveness should be judged by the quality of student learning. Definitions of effective teaching. . . . in the institution should take into account what is known about student learning and academic achievement. Quality teaching and effective learning should be highly ranked institutional priorities. University (and college) leaders should clearly assert high expectations for quality teaching to newly hired and current faculty. . . . [All faculty] should be given opportunities for ongoing professional development in teaching and recognized and rewarded for taking advantage of those opportunities.

It is our expectation that the graduates of the GESE course are better prepared to understand student learning, effective and research-based instructional practices, and quality teaching. The primary goal of GESE is to prepare them in this way before they accept a position that requires them to teach. It is hoped that they will be more knowledgeable about teaching and learning; better skilled to instill in their future students their passions for science, technology, engineering, and mathematics and for teaching these subjects; and do so in way that attracts and retains more young scientists into these fields. Unlike Bower, our students should be able to look back on their teaching and cite the positive effects of their good work with students.

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