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Scaffolding the Science: Problem Based Strategies for Teaching Interdisciplinary Undergraduate Research Methods

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Previous research has highlighted the effectiveness of Problem-Based Learning (PBL) in multiple disciplinary settings, including medicine, teacher education, business, allied health, and the social sciences. Yet interdisciplinary educators have very little information about how to implement PBL in classrooms where multiple disciplines are represented. This paper offers practical strategies for the successful implementation of PBL in an interdisciplinary context in which learners have a limited knowledge base. In this paper we will a) highlight challenges to interdisciplinary teaching, b) demonstrate how PBL and traditional teaching techniques can be used in an interdisciplinary context, and c) discuss strategies to engage students in making scientific discoveries of their own.

During the past decade there have been a number of case studies that have examined the effectiveness of Problem-Based Learning (PBL) and other curricula that are called inquiry-based, design-based, challenge-based teaching/learning. While there are some variations in these pedagogies, they are increasingly viewed as "close cousins" with many similar, yet discipline-specific, characteristics that focus on learners developing a mastery of the subject matter through direct engagement with real life problems (Barron & Darlington-Hammond, 2008; Savery, 2006). The effectiveness of these teaching strategies has been shown to be valuable in the development of reasoning skills (Hmelo, 1998), problem solving skills (Gallagher, Stepien, & Rosenthal, 1992), self-directed learning (Hmelo & Lin, 2000), and the preparation for future learning (Schwartz & Martin, 2004) across a wide range of disciplines. For instance, specific case studies show success with medical (Hmelo, 1998), educational psychology (Derry, Hmelo-Silver, Nagarajan, Chernobilsky, & Beitzel, 2006), and MBA (Capon & Kuhn, 2004) students.

These and other studies suggest that the direction of scholarship related to PBL should proceed in the direction of practical and effective classroom strategies that facilitate the scientific practices of questioning, investigation, and argumentation. Recent scholarship about PBL has asked for specific practices that effectively provide "optimal scaffolding, coaching, and modeling strategies for successful facilitation of PBL" (Ravitz, 2009; Strobel & van Barneveld, 2009). Our paper answers this call for practical techniques for using PBL strategies in undergraduate classrooms where learners have a very limited knowledge base about scientific research. Moreover, the paper addresses how we used PBL within an interdisciplinary context in which the four instructors were rooted in different natural and social scientific disciplines.

The Course

The impetus for this course emerged from Professor David Lynn and other Emory University faculty who envisioned a program that would provide freshmen an opportunity to learn how scientists in various fields conduct research and then to inspire these students to do research of their own. The goals of the course were to address gaps in college science teaching by emphasizing the practice of scientific research through the use of an interdisciplinary teaching team who would use their ongoing research projects as the basis for the course content (see Leonard 1991; Stukus 1995; Lawson 1999; Tolman 1999; Dimaculangan 2000). The members of the 2006-2007 cohort of instructors included a seemingly dissimilar group of researchers, including a sociologist, an epidemiologist, an economist, and geneticist (Table 1). The instructors aimed to develop a research methods course that would maintain the integrity of each of their disciplines while simultaneously bridging their diverse research endeavors through the commonalities of scientific inquiry. In this process, we used our own projects to demonstrate practical research while simultaneously allowing students to engage in increasingly complex, problem based research tasks throughout the semester. Through these sequential and cumulative tasks, as well as the necessary supports of instructors who provided modeling, coaching, task structuring, and relevant feedback or engaged questions, students became increasingly accomplished problem solvers and budding researchers. In short, using PBL allowed our interdisciplinary team to bridge our differences and to inspire students to engage in scientific research of their own.

