Scientific principles of education research: Experimental Biology 2007

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In 2002, the Committee on Scientific Principles of Education Research of the National Research Council (NRC) revisited long-standing ideas about the nature of science, so as to place them in the context of modern education research. Their report, Scientific Research in Education (3), investigated “scientifically based” education research to be used for improving education policy and practice. The report showed that while researchers may disagree about philosophical or methodological approaches to education research, they readily agree about the definition and pursuit of good quality education research (3). Research designs were categorized as quantitative versus qualitative, depending on the type of data collected. There were also categorizations of experimental versus observational, depending on the study design and the investigators’ ability to draw conclusions about cause and effect. This featured topic sponsored by the American Physiological Society Teaching Section was designed to host Drs. Margaret Eisenhart and Robert DeHaan, members of the NRC committees and experts in the field of educational research. Their talks were complemented by selected educational research abstracts submitted to the Experimental Biology meeting in Washington, DC, in 2007.

Experimental and Nonexperimental Approaches to Scientific Research in Education

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Dr. Eisenhart began by describing the short history of including a definition of “scientific research” within federal legislation regarding education. The first time such a definition appeared was in the United States Reading Excellence Act to reauthorize K–12 reading programs in 1998; the Act required that federally supported reading programs must be based on “scientific research.” The definition of “scientific research” included in the law was “scientifically based” research to consist of causal, experimental studies and scientifically based qualitative research to consist of traditions of inquiry, historically based in the humanities, that can also be assessed experimentally for validity and reliability.” Subsequently, The No Child Left Behind Act and the Education Sciences Reform Act, both in 2001, confirmed that scientifically based research was needed to justify federal support for education programs. The NRC convened its Committee on Scientific Principles of Education Research in 2000 to bring the perspectives of education researchers to bear on the following question: What is scientifically based research in education? The committee’s general findings were that scientific research depends on using systematic methods of data analysis (both quantitative and qualitative) that are appropriate for the question being asked, that delineate how the evidence is collected and interpreted, and that can be scrutinized by others. In their final report, Scientific Research in Education (3), six criteria were specified for scientifically based education research: 1) pose significant questions that can be investigated empirically; 2) link investigations to relevant theory; 3) use methods that permit direct investigation of research questions; 4) provide an explicit and coherent chain of reasoning for decisions and conclusions; 5) replicate and generalize, when appropriate; and 6) publish to encourage professional scrutiny and debate. Subsequently, in 2006, the American Educational Research Association (AERA) published its Standards for Reporting on Empirical Social Science Research in AERA Publications (1). This publication builds on and elaborates the standards specified in Scientific Research in Education.

Graduate Instruction for Scientifically Based Education Research

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Dr. DeHaan discussed strategies for training future faculty members to implement the criteria listed above in their scientifically based research. Doctoral students need contextual knowing (including problem-solving skills and expert level modes of reasoning), access to the knowledge of their field (including the culture of investigation and the language of experimentation), and enculturation and enhanced scientific literacy (including training in both quantitative and qualitative research techniques in the context of ongoing research). To help doctoral students become researchers, science fields offer journal clubs, advanced seminars, and ongoing investigation under supervision by a more senior investigator. Supervisors offer physical facilities including equipment and funding and mentoring including advice, encouragement, technical, and professional expertise. In return, advisors expect that doctoral students will develop and show a commitment to scholarship, accept the mentoring relationship with the advisor and others for help with their future career choices, and endeavor to increase their capacities for research independence and creativity. Such training and mentoring programs apply equally to scientifically based bench research and to scientifically based education research. An effective way to engage students and recruit them into research careers is to offer opportunities for undergraduate research experiences as well as inquiry-based learning in undergraduate science courses, undergraduate seminars, and journal clubs. All of these experiences serve to enculturate students into the “culture of science” and are vital for adequate training of future faculty members who will be involved in scientifically based research.
E-Learning Support of Research-Led Learning in Physiology Practicals

