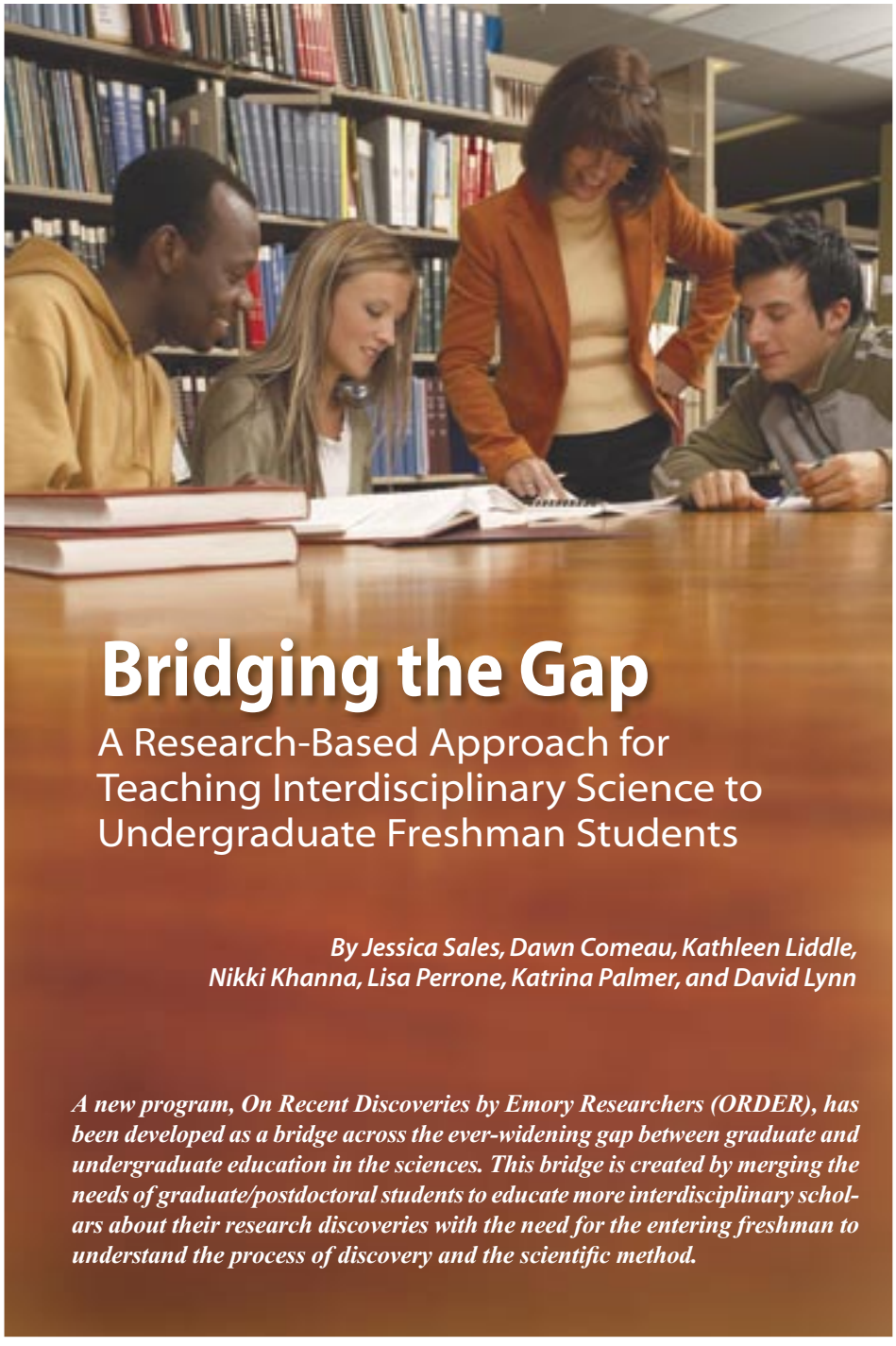

Bridging the Gap

A Research-Based Approach for Teaching Interdisciplinary Science to Undergraduate Freshman Students

By Jessica Sales, Dawn Comeau, Kathleen Liddle, Nikki Khanna, Lisa Perrone, Katrina Palmer, and David Lynn

A new program, On Recent Discoveries by Emory Researchers (ORDER), has been developed as a bridge across the ever-widening gap between graduate and undergraduate education in the sciences. This bridge is created by merging the needs of graduate/postdoctoral students to educate more interdisciplinary scholars about their research discoveries with the need for the entering freshman to understand the process of discovery and the scientific method.

