Rapprochement Among Undergraduate Psychology, Science, Mathematics, Engineering, and Technology Education

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A discourse originating at liberal arts colleges has begun to influence national policy for science, mathematics, engineering, and technology education. The discovery-oriented, research-rich curriculum traditional for the graduate student is being developed for wider implementation in the service of new national goals. Though largely absent as a participant, the discipline of psychology has a great deal to contribute to and gain from joining in this agenda. The content of our field has many direct applications to the issues under consideration. We have common interests as a scientific field in developing science education. And, interdisciplinary and interinstitutional cooperation would be invigorating and constructive for our science, for our scholarship, and for our students. Psychologists should be proactive, not passive or reactive, in the improvement of undergraduate science education. This article presents both an invitation and an argument for fostering a new scientific and educational rapprochement.

Most psychologists are aware of the ongoing discussions at universities that have resulted in highly successful graduate programs to train future psychological scientists and practitioners and that, at colleges, have produced very fine programs to prepare future graduate students. These programs have received strong support in their activities through national forums such as the Council of Graduate Departments of Psychology and the Council of Undergraduate Psychology Programs. In all sciences, conversations about curriculum and pedagogy in higher education are common within academic departments at the institutional level and within academic disciplines at the national level. However, these discussions have begun crossing boundaries between fields. Psychology has been relatively unaware and uninvolved in a growing interdisciplinary conversation regarding science education, which has many implications for our own activities.

New questions are being asked about the goals of higher education in the sciences. Addressing these questions has led to a focus on research-rich, discovery-oriented curricula and undergraduate research experiences. The discussion originated among physical and life scientists at the liberal arts colleges. However, many of the issues have a specific relationship to the disciplinary content of psychology, and psychologists have much to contribute and should be active collaborators in this project. Further, the successes of both research universities and liberal arts colleges suggest that psychology as a field has much to gain from investigating stronger collaboration between teaching and research institutions and wider implementation of programs that work.

In this article, three points are made supporting closer integration of higher education in science and psychology. First, it is apparent that the scientific traditions of the liberal arts college and the research university complement each other. As science education changes to meet new demands, we will need more explicit integration and communication of successes and failures between these institutions and their component disciplinary departments. Second, as a discipline, psychology is in a much stronger position than ever before to make substantive empirical and methodological contributions regarding the acquisition of knowledge and abilities. We should be actively participating, not merely standing by as a passive resource. Third, as a science itself, the field of psychology will be influenced by science education pedagogy and policy. We have a vested interest and a common cause in how science is taught and implemented, but we are not sufficiently engaged in making alliances with other science educators and practitioners.

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Author's note. To learn more about the organizations supporting undergraduate science education, contact Project Kaleidoscope, Independent Colleges Office, Suite 803, 1730 Rhode Island Avenue, NW, Washington, DC 20036, (202) 232-1300, http://www.pkal.org. Or contact Council on Undergraduate Research, 734 15th Street, NW, Suite 550, Washington, DC 20005, (202)783-4810, http://www.cur.org.

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Photo by William Wade.

The Foundation for Cooperation

Science education in the United States has been under critical examination almost continuously during the past 50 years. However, that examination has had at least three peaks. Issues of science education became particularly significant after the launch of Sputnik during the cold war, with the search for relevance during the period of student activism and with the changes in student demography during the early 1980s. In each case, psychological knowledge was called on to assist the nation's science education system, especially in the area of selection testing and mental abilities theory (Carey, 1986; Resnick, 1983).

It was during the last peak of attention that the foundations for the current reevaluation were laid. A series of demographic studies, culminating with "A Nation at Risk" (National Commission on Excellence in Education, 1983), suggested that the scientific "pipeline" from K–12 through graduate studies was not producing enough scientists, mathematicians, and skilled citizens to fill the needs of a technological future. In response, the science, mathematics, engineering, and technology (hereafter referred to as "science") education community organized itself to update curriculum, laboratories, and opportunities in face of a "more-with-less" environment. However, the expected failures of the pipeline and demand for science faculty in the 1990s would not materialize.