Each instructor had four weeks to teach his/her individual module, in which she/he aimed to convey the essence of how an interest evolves into a research

Table 1
ORDER 2006-2007 Instructors and Modules

Instructor	Discipline	Module Title
Heather Jamerson	Sociologist	Globalizing the Economy: Mapping Production and Consumption
Lyndsey Darrow	Epidemiologist	Air Pollution and Health In Atlanta
David Tan	Economist	The Economic Sociology of Emerging Technologies
Alaine Keebaugh	Geneticist	Human Genome Project: The Technology, the Controversy and Our Future

question and the methods best suited to answer that question. The overarching goals for the course were that students would have a better sense of each individual discipline, see the role of science as unifying divergent scientific disciplines, and understand how to formulate their own research question and most appropriate methods for investigating it. To achieve these goals, the course was also designed to incorporate PBL, whereby the students learn through demonstration (examples) and discovery/exploration, as well as active learning including readings from primary literature, mini-lectures, movie nights, debates, experiments, and computer labs. At the end of the course, each student developed, wrote and shared their work in a final presentation.

One of the unique characteristics about our teaching team is that we share very little overlap in our research interests and agendas. More specifically, we are not interdisciplinary scholars studying a common topic like "water" or "poverty" or "disease." Instead, our areas of research diverge in almost every imaginable direction—including our topics of inquiry and our chosen research methods. For instance, Darrow's research investigates the effect of air pollution in Atlanta on infant mortality and pre-term birth by using an observational research design. Tan's research uses economic modeling to understand how existing patent classifications can restrict technological innovation. Keebaugh's research uses the information generated from multiple genome sequencing endeavors to explore how gene duplication has contributed to species differences and human disease. Lastly, Jamerson's research seeks to understand the mutually constitutive processes of production and consumption within an increasingly globalized society by using a multi-site case study and qualitative methods. From these brief descriptions, one can easily see that we share very little in terms of substantive connections or methodological similarities.

In order to bridge these differences and to provide a scaffold for the course, the instructors met approximately every two weeks during the summer prior to our first semester teaching the course. In this planning stage, each of us were charged with the task of explaining our own research projects to colleagues who did not share a common language, theoretical framework, or disciplinary understanding. However, discussing our own research and our own disciplines was essential to developing a unified framework for the course and deciding how to convey our particular research projects without using the language specialized to our discipline. To discover these connections we needed to know something about the others' disciplines and research. Hence, we spent many of our early meetings trying to locate commonalities and differences in our levels of analysis, research methods, scientific vocabularies, and theories.

Challenges and Successes of Interdisciplinary Teaching

Developing a Meta-language

One of the major challenges of interdisciplinary teaching begins with the fact that each instructor is trained in only one discipline. Therefore, we were immediately faced with the question, "How can we integrate our disciplinary differences into a coherent course?" Over several meetings, we stopped trying to decipher the discipline-specific language in favor of a shared terminology that emphasized commonalities such as independent and dependent variables, unobserved and observed processes, inference and hypothesis testing. In a sense we began to recognize a meta-language – about the scientific process – through which we could communicate about each other's research. This allowed us to construct a course that was integrated by the underlying unity of science that is evident in each of our natural or social scientific disciplines. Take for example, how each of our disciplines maps causal relationships. Epidemiologists use directed acyclic graphs to represent hypotheses about the relationships between variables while economists use comparative static models. Similarly, geneticists use phylogenetic trees to illustrate relationships between genes or species while sociologists might use a theoretical diagram to visually represent causal processes. In the early stages of our planning the specificity of our disciplinary language (e.g., acyclic graph, comparative static models, etc.) masked the more general commonalities among our research processes. However, once we were able to agree upon an overarching methodological terminology the focus of the course became much easier to envision. With this awareness, we decided not to offer the students a mini-session in genomics, epidemiology, sociology, or economics. If we had taken this approach, then our students would have ended up with independent unrelated modules, which would have been essentially crash courses in each of our separate disciplines. Instead, we decided to use our disciplinary differences as our greatest strength—whereby students would be offered a spectrum of disciplinary interests and methodological approaches to ignite their own interests in scientific research. To do this we decided to use a combination of traditional instruction that would provide basic content for freshmen learners and PBL strategies that would offer students the opportunity to develop critical thinking and reasoning skills needed to propose their own research projects.