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Many studies published within the past decade evaluating college science teaching have resonated with a common theme: Teach what you practice (Deutch 1994; Dimaculangan et al. 2000; Glasson and McKenzie 1997; Gottfried et al. 1993; Harker 1999; Lawson 1999; Stukus and Lennox 1995; Tolman 1999). This common-sense advice often gets lost in the demands for covering the increasingly voluminous background materials of introductory science courses, and the process of scientific discovery is lost.

Specifically, three common recommendations for changes in college science teaching are: (1) Place an emphasis on science as it is practiced by scientists rather than simply verifying information that is already known (Stukus and Lennox 1995; Lawson 1999; Leonard 1991), (2) Engage students in the design and conduct of scientific research that promotes independent learning and critical thinking (Tolman 1999; Dimaculangan et al. 2000), and (3) Increase emphasis on the students' ability to effectively present and communicate scientific information.

Related to these recommendations, Gottfried and colleagues (1993) suggest that college science instruction should demonstrate the nature of science by specifically introducing students to the processes and methods of scientific discovery. As a means to develop critical-thinking skills and facilitate understanding of science, students should formulate and test hypotheses, design experiments, develop research plans, control variables, and communicate scientific ideas. In response to these suggestions and with initial funding provided by the Howard Hughes Medical Institute, Emory College, and the Emory School of Medicine, we introduced a program entitled On Recent Discoveries by Emory Researchers (ORDER).

The ORDER class was offered as a freshman seminar. Freshman seminars fulfill a general education

requirement for all students at Emory University and were designed to expose entering students to faculty interests at the beginning of their academic career. Approximately 40 freshman seminars are offered each semester from departments across the university. Our intent with ORDER was to: (1) expose undergraduates immediately to disciplines widely dispersed across the natural sciences, (2) employ graduate/postdoctoral student instructors—a central intellectual resource available at research universities—to bridge the generational and intellectual gap between undergraduates and faculty (see Sales et al., Forthcoming, for a description of how the program benefited the graduate student teacher-scholars), and (3) use recent discoveries and the framework of the research process to stimulate thinking and learning about science.

We felt it appropriate and important to inform students as early as possible in their college academic careers about the range of scientific opportunities available in a research university. Accordingly, ORDER was team-taught by a group of graduate and postdoctoral students—near-peer mentors—from across the natural sciences, each presenting their recent discoveries in a three-week module format during the semester. The interdisciplinary nature of this teaching collaboration exposed the undergraduates to the diversity of new and exciting research discoveries being made at a research university, all unified through the common underlying theme of the discovery process. The focus on research has the potential to be an immediate and timely vehicle for experiencing scientific discovery, evaluating and comprehending research findings, and critically assessing the impact of new information, all through the eyes of a near-peer mentor and the actual discoverer.

Program details

The ORDER experiment required the convergence of several different elements. An announcement to the natural science departments netted 76 applicants from which 10 teacher-scholars were selected by a college-wide committee composed of students, faculty, and administrative representatives in the spring of 2003 (see Sales et al., Forthcoming, for details of the selection process and for findings on how the program impacted the teacher-scholars). The teacher-scholars were divided into two separate classes of five, and both courses were optimized for diversity in their academic coverage. Section 1, entitled Choose Your Own Adventure, was designed and taught by teacher-scholars with primary intellectual interests in psychology, chemistry/public health, physics, developmental biology, and molecular genetics. Section 2, entitled Size Does Matter, was designed and taught by teacher-scholars with intellectual interests in pharmacology, pathology, psychology, inorganic chemistry, and chemical biology. See Table 1 for more specific information about the two sections of ORDER.