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The Boyer Commission report in 1998 on Educating Undergraduates in the Research University stated that advantages of being a research university should be incorporated throughout all aspects of teaching (6). Thus, faculty members in the Department of Physiology at the University of Melbourne have been focusing their curriculum change on student-centered activities that represent research-led learning. They developed a plan to introduce science students to research-led learning during their second year and enhance the experience during their third year with the student outcome being a good knowledge base in the professional area with the addition of many generic and core scientific skills. Graduates of this program have experience in the philosophy and methodology of research, develop teamwork skills, participate in peer reviewing, and practice decision making based on scientific evidence. During the second-year course in physiology, students participate in 3 h/wk of practical classes or workshop discussions and 1 h/wk of active lectures in addition to using online e-learning activities to enhance and support their experience. During the first semester of the course, they learn experimental design for research projects and various practical physiology and investigative skills. During the second semester, they apply their experimental design skills by designing, executing, analyzing, and reporting on their group project and writing a manuscript in the style of a Journal of Physiology article. To help develop critical thinking skills in the students, faculty members use an audience response system during the active lectures. In addition, extensive involvement in e-learning activities throughout the course includes reminders of deadlines, submission of all work for review, and prelaboratory activities to develop and interpret physiological concepts (i.e., blood pressure and ECG, etc.) with automatic feedback or tutor’s electronic feedback on appropriate answers. The e-learning component offers a variety of learning styles and modules for the students to address misconceptions that they might have prior to the laboratory experience. For the experimental design of their group project, e-learning helps with checklists for designing research projects, modules on the ethics of research, and opportunities for feedback from the tutors and their peers. Early data collected from the students in the second-year courses showed both enhanced student interest and engagement in the courses and enhanced student performance on written reports and exams. Faculty members involved in the new Science and Biomedicine curricula at the University of Melbourne are planning on implementing these techniques more broadly and are seeking better authentic assessment tools to evaluate the research-led learning curricula both during and after the curricular changes.

Having Students Design and Develop Laboratory Exercises Improves Student Learning Outcomes in Undergraduate Physiology

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Dr. Rodenbaugh and his students tested the hypothesis that students creating undergraduate physiology exercises would have increased comprehension and retention compared with students performing laboratory exercises created by the students. Four students were the research students who created the inquiry-based spirometry and ECG laboratory activities for the students in a physiology class of 17 students. All 21 students took pre- and postactivity quizzes with basic, intermediate, and difficult quiz questions. Research students took the postactivity quiz 3 mo after completing the project, whereas physiology class students took the postactivity quiz 1 wk after completing the 4-wk laboratory activities, which included inquiry-based experiments with spirometry and ECG, written individual laboratory reports, and group presentations. The research students had significantly improved overall knowledge and retention for the advanced conceptual information on the postactivity quizzes. The experiment described in this presentation provides an alternative active learning process where generating physiology laboratory exercises to be used by other students improved knowledge and retention. In addition, having the students participate in pedagogical research can supplement and enhance traditional “bench top” research at undergraduate institutions via the application of the scientific method to educational activities.

Undergraduate Science Labs: Developing a Vision for the 21st Century: Are Physiology Labs Necessary or Sufficient?

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The NRC formed the Committee on High School Science Laboratories: Role and Vision and charged it to review the status and future directions for the role of high school science laboratories. The findings of the committee showed a lack of agreement on how to define high school science laboratories and a lack of consensus on the goals of laboratory experiences. The committee’s work was published in America’s Lab Report: Investigations in High School Science in 2005 (4). Dr. Pelaez was a member of the committee. Dr. Pelaez began with an historical review of the role of laboratories in learning going back to the efforts of the Royal Society of London from 1640 to 1840 up to the National Science Foundation (NSF), reporting in 2004 a “troubling decline” in the number of United States citizens training to become scientists at a time when many existing scientists will retire. The committee defined “laboratory” as “laboratory experiences provide opportunities for students to interact directly with the material world (or with data drawn from the material world), using the tools, data collection techniques, models, and theories of science.” Thus, the goals of laboratory experiences could include the following: mastery of subject matter, developing scientific reasoning, understanding the complexity and ambiguity of empirical work, developing practical skills, understanding the nature of science, interest in science and science learning, and developing teamwork abilities. Unfortunately, numerous current laboratory experiences are focused on procedures and not learning outcomes, are isolated from the flow of the science instruction, do not integrate learning of science content and processes, and provide few opportunities to the students for reflection and discussion. And, unfortunately, students in lower-level science classes in high-minority schools spend less time in laboratories than other students. Will our undergraduate physiology laboratories be necessary and sufficient for training future scientists? The hypothesis that needs to be tested by physiology educators is as follows: “Will undergraduate students who complete a laboratory component of their physiology class report better knowledge, experience, and confidence with practical laboratory skills, scientific reasoning, subject matter mas-
tery, and science teamwork skill than their peers who do not
take a physiology laboratory?” These research interests will
mesh nicely into the mission of the Division of Undergraduate
Education at the NSF (“to promote excellence in undergraduate
science, technology, engineering, and mathematics education for
all students”) and its programs to provide evidence from scientif-
ically based education research to approach the mission. Thus, the
NSF is developing a project on “Vision and Change in Under-
graduate Education: a View for the 21st Century” and will be
asking for input from leading scientists and biology educators.

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