The need for yet another cycle of reform was anticipated as soon afterward as the Neal Report of the National Science Board in 1986 (National Science Foundation [NSF], 1996). During the next decade the lack of jobs in academic science became acute. The end of the cold war resulted in a general decrease of public interest in science. And, possibly of most importance, the system of science education based on "skimming the cream" with successively more rigorous and difficult learning environments was discovered to be inadequate for an evolving society. It was plain that an elite cadre of scientists formed by "natural selection" would no longer be able to meet the goals of new generations.

Major presidential policy addresses of the past two years have again made education a special focus of our national agenda. Pointing to the increasingly technological world, the urgent environmental and health crises, the highly competitive international market in business and industry, and the need of all U.S. citizens for postsecondary educational opportunity, President Clinton placed a challenge before the science education community. As before, this challenge draws on the psychological community for expertise. However, the previous reform efforts admittedly did not have the best records for interpreting and adapting psychological knowledge to educational ends. This time psychologists must be more directly involved with science educators and education policymakers in defining and developing successful programs.

Defining Successful Science Education

The introductory paragraph from the report of the National Research Council (NRC), "From Analysis to Action," clearly indicates the central function of the college science experience in reaching national goals.

> Undergraduate education in science, mathematics, engineering, and technology is a critical determinant of our national future. The undergraduate years are a springboard to advanced education for students who choose to major and then pursue graduate work in science, mathematics, and engineering—students who will help create the world in which we all live. The undergraduate years are the last opportunity for rigorous academic study of these subjects by many of the future leaders of our society—the executives, government officers, lawyers, clergy, journalists, and others who will have to make momentous decisions that involve science and technology. Colleges and universities prepare the elementary and secondary teachers who impart lifelong knowledge and attitudes about science and technology to their students. And undergraduate institutions help train many of the technical support personnel who will keep our technological society functioning smoothly in the years to come. (NRC, 1996, p. 1)

Of course, there is a need for " 'a simultaneous renewal' of higher education and the nation's K–12 schools as one continuous learning system" (The Wingspread Group on Higher Education, 1993, p. 11). But, in preparing students both for teaching science in K–12 and for graduate study and science careers, the undergraduate experience is key to this renewal. It is also clear that a simple requirement of "more science" will not reform science instruction (Bower, 1996).

The Wingspread Group (1993) was particularly supportive of higher education in the liberal arts and sciences tradition. They felt that this tradition puts student learning first, prepares the individual for lifelong learning, and takes values and civic virtues seriously. Indeed the earlier study ''Scholarship Reconsidered: Priorities of the Professoriate'' (Boyer, 1990) critiqued the reward system of higher education for favoring research and graduate training above undergraduate education. Boyer's (Carnegie Foundation for the Advancement of Teaching) report presented a summary of what enters into decisions for granting tenure, promotion, and merit salary increases. The number of publications and research grants obtained were weighted very high at research universities and doctoral granting programs, intermediate at comprehensive institutions, and low at liberal arts colleges. Alternately, service to the institution, observation of teaching, course evaluations, and student and colleague recommendations were weighted high at liberal arts colleges, intermediate at comprehensive institutions, and low at research and doctoral universities. However, the view that this skew and difference in values indicates a failure of the whole of higher education is a devaluation of both the contribution of the liberal arts colleges and the role of research universities.

Instead of condemning higher education across the board, one might rather look at the particular successes of liberal arts colleges and research universities and examine how they might be adopted and adapted more generally. Foremost, the liberal arts colleges have been very successful in the more-with-less environment. It is true that tuition has more than tripled in the last 15 years at private liberal arts colleges, with some schools approaching $30,000 per year in tuition and fees. However, it seems these increases have not been spent on instruction but on ancillary services. During the same time, the percentage of funds spent on instruction and faculty salaries has decreased, whereas the number of faculty members has remained stable and the number of students has increased (Heller & Eng, 1996). Further, if one looks at money obtained through grants from all federal agencies for science activity in a typical year (FY 1992), 88% went to the nation's 125 research universities, 6.2% went to the 111 doctoral universities, 4.2% went to 200 of the comprehensive institutions, and only 0.7% went to a very select 100 of the nation's liberal arts colleges (NSF, 1996). In such a financial environment, what kind of scientific and academic successes could one even expect at colleges?