Over the summer, the teacher-scholars were challenged to identify unique features of their research discovery and their discipline that would generalize and unify across the larger intellectual community. The themes that emerged were central to the scientific method: how to identify and focus a scientific question, how to develop and implement an experiment, how to determine controls for possible confounding variables, and how to realistically access the results. In addition, the teacher-scholars worked together to identify analogies and metaphors that would facilitate explaining their discoveries to entering freshmen. These in-class exercises ranged from diagnosing the main character in the movie *Memento* to understand short-term memory, to taking a field trip to the Yerkes National Primate Research Center to observe stress in primate behavior, and from building a scale-accurate model of muscle out of bungee cords to designing experiments to determine if *solid* or *liquid* best describes shaving cream, ketchup, and peanut butter. To view the syllabi for both sections visit *www.cfkeep.org/HHMI*.

In addition to learning about the research conducted by graduate/postdoctoral students at Emory, the undergraduates in both classes were

TABLE 1

The teacher-scholars and their teaching module titles for ORDER

Teacher-scholar	Program of study	Module title
Class 1: Choose Your Own Adventure (in Science)		
Jason Davis	Psychology	How do monkeys deal with stress?
Piotr Habdas	Physics	What do peanut butter, Silly Putty, sand, and shaving cream have in common?
Steven Girardot	Chemistry/Public health	How does air pollution affect pulmonary health?
Brenda Minesinger	Genetics	How can fungus help in our understanding of cancer development?
Christine Schaner	Developmental biology	How can worm stem cells help to heal human distress?
Class 2: Size Does Matter		
Kris Bough	Pharmacology	Diet and epilepsy
Denise Flaherty	Pathology	Why worms?
Wade Neiwert	Inorganic chemistry	Chemical warfare and POMs
Lisa Rattiner	Psychology	Learning and memory
Kenneth Walsh	Chemical biology	Origins of life

TABLE 2

Sample proposals from the students in the spring 2004 ORDER classes

Titles of students' proposals
Choose Your Own Adventure:
Playing surfaces and the risk of injury
The best time of day for creatine supplementation
Effects of Atkins' diet on type I diabetes
Autistic children: Perfecting learning environments
Real-world wireless fidelity performance
Oxygen levels: Natural suppressor of "sickling" in sickle-cell anemia
Quality of healthcare and appearance
Size Does Matter:
Drowsiness: Roxicet vs. Tylenol with codeine
The dimple effect: Better dimples make a better golf ball
The effects of sleep deprivation on generalized anxiety disorder and panic disorder
Fear and euphoria: Is there a difference?
The effect of lung conditioning exercise on improving the respiratory tracts of asthma sufferers
Effect of shark and bovine cartilage protein on cancerous tumor cells
Can exercise provide therapeutic benefit to myopic vision?

asked to "choose their own adventure in science" by writing a 10-page scientific proposal as a final project for the course. They were not asked to perform the experiments, but to pose a question that was of interest to them, develop the question into a testable hypothesis, and identify the methods and controls necessary for the experiment. We required that students place their questions in the larger context of the course and present their overall proposal orally to their class during the final exam period. The teacher-scholars served as both role models and mentors throughout the process; facilitated access to institutional resources, electronic databases, and library resources; and introduced students to experts across the campus.

Each course was offered in both the fall of 2003 and spring of 2004, meeting twice a week for 75 minutes. Over the course of the semesters, each teacher-scholar independently taught a research module over the span of five class sessions, relying on a variety of methods to make each module hands-on and interactive. Two introductory periods each semester were used to introduce the personal story of each of the teacher-scholars, establish the overarching research theme, and lay out the course structure. One day was also reserved mid-semester to allow students the opportunity to explain their proposals to their classmates. The class was divided into small groups of four to five students, where each student was then given four minutes to explain his or her basic idea and receive feedback from the other students. After all students presented to their small group, the groups were redistributed for two more rounds of presenting ideas, and receiving and giving feedback. Each teacher-scholar also selected three to four students to mentor throughout the semester. The final written proposals were due prior to the end of the semester and the oral defense of each proposal occurred during the three-hour final examination period. See Table 2 for sample proposal titles from ORDER students.