Implementing PBL in an Interdisciplinary Setting

Minimally structured, exploratory learning (a PBL-like strategy) is appropriate for learners already familiar with a given content area; however, for learners who are novices in a content area, learner guidance is essential. Using the common language of scientific research we sought to create a sense of continuity between the four very distinct modules by first introducing the different disciplines using a “delayed teaching” approach in which we first create a need for, and interest, in information before it is presented. Specifically, we used our own research projects to stimulate interest in a topic and then that used traditional teaching methods, e.g., lectures, to establish a general knowledge base. This approach paved the way for more exploratory, self-guided instruction later in the module (Mergendoller, Maxwell, & Bellisimo, 2006). Furthermore, because PBL inherently positions learning in complex tasks, various scaffolding strategies (e.g., delayed teaching) were often embedded within activities to help students engage in the problem solving processes, articulate their thinking, and reflect on their learning (Quintana et al., 2004). To maintain a sense of continuity, each module contained (a) a similar structure, (b) content overlap, and (c) instructor-student mentoring.

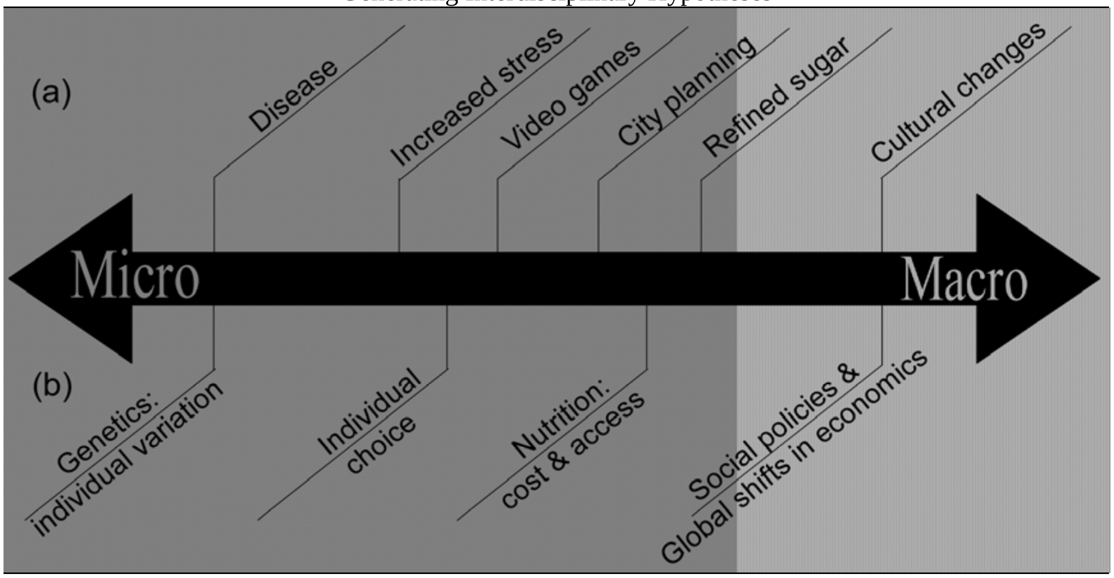
Similar structure for each module. First, by maintaining a similar structure – through a progression from more traditional teaching methods to more sophisticated PBL strategies throughout the semester – for each of the modules we were able to create a sense of continuity between the four very distinct modules. First, each of the four modules started with a basic background of our disciplines, especially given that many freshmen may have never even heard of our field of research. Again, the focus provided less of a crash course in the discipline, but rather it introduced students to the type of research being undertaken in our respective fields. Therefore, in each module students worked in groups with primary research articles to identify important aspects of the study, such as locating the hypothesis, identifying how variables were measured, understanding the control variables, and determining whether the hypothesis was supported by the data. Care was taken to choose an article that would be manageable to freshman. Additionally, the students presented this information to their peers, giving them a chance to clearly explain the research methods being used in the study. Not only did this exercise introduce students to our disciplines, but it also gave them a chance to read research articles and identify various aspects of a research design, and it provided good practice for the end of the semester when they presented their own project proposals.