Research Success at Liberal Arts Science Programs

Measuring academic success is very problematic. One of the reasons for the current structure of faculty rewards is the difficulty in evaluating any kind of achievement (Boyer, 1990); the same applies to the assessment of programs. The need to develop valid measures for the program evaluation of science education is frequently cited in reports (NSF, 1996; NRC, 1996; Project Kaleidoscope [PKal], 1991). Like considering publication frequency for promotion decisions, we are currently forced to consider quantitative indicators of departmental productivity within the scientific career track. Rather than considering broader aspects of general scientific literacy, we count students to evaluate programmatic success. The report by PKal (1991) indicated significant institutional differences in the number of math and science bachelor degrees awarded per 100 graduates: research universities, 9; doctoral universities, 6; comprehensive institutions, 6; liberal arts colleges, 14. Similarly, there are differences in the numbers of natural science doctorates earned per 1,000 of these degree recipients: research universities, 10; doctoral universities, 5; comprehensive institutions, 3; liberal arts colleges, 12.

Newman (1994) reported a ratio measure of the baccalaureate origins of doctoral recipients. The number of doctorates obtained during the period 1981 to 1990 by graduates of an institution was divided by the number of bachelor degrees granted at the institution from 1976 to 1985. Of the 20 institutions with the highest ratio of students going on to receive doctoral degrees in all engineering and science fields, 10 were in the Carnegie Foundation classification of Research University Type 1, and 10 were in the category Liberal Arts College Type 1. No doctoral granting or comprehensive universities were represented. Examined by scientific discipline, the representation of the top 20 programs was more inclusive of institution types but still disproportionately skewed toward liberal arts and research institutions (Table 1). This kind of data is publicly available from the National Academy of Sciences Survey of Earned Doctorates (managed by the National Opinion Research Center) and from the Integrated Postsecondary Education Data System surveys (managed by the National Center for Educational Statistics).

Why are the research universities and liberal arts colleges so successful in producing students who go on to scientific careers? Surprisingly, it may be that both the

Table 1
Institutional Category of Top 20 Schools for Baccalaureate Origins of Science Doctorates

	Carnegie category			
Discipline	R	D	C	L
Physical sciences	7	2	1	10
Life sciences	9	1		10
Math and computer science	8	2		10
Geoscience	5	3		12
Psychological sciences	4	1		15
Social sciences	4			16

Note. Contains all schools with a Carnegie Foundation classification during the period 1976 to 1985. Inclusion in the top 20 was based on the ratio of doctorates received by graduates from 1981 to 1990 to bachelor degrees awarded from 1976 to 1985. R = research university; D = doctoral university; C = comprehensive institution; L = liberal arts college.

research university and the liberal arts college have an environment with a strong tradition of scientific research that stimulates student interest. Yoder and Spencer (1987; Spencer & Yoder, 1981) examined research in chemistry departments at 174 undergraduate institutions. Of these colleges, 37 published 10 or more papers in peer reviewed journals during the 1970s. This publication rate was maintained at 23 of these programs in the subsequent six years (1980–1985), and 11 departments published 128 papers with 188 undergraduate students as coauthors during that period.

Student coauthorship is common at primarily undergraduate institutions. Stevens (1994) reported that 30% of all science articles published out of teaching institutions have a student coauthor. Further, the research at teaching institutions is of a high quality. In a study of physical and life sciences publication at 74 schools in the Liberal Arts College Type 1 category, 27 colleges showed citation impact rates above the world average for doctoral and research universities (Garfield, 1993). The citation impact is calculated by the number of times published articles from an institution in a given year are cited in articles of the subsequent five years, divided by the number of the initial publications. Over a third of those undergraduate colleges studied consistently published papers deemed to be of above average interest to the scientific community.