Goals of the study

The goals of this study were to determine whether ORDER impacted undergraduates' (1) ability to think critically about science and research, (2) ease and confidence in communicating scientific information and formulating research questions, and (3) interest in pursuing a greater research focus in their future coursework. Most importantly, we wanted to examine if ORDER was able to stimulate undergraduate interest in research in a way that would complement traditional science course formats. In our attempt to measure the success of ORDER in achieving these goals, we surveyed undergraduates after completing the course on several issues related to science and their future plans. In addition, we administered the same survey to undergraduates who had completed a required General Chemistry course as a comparison group.

Method

Participants

At the end of the spring 2004 semester, the ORDER students and General Chemistry students (both courses that fulfilled requirements of the university, and were open to all majors) were asked to voluntarily complete a survey regarding their knowledge of and experience with science and research. The University's Institutional Review Board (IRB) approved the survey. Neutral individuals who were appointed to evaluate the efficacy of the ORDER program administered the surveys, handled all the data, and also re-

TABLE 3

Descriptive summary of class composition by course type

	Gender		Prior exposure to research		Enjoy science *	
	% males	% females	% yes	% no	mean	SD
ORDER	62.1	32.9	13.3	87.7	4.60	.93
Chemistry	42.3	57.7	22.2	77.8	4.54	1.21

* Enjoyment of science was assessed on a six-point Likert scale, with 1 meaning not at all and 6 meaning a great deal.

Note: Chi-square tests were used to determine if there were statistically significant differences between courses in gender and prior exposure to research. One-way ANOVA test was conducted to determine if a statistically significant difference existed between courses in regards to overall enjoyment of science.

The open-ended questions addressed their reason for enrolling in the course, the perceived roles of faculty and graduate students in universities, the aspects of science that interested them most and least, and their future course plans and career aspirations after taking the course.

moved all identifying information from the surveys before any of the ORDER or General Chemistry instructors examined the responses. Thirty of the 31 students enrolled in the two ORDER courses and 27 students from the General Chemistry course completed the survey.

Survey and coding

The survey contained open-ended and multiple-choice questions. The multiple-choice questions of interest for this study addressed the students' enjoyment of science, prior exposure to research, and perceived improvement in various science-related skills. Specifically, students were asked, "How much do you think you improved in the following areas this semester?" and perception of improvement was measured in the following areas: (1) communicating scientific ideas, (2) formulating research questions, (3) developing a research plan, (4) receiving feedback from peers, (5) giving feedback to peers, (6) understanding scientific writing, (7) working collaboratively with others, (8) presenting information, and (9) analyzing data. The level of improvement in these nine areas was measured on a five-point Likert scale, with 1 indicating no improvement and 5 indicating greatest improvement.

The open-ended questions addressed their reason for enrolling in the course, the perceived roles of faculty and graduate students in universities, the aspects of science that interested them most and least, and their future course plans and career aspirations after taking the course. Two questions on the surveys specifically examined the impact of the ORDER program on undergraduates' thinking about science and future plans. The questions were: (1) What do you enjoy most about science? and (2) How, if at all, has this course changed the courses you plan to take at Emory?

To extrapolate common themes and general information from the open-ended survey responses, two independent coders read through all responses to gain a general familiarity prior to systematically assessing themes/common responses for each question. An iterative process of incorporating emergent themes was employed, followed by clustering these themes in logical groupings, and then summarizing in text the patterns that emerged.

Results

Given the possible selection bias of students who chose an ORDER class as a freshman seminar, we first explored, to the extent possible, whether the students who enrolled in ORDER were different from the students in General Chemistry. We found no difference in terms of gender, prior exposure/experience with research, or overall enjoyment/interest in science (see Table 3 for descriptive statistics by class type).

To examine the impact of ORDER on increasing students' science-related skills, a series of Mann-Whitney tests were conducted to explore differences between the ORDER and the General Chemistry control students' perceived improvement on nine science-related skills (understanding scientific writing, communicating scientific ideas, formulating a research question, developing a research plan, analyzing data, giving feedback, receiving feedback from peers, working collaboratively with others, and presenting information). Students in the ORDER courses showed significantly higher levels of improvement in six of the nine skills assessed, with one area showing a trend in level of improvement in favor of the ORDER students, and no difference in the level of improvement in the two remaining skills (see Figures 1–9 with the online version of this article at *www.nsta.org/college*).