Second, each instructor used his or her own research to illustrate some aspect of the research process. For instance, during the first module, Jamerson used her own research to introduce the process of transforming broad research interests into a scientific research question and generating a testable hypothesis. Darrow then discussed the relationship between variables and issues related to measurement using epidemiological research. In Tan’s economic module, he demonstrated the use of theory in research by illustrating inference, observable and unobservable variables, and measures. In the last module, Keebaugh used her research to demonstrate how to access genomic sequence databases and how to use the data to accept or reject hypotheses. By the end of the semester, students not only understood the continuity of the scientific process, but they could also identify variations among projects, such as why one researcher might use qualitative methods to answer one research question, while other researchers might use quantitative methods to answer different research questions (See Figure 1).

Third, each module culminated in a class debate or discussion where students could apply what they had learned in the module and make arguments related to ethical issues surrounding our research. The debate topics highlighted how the results of our research could either inform public policy and/or influence human behavior in some way. Not only did this provide continuity across modules, but it also helped students grasp the everyday significance of scientific research in politics, labor markets, medicine, or business innovation.

Content overlap. The most obvious example of content overlap was the fact that the instructors provided a repeated focus on scientific research methods and their relevance for answering questions

Figure 1
Generating Interdisciplinary Hypotheses



Note. Student generated (a) and teacher-scholar generated (b) hypotheses for "What is causing the rise in obesity in the United States?" Hypotheses ranged from the microscopic level of heritability to the macro level of globalization, helping students appreciate that how we recognize a problem will have an impact on how we choose to study the problem—in terms of our level of analysis, our hypotheses, and the methods we choose to use.

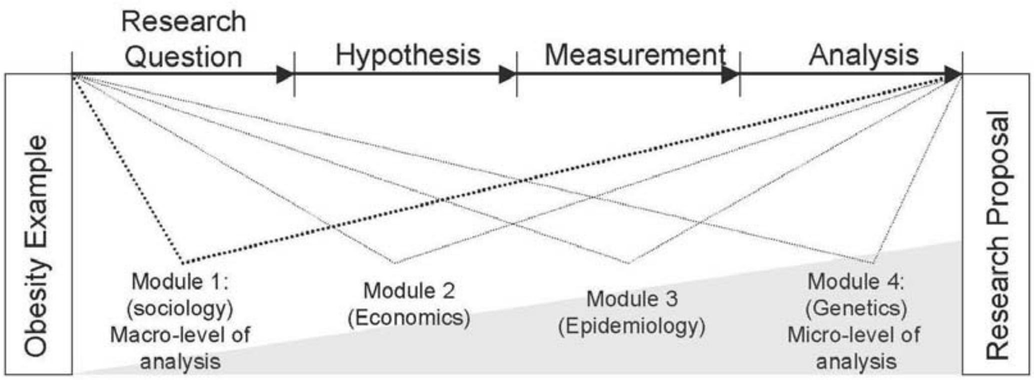
connected with real-life events. As discussed above, one of the primary goals of the course was for students to recognize continuity across various scientific disciplines. Therefore, we each prepared modules that would invoke questions from students about our topic of inquiry. In other words, the instructors engaged students in discussions that would stimulate their own questions and then walked them through the various stages of research that could lead to an answer. Throughout the semester, the level of sophistication of these research designs improved dramatically as students understood the how to generate a testable hypothesis, define variables, consider sampling parameters and discuss measurement issues. Again, we began with traditional instruction, and then PBL strategies facilitated more advanced self-guided learning by providing a foundation of knowledge.

While the course was intended to teach research methods, an underlying objective was to generate student interest in conducting their own scientific research. To do this, we wanted to take advantage of our strengths as a broadly trained teaching team. From early in our planning meetings, one of our strengths became very clear—namely the breadth of knowledge that we all brought to the classroom. For instance, rarely were we able to discuss a topic within popular culture about which we did not have differing knowledge, interests, or interpretations. In most cases our differences were due to the varied levels of analysis on which our disciplines focus. This awareness provided us a springboard from which we could structure the semester. Therefore, the order of our teaching modules was structured from the macro level of analysis (e.g., globalization) at the beginning of the semester to the micro level of analysis (e.g., genetics) at the end. Darrow's research at the population level and Tan's research at the individual level fit nicely in the middle of these two poles.