Research Success at Liberal Arts Psychology Programs

As measured by publications or future graduate students, psychology departments at primarily undergraduate institutions do not seem less productive than the physical and life sciences. Terry (1996) reported on the characteristics of 284 psychology departments at institutions with a median size of about 1,700 undergraduate students and 9 graduate students (M.B.A., M.Ed., M.A.). In 1994, the typical department had five faculty members and graduated 25 seniors. Eighty percent of the departments reported that their faculty published in a refereed journal in the previous two years. The typical number of classroom lecture hours for a faculty member was 12 per semester, and only 9% of departments offered release time for faculty research. The median amount of departmental space allocated for research was 500 square feet, and 49% of departments received no extramural funding for research. The typical number of support technologists and research or teaching assistants was zero, and departments generally had only one secretary. The average amount of funds provided to a faculty member for travel and development was $531, with only 5% of departments providing moneys in excess of $1,000 per year. However, a median 57% of students had done independent research, and 48% of programs required research experience for graduation—some (N = 75) required an undergraduate thesis. A median of 22 graduating psychology majors received some form of research experience, 3 presented their research outside their institution in some fashion, and 4 went on to graduate study. Regardless of the prevalence of student research involvement, only 15% of departments considered research supervision part of the teaching load.

The research university and the liberal arts college appear to have achieved very similar objective results in undergraduate science education outcomes for those students on the scientific career path. However, because of the very different roles these two kinds of institutions play, it is less clear what mechanisms are functioning to produce these results. It may be as simple as resource allocation or institutional selectivity. The top 100 liberal arts colleges and the private research universities "have been spending 75% more per student than public research universities. Public research universities spend 20% to 40% more than other four-year institutions and 60% more than public two-year colleges" (NSF, 1996, p. 30).

Among psychology departments, Kierniesky (1984) found that admissions competitiveness was significantly related to the frequency of student research and the number of student projects presented off campus in professional or student forums. He also reported that the determining factor between presentation in professional or student-oriented forums was whether the research ideas were generated by a faculty member or a student. In over half of the 262 liberal arts colleges surveyed, psychology departments reported that students researched their own ideas. In addition to this being useful for admission to graduate school, the four most reported justifications for student-conceived research are that it is an important part of the educational program, that it teaches research skills and applications, that it encourages critical and independent thinking, and that it should be done even if not going to graduate school. Our new goals (for a society-wide, general-science literacy; a technological preparation for all levels of life and career; and an entirely new functional scientific expertise for those people in civic leadership and K–12 teaching) are just the accomplishments claimed for student-initiated research. However, given their different overall responsibilities and academic pressures, can the research university and liberal arts college be equally successful in maintaining student-centered research programs?

Educational Success

Boyer (1990) recognized the different demands society places on different institutions of higher education and the way in which these roles developed historically. The primacy of faculty research and graduate education at the research university is accepted, as is the primacy of liberal education and undergraduate student mentorship at the liberal arts college. However, Boyer did warn against "upward drift" in all types of institutions as pressures to gain institutional prestige through the very visible and publicly admired product of the research university become common. The university model places strain on the science education function of an institution.

Across all institutions there are consistent student complaints with science courses. The problems often lead to a dislike of science and mathematics as subjects, and they are more prevalent at the research and doctoral universities (NSF, 1996, pp. 36–38). Lack of the student–teacher dialogue that is now common in the high school classroom was seen to reflect faculty indifference. Perceived lack of classroom preparation by instructors, dry presentations, monotone voices, focus on note-taking and memorization, classroom tedium, an aggressively competitive environment, and a disconnection between lecture and laboratory content were frequent negatives for science classes. The apparent "weeding out" objectives of introductory courses were seen to shortchange the preparation of science majors and the basic understanding of nonmajors. Students most strongly condemned faculty preoccupation with research and contrasted science teaching styles with other fields as cold, elitist, aloof, and rejecting as opposed to warm, democratic, open, and supportive.

There are also complaints from faculty members. "The existing balance of rewards is seen to be slanted toward research because the system for measuring teaching performance on most campuses does not include broad evaluation of faculty accomplishments in improving the learning of all students" (NSF, 1996, p. 45). Of the impediments to improvement, the most frequently cited by university faculty is the allocation of institutional resources. Resource scarcity affects faculty development, the dissemination of good practices among faculty, and the availability of modern instructional equipment. Idealistically, the report of the NSF (1996) called for improvements that would "nurture a sense of wonder among students about the natural world, while equipping them with tools to explore it and learn" (p. 18). More concrete recommendations included (a) preparing graduate students for teaching duties, (b) advancing research on human learning, (c) providing for faculty development, (d) making interdisciplinary links among departments, (e) focusing faculty rewards on teaching and learning, (f) holding academic units accountable for learning, and (g) developing partnerships with other organizations.