Next, the responses to the two open-ended questions of interest were examined. Students' responses are descriptively summarized below, separately for each question.

What do you enjoy most about science?

Both the ORDER and General Chemistry students were asked what they enjoyed most about science. The majority of the ORDER students

(70%) stated that they enjoyed the process of scientific discovery and the "hands-on nature" of research. Specifically, one ORDER student remarked, "I love that science explains unknown things. This course has taught me to ask my own questions and try to explain my own answers." Another enjoyed "being able to take one thing I've learned and apply it to something else, and being able to deductively uncover the nature of a problem." One student said, "I enjoy doing experiments because I like hands-on learning" and went on to say that this was a more effective strategy than simply copying down notes and reviewing PowerPoint presentations. The remaining students stressed their enjoyment of the real-life applications of science. A common theme that emerged in these responses was that relating science to everyday life made it more enjoyable and interesting.

The General Chemistry students' favorite aspects of science were very similar to those of the ORDER students, with the majority stating that they most enjoyed the hands-on nature of science, experimentation, and new research discoveries in science (50%). These individuals particularly emphasized their enjoyment of the lab component of class. The remaining students' responses were divided between enjoying the application of science to everyday life (25%) and the "straightforward, factual nature of science" (25%). Two students explicitly stated that they enjoyed "the definite answers" and "proven facts" presented in class.

In summary, the majority of students from both classes stated that the process and method of scientific inquiry and discovery were the most enjoyable aspects of science. In spite of a common favorite aspect of science, there were qualitative differences in the responses to this question between the students in ORDER versus General Chemistry course. Specifically, ORDER students referenced their *thinking* about science, whereas very few of the General Chemistry students' responses resonated with this same message. Instead, what was communicated in the General Chemistry students' answers was their enjoyment of the laboratory component of the course rather than the lecture component.

How did this course change your future course plans?

Both the ORDER and General Chemistry students were asked about how, if at all, the course had affected their future course plans at the university.

The majority of the ORDER students (61%) stated that the course had not altered their course plans. Two did not specify whether it had altered their course plans, but mentioned, respectively, that research was harder than he or she previously thought, and he or she was now more aware of what could be done with a medical degree other than being a physician. The remainder of the respondents indicated some increase in their interest in science. One stated, "This course has opened my eyes to the world of science. It now fascinates me whereas it bored me before." Another student described being more aware of research opportunities and wanting to "help out in a research lab now that I know some of the laboratories around campus and what they do." One student debated between majoring in economics or biology, and is now leaning toward biology. A number of students specifically mentioned their increased interest in research or how the process of doing a research proposal encouraged them to take more science courses.

In comparison, the majority of General Chemistry students either did not change plans (48%) or did not report whether or not their plans had changed (30%). Of those who did change plans, one decided to minor in chemistry, one decided to major in chemistry, and two are dropping out of the pre-med program. When students did not indicate whether plans had changed, their comments about the course experience were mostly negative. For example, students reported learning that they don't like chemistry and that the course "brought me down."

While the majority of both groups (approximately 70%) did not change their course plans as a result of their particular class, a number of ORDER students had increased interest in science, generally, and research, specifically, after completing the ORDER course. In contrast, none of the General Chemistry students offered responses that indicated an increased desire for science or stimulated interests in research.

Discussion

As recommended in many independent studies published throughout the past decade, we found that employing research as a teaching strategy is highly effective in improving students' perception of their science-related skills and critical-thinking abilities. Additionally, teaching research also proved to be an effective method for increasing students' interest in science and scientific research. This is not surprising in light of student responses to the questions, "What do you enjoy most about science?" Overwhelmingly, they identified the "process of scientific discovery" and the "hands-on nature of research" as their favorite things.