Research Questions

We wanted students to understand that each of our disciplines might use science to study similar issues differently. Thus we began the course with exercises that are often used in sociology. Employing the formative article, "The Sociological Imagination" written by C. Wright Mill, students were asked to consider a social problem and its causes, ranging from "private troubles" – individual level explanations – to "social problems" – structural level explanations (Mills, 1959). As one example, students were asked to break into small groups and brainstorm about the causes for rising rates of obesity in the United States. This topic made for a great introductory example, not only because of its popularity within the news and popular press, but also because research shows that college age students are concerned with issues related to body image (Striegel-Moore, 1989). Moreover, there are major health consequences associated with obesity – e.g., diabetes, heart disease, strokes, and certain kinds

Figure 2
Scaffolding for Teaching Research Methods



Note. The course was organized into four different disciplinary modules, each focusing on how to approach a real life question (such as the rising rates of obesity) using the scientific method; the modules were organized so that each module was directed at different a level of analysis with the cumulative goal that students would develop the skills needed to ask and answer their own unique questions in the form of a research proposal. To accomplish this goal each module went through the scientific process using discipline-specific theory and expertise. This type of scaffolding provided an environment that allowed the students to engage in this complex task, which would have otherwise been beyond their current abilities.

of cancer – all of which have individual as well as social effects (Brownell 2004). Significantly, obesity in the United States (and other industrialized countries) is on the rise. The Centers for Disease Control found that during the 1970s the obesity rate for adults ages 20-74 years of age in the U.S. was 15%. By 2004 that percentage had jumped to 34% while the rate tripled in children during those same years (www.cdc.gov/nccdphp/dnpa/obesity/index.htm).

Explaining to students that these trends are empirical findings, they were asked, “What is causing the rise in obesity in the United States?” Students came up with many hypotheses that ranged from the microscopic level of heritability to the macro level of the globalization of food systems. In class, we placed these explanations on a visual continuum, showing that this problem spans many levels of analysis (see Figure 2). Once the students had offered their ideas, each of the instructors discussed how his/her discipline might begin to explain and research the problem of obesity. The breadth of our interests and knowledge ranges from the microscopic level of DNA all the way up to global value chains. Thus, in the case of rising obesity rates, each of us in our disciplines ask different questions directed toward different levels of analysis. For instance, a sociologist might ask, "How do state level policies affect the production of particular products (e.g., corn) that contribute to obesity?"; however, an epidemiologist might question the effects of hormonally active compounds (e.g., in meats) on weight gain (i.e., obesity). In a similar way, an economist might focus her/his research on the incentives that influence individual level choices about food, and a geneticist might examine genetic novelties that could cause rising rates of obesity.

Equal in importance to the research questions are the methods we might use to explore our question and hypotheses. In this example, a sociologist might focus on the patterns of subsidies to U.S. corn farmers and determine the major actors who initiate these policies: were they special interest groups, lobbyists, coalitions, politicians, corporations, etc.? To explore the question whose interests are being served by subsidies to corn farmers, the research methods might include tracing historical patterns in subsidies – money spent by state and federal agencies – to corn producers and rising rates of obesity to see if there is a correlation between these variables. Alternatively, an epidemiologist might investigate whether or not the growth hormones injected into livestock – hormones that end up in our dairy and meat products – effect obesity rates. To examine this, one could compare a sample of obese individuals to a group of individuals from the same population who are in the healthy BMI weight range. Methods might include measuring dietary intake and collecting blood samples to directly measure biomarkers of exposure to hormonally active compounds. One could then compare the obese group to those who are within the healthy BMI range to see if the obese group was exposed to more growth hormone than the non-obese group (while controlling for a variety of other factors). This example helped students to appreciate that the way we recognize the problem will have an impact on how we choose to study the problem, in terms of our level of analysis, our hypotheses, and the methods we choose to use. Using this exercise early in the semester allowed us the opportunity to introduce problem-based learning, whereby students were given a problem that stimulates multiple theoretical explanations and methods of investigation. Therefore, this exercise set the precedent for the course, whereby the students were inspired to identify a problem in their lives and develop a research project of their own.