The first recommendation listed above is receiving some attention from the psychologists in charge of graduate training programs (Fernald, 1995). But, it is the second recommendation that stands out as directly relevant to the scientific expertise of psychology and for being of special concern to science education policymakers. In traditional science fields "faculty are still not, in general, familiar with the research about learning and the positive impact of research-based learning strategies on student performance" (NSF, 1996, p. 47). The National Academy of Sciences (NAS, 1997) handbook on undergraduate science teaching states

> Research has taught us a great deal about effective teaching and learning in recent years, and scientists should be no more willing to fly blind in their teaching than they are in scientific research. (p. v)

Psychological Science and Science Education

The field of psychological science has been receiving increased attention from the science education community. With increased interest in undergraduate programs based on the teaching-laboratory and discovery-oriented, research-rich curricula, science fields have become more aware of psychology as a science and the application of psychological knowledge to their own goals. Although both the NRC (1996) and NSF (1996) reports limited themselves to considering physical and life sciences education, they specifically acknowledged the importance of psychological research in reaching their conclusions.

> Cognitive research has much to offer undergraduate education, both in its past results and its potential for further insights (Bok, 1986). Research on differences in learning styles among students, for example, can help instructors engage larger groups of students in learning. Studies of how extensive exposure to television, computers, and video games has modified the ways in which young people learn can help faculty take advantage of the particular skills undergraduates bring to the classroom. (NRC, 1996, pp. 22–23)

> Such a vision is possible today only because of the enormous advances that have been made both in our understanding of human learning and in science, mathematics, engineering and technology education in the past 10 years, many of them with the strong support of the National Science Foundation. . . . In the area of learning, we know through research in cognitive psychology that the mind is active—it always interprets and is *not* simply a passive receiver of information "broadcast" to it. We know that students interpret new information in terms of what they already know; so, to promote learning, teachers must provide "stepping stones". . . . We know that students rarely realize the applicability of knowledge from one context to another. We know that the diverse communities or cultures from which our students come have different values, norms, and expectations about the educational process; learning is inhibited when those culturally-determined norms clash with what the instructor is doing. Research in sociology suggests that working in groups in a cooperative setting produces greater growth in achievement than straining for relative gains in a competitive environment. (NSF, 1996, p. 3)

Such important recognition is a marvelous opportunity for our field. However, if parts of such statements from outside the field make us slightly uncomfortable and seem to misconstrue our professional understanding of psychological research, it only strengthens the argument that psychologists should be involved in forming science education policy and research. *The American Journal of Physics* (1994, as abstracted in Redish, 1996) reported on the impact cognitive studies can have on the teaching of physics. The role of mental models, the difficulties of accommodating schemata, and the importance of learning styles were identified as core contributions; yet, those concepts are hardly the most rigorous or current cognitive science.

In handbooks on undergraduate science instruction (McNeal & D'Avanzo, 1997; NAS, 1997), much of the empirical work cited is from the research of "hard" scientists engaged in classroom studies. Many of the studies do not seem to address the problems of assignment to conditions, demand characteristics, experimenter bias, cohort effects, and other issues important to the investigation of human beings. Redish (1996) warned physical scientists doing educational research against regarding the larger variability of individual differences found in psychological phenomena as error. One of course realizes what he intends, but it is a statistically imprecise operational notion on which to build research. Redish proposed that "we must treat the teaching of physics as a scientific problem" (p. 4). Psychologists would have a great wealth of information and experience to contribute.

Beyond what cognitive fields have learned about perception, learning, memory, and thought, psychological science has much more to offer the endeavor to improve science education. There is of course our methodological expertise in the scientific investigation and description of human phenomena, and we continue to make great advances in the assessment of mental abilities and the quantification of knowledge stored in the human memory system. A most obvious application of modern psychometrics is found in the improved understanding of intelligence and its relationship to processes of lifelong learning (Neisser et al., 1996; Sternberg, 1997). But, in addition, the fields of social psychology and organizational behavior are intimately involved in the study of group processes. The specialties of human factors and behavioral engineering have much to contribute to the design of teaching-laboratories and classroom learning environments. Industrial and educational psychology can help develop program evaluations necessary to determine the outcomes of interventions proposed to reinvigorate science education. And, developmental psychology can provide information on the intellectual and motivational progress from adolescence through young adulthood and on into midlife and old age. These kinds of knowledge clearly affect the new issues of science education and teacher–student interaction.