More specifically, we feel that much of the success of ORDER in stimulating students' interest in science and scientific research can be attributed to the interdisciplinary nature of the course. By exposing freshmen to a variety of disciplines and their respective research methodologies and discoveries, we were more likely to ensure that each student would encounter at least one type of science that appealed to him or her. Additionally, by extrapolating a common theme across all disciplines represented in the course,

we were illustrating the underlying and unifying concepts of science in a very tangible way, which is possible, but far more difficult to make central within a traditional, single-discipline course.

Our observations strongly suggest that having graduate/postdoctoral students teach about their own research and scientific discoveries is a critical factor in the success of ORDER for several reasons. Graduate students represent the next level after undergraduate training in the career path of a scientist. Also, having graduate students teach about their own research discoveries while still in the process of their own graduate training provides a very real academic model for undergraduate students, one they feel connected to and capable of pursuing because the models are people with whom they can easily identify. Finally, seeing that graduate students—individuals who were themselves taking undergraduate classes only a few years earlier—are contributing to our scientific knowledge base is both very motivational to the undergraduate students and empowering for the graduate student Teacher-Scholars. For example, Teacher-Scholars reported that teaching in the ORDER program provided them with invaluable teaching experience that, because of the subject matter, allowed them to think more clearly about their own research and its significance to the larger scientific community (see Sales et al., Forthcoming, for a detailed description of the programs benefits for the graduate student teacher-scholars).

For at least these reasons, ORDER was able to successfully increase freshman students' critical-thinking abilities and science-related skills such as formulating research questions and communicating scientific information, and perhaps most importantly, stimulate many of these young students to pursue research-related interests in the future. This course is not, nor is it intended to be, foundational in the traditional sense, providing the bedrock on which a discipline-specific curriculum can be built, but rather it provides a broad interdisciplinary perspective on scientific research that can infuse excitement and breadth into any selected natural or social science educational track. We must now determine if these seeds planted by ORDER do indeed grow and flourish within a four-year college career and beyond. ■

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References

Deutch, C.E. 1994. Restructuring a general microbiology laboratory into an investigative experience. *American Biology Teacher* 56 (5): 294–96.

Dimaculangan, D.D., P.L. Mitchell, W. Rogers, J.M. Schmidt, J.L. Chism, and J.W. Johnston. 2000. A multidimensional approach to teaching biology: Injecting analytical thought into the science process. *Journal of College Science Teaching* 29 (5): 330–36.

Glasson, G.E., and W.L. McKenzie. 1997. Investigative learning in undergraduate freshman biology laboratories: A pilot project at Virginia Tech—new roles for students and teachers in an experimental design laboratory. *Journal of College Science Teaching* 27 (3): 189–93.

Gottfried, S., R. Hoots, R. Creek, R. Tamppari, T. Lord, and R.A. Sines. 1993. College biology teaching: A literature review, recommendations, and a research agenda. *American Biology Teacher* 55 (6): 340–48.

Harker, A.R. 1999. Full application of the scientific method in an undergraduate teaching laboratory: A reality-based approach to experiential student-directed instruction. *Journal of College Science Teaching* 29 (2): 97–100.

Lawson, A.E. 1999. What should students learn about the nature of science and how should we teach it? Apply the "if-and-then-therefore" pattern to develop students' theoretical reasoning abilities in science. *Journal of College Science Teaching* 28 (6): 401–11.

Leonard, W.H. 1991. A recipe for "uncookbooking" laboratory investigations. *Journal of College Science Teaching* 21 (2): 84–87.

Sales, J.M., D.L. Comeau, K. Liddle, L. Perrone, K. Palmer, and D.G. Lynn. Forthcoming. Unifying graduate and undergraduate education: An interdisciplinary undergraduate science course engaging graduate/postdoctoral teacher-scholars. *Journal of College Science Teaching.*

Seago, J.L. 1992. The role of research in undergraduate instruction. *American Biology Teacher* 54 (6): 401–5.

Stukus, P., and J.E. Lennox. 1995. Use of an investigative semester-length laboratory project in an introduction microbiology course: Acquainting students with the research process and the scientific frame of mind. *Journal of College Science Teaching* 25 (2): 135-39.

Tolman, D.A. 1999. A science-in-the-making course for nonscience majors: Reinforcing the scientific method using an inquiry approach. *Journal of College Science Teaching* 29 (1): 41–46.