A Real-Life Example

We also used films and other content to provide concrete real life connections across modules. For instance, we showed the movie *Made In China* during the first module on globalization and then revisited the film's content in subsequent modules. This film follows the life-cycle of plastic Mardi Gras beads from their production in a small factory in China to their consumption at Mardi Gras in New Orleans. In the class following the film, students were asked to map the commodity chain starting with the production of beads in China and ending in their consumption in the U.S. The film also offers an opportunity to discuss the rewards and risks along the value chain – e.g., where are wages the highest, where are the biggest risks to the environment or to human health – as well as the culture and structure of consumption in the United States. Not only does the film provide a source for conversation about globalization, but it also humanizes the people associated with the beads, from workers in China to revelers in New Orleans, and it shows how ordinary people are connected to each other through beads exchanged during Mardi Gras. This allowed for a more personal discussion about abstract and distant processes such as globalization, production, and consumption. In the next module, Darrow used the film to discuss the pollution associated with the transportation of the beads from China to the U.S. and the health consequences of polyvinyl chloride (PVC) on human health and the environment. Again, this strategy emphasizes our focus on problem-based learning, since PVC is the most popular plastic used in the United States despite the fact that it has been linked to numerous public health risks such as cancer, birth defects, genetic changes, chronic bronchitis, ulcers, skin diseases, deafness, vision failure, indigestion, and liver dysfunction (www.ecologycenter.org). In the third module, Tan used the film to illustrate economic modeling by creating predictions about the effect of increasing wages to factory workers in China on the production output of the beads. The film provided real-life characters and concrete examples of abstract theory and mathematical modeling that can often be difficult for freshman students. Finally, Keebaugh used the film to discuss the carcinogenic effects of the plastics as an example of tracing genetic mutations in a phylogenetic context. Then, phylogenies were then used to illustrate how the emergence of genetic mutations can be identified and dated in a population.

Given the brevity of each instructional module (five class days), using content presented in previous modules proved to be indispensable for the instructors. For example, Tan used the example of the disparity in lifestyles between the factory owner and factory workers to examine the effects of increased wages on bead production. The students were already connected to the characters, and thus Tan was able to effectively illustrate economic modeling in one class period. Without the movie and previous discussion about the film, Tan would have had to spend precious time setting up the relevance and context and then communicating the content of modeling.

Final Project

The final project was the unifying scaffold that pushed students to articulate their thinking, identify the limits of their knowledge, and design a research plan to expand their knowledge. One of the most challenging and rewarding portions of the course involved the final project, in which the students developed their own research proposal on a topic of interest to them. The written proposal and the class presentation made up over 50 percent of each student's grade for the course, so we began working on the project during the first week of the semester and continued to build upon it throughout all of the modules. The overall purpose of this project was twofold. First, we wanted to evoke a sense of curiosity, creativity, and critical thinking that are the essence of valuable research. Second, we sought to empower students with the skills, knowledge, and confidence necessary to embark upon scientific research on their own. The assignment included all of the major sections found in scientific proposals, including a clearly stated research question, defined independent and dependent variables, a literature review that included at least five scholarly citations, a testable hypothesis, sampling criteria, methods for data collection, controls, and a brief section on contributions to the scientific community and society as a whole (we omitted the requirement for specific types of analysis).

The topics of inquiry needed to have some relevance to the students so that they would have an intrinsic motivation to stay engaged with the project. For instance, the instructors encouraged students to identify a problem that they faced in their everyday lives at Emory, such as racial segregation on campus, increased risk of STD's among college students, alcohol consumption within fraternities, and the dangers of weight loss supplements. By exploring their own real-world problem, students were given ownership of the learning process and thus were motivated to engage in a research process that would provide them answers (Savery, 1995). After students were given ownership of their question, our goal was to provide them the “instructional scaffolding” necessary to succeed (Chin, 2006; Guzdial, 1994; Linn, Davis, & Bell, 2004; Reiser et al., 2001). Therefore, we offered them a range of structure and tools to support the development of problem solving skills, including structured deadlines, collaborative workshops and mentoring.

Aspects of Support

First, the syllabus outlined dates when various sections of the project were due, and these dates corresponded with the information covered in each of the modules. For instance, during the first module students were introduced to the process of transforming a broad research interest into a feasible research question. This instruction corresponded with assignments to brainstorm about their interests, to narrow their interests down to one area of focus, and then to develop a research question that included a clear dependent and independent variable. Similarly, other assignments related to their project were due immediately following methods instruction contained in each of the modules.

Second, throughout the semester we scheduled “workshop” days that complemented their research project development. For example, early in the semester the instructors coordinated with the Emory library staff to assist students in using library and web-based resources to look up scientific articles to use in their literature review. Next, we scheduled a day when students were divided into small groups in which they presented drafts of their research designs to an instructor and several peers. These sessions were invaluable as students got feedback on various aspects of their design while they also offered their insight to others working through similar research-related issues. This technique also corresponds with the collaborative nature of the sciences and the necessity of peer review and the exchange of new ideas from across disciplines.

Third, an instructor was randomly assigned to mentor each student throughout the course of the semester. While each student was required to meet with his/her mentor at least once, most students met with their mentor many times to gain assistance throughout the process of developing their research question and design. The assignment of mentors to students allowed for the easy transition from teacher as expert to facilitator of learning (Ertmer 2006). Not surprisingly, students had a difficult time narrowing down their question to a testable hypothesis and then identifying the appropriate methods to explore it, so one-on-one mentoring helped students work through these difficulties. Again, one of our greatest strengths as a teaching team was our divergent interests, skills, and experience conducting research of our own. Therefore, even though we were randomly assigned students before they decided on their research interests, we were able to gain assistance from other instructors for particular issues related to student topics. For instance, when a student wanted to research social scientific questions on religion, politics, race relations, etc., the student could get assistance from the social scientists as well as his/her mentor in the natural sciences, and vice versa. As mentors we also guided students to appropriate graduate students, postdoctoral fellows, and Emory faculty members in a variety of disciplines who facilitated further development of their theories and research methods; this also gave them experience communicating with other researchers about science and the process of their own discoveries.

Conclusion

Interdisciplinary teaching poses a unique set of problems for educators. Not only do we have to learn how to speak more clearly to each other as scholars, we also have to develop a coherent set of ideas and teaching strategies to facilitate communication with undergraduate students who have very little understanding of the disciplinary divides that can confine us as teachers and researchers. While this certainly can present challenges, it also opens up a range of intellectual and pedagogical possibilities not available to us when we remain within our discipline-specific categories of knowledge and interactions. Our teaching team was able to offer a course that exposed undergraduate students to four different scientific disciplines, introduced basic research methods and design, inspired students to ask questions about their everyday world, and provided the skills for them to develop a research proposal of their own. The seminar was successful in engaging students in the process of scientific discovery, as evidenced by their final research proposal and their own initiative to undertake their research projects beyond the semester’s end. Several students have joined the staff of the *Emory Undergraduate Research Journal*, which offers a forum for undergraduate researchers to publish their findings for the larger Emory community (www.eurj.com)

A key aspect in the successful implementation of our course was using a combination of instructional strategies. Employing the key pedagogies of both traditional and PBL instruction was significant in that it allowed students to develop a knowledge base that spanned disciplinary boundaries and was sufficient to foster self-directed inquiry. Furthermore, it allowed us, the instructors, to capitalize upon the theoretical and methodological strengths of our disciplinary differences while also engaging students in real-life issues. We also found that the incorporation of scaffolding strategies (e.g., debate/discussion, mentoring, and mini-lectures) was essential in that it reduced the initial cognitive load on the students, allowing them to engage in more complex tasks that would have otherwise been beyond their current abilities.

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