Psychology is a very fertile field for ideas that would interest the science education community. Several recent articles have presented ideas that science educators would be eager to explore as informing their efforts in curriculum development. Expanding the domain of undergraduate science to include socially responsive knowledge (Altman, 1996) is entirely consonant with the new goals of science education. The "situative" approach merging cognitive, behavioral, and social perspectives and proposed for changing educational practice in secondary mathematics education (Greeno & the MSMTAP Group, 1998) could be useful as a theory to ground research into undergraduate math-lab design. Certainly, the evolutionary–cultural explanation of mathematical development and math aversion in children (Geary, 1995) has equally meaningful implications for the instruction of college students. Further, the more current ideas on human information processing as they involve learning skills, solving problems, developing expertise, and the simple importance of practice (Anderson, 1993; Ericsson & Charness, 1994) would be a pedagogical eye opener for science educators. This is only a short list of potential contributions found by skimming a few issues of a single general psychology journal; adding to the list is left as an exercise for the reader.

Involvement With Science Education

Psychologists should also benefit from the two-way nature of collaboration. The convocation of the NRC (1996) reached many conclusions that could be taken to heart by educators in psychology. Recognizing the emerging need for a "revolution" in a science education system that has nonetheless shown amazing success over the years, they pointed out some developing deficiencies.

> Many undergraduates do not receive enough education in science, mathematics, engineering and technology subjects. From some of the most prestigious institutions in the country, it is possible for students to graduate with not more than six percent of their work in science and technology. Many classes rely on textbooks heavy on "coverage" but weak on example, so that students are exposed to encyclopedias of fact without ever engaging in the process that is science. Drop out rates from science major programs are alarmingly high. Faculty members who teach in science, mathematics, engineering and technology often are occupied with exciting programs of investigation, but their students only rarely get to experience these programs. (NRC, 1996, p. 2)

They provided four main recommendations and four cautious proposals.

> [1] All students should have access to supportive, excellent programs in science, mathematics, engineering and technology and all students should acquire literacy in these subjects by direct experience with the methods and processes of inquiry. [2] Departments and programs should define their missions and establish explicit educational goals; they should be evaluated against those goals by fair assessments that are as rigorous as those applied for research; and they should be rewarded both as groups and as individuals for success in reaching these goals. [3] Institutions must promote a new balance and a new linkage between teaching and research, so that teaching is enlivened by investigation and research is defined more broadly, and so that faculty may be rewarded for educational scholarship as well as for other kinds of scholarship. [4] Institutions and departments should promote educational innovation both through broad cultural change and through providing resources and support needed for effective teaching. (NRC, 1996, pp. 4–6)

The cautious proposals considered included the following:

> [1] Professional societies should increase their efforts to incorporate educational research and ideas into disciplinary journals and annual meetings. [2] Federal funding agencies, including mission agencies, should require explicit statements of undergraduate research objectives in all research proposals associated with undergraduate institutions. [3] Postdoctoral fellows should be given opportunities to integrate teaching and research interests. [4] Doctoral dissertations should be required to con-

tain material relevant to the candidate's teaching accomplishments. (NRC, 1996, p. 9)

One could easily go through the document and substitute "behavioral, cognitive, and social sciences" in the appropriate locations referring to "science, mathematics, engineering, and technology." Additional issues addressed by the NRC and adaptable to psychology expand on the use of new technologies and teaching materials, the articulation of connections between education and workplace, and the reluctance to "mix missions" given the outstanding success of the scientific enterprise in academia. The NRC's proposals resulted from the discussion of many interesting questions of which a selected list can be found in Table 2.

The Growing Conversation

Questions of these kinds have been discussed for several years by a number of organizations concerned with science at teaching institutions (Newman & Morgan, 1996). PKal was initiated in 1989 by the Independent Colleges Office with a grant from the NSF. The original group of elite liberal arts colleges involved has grown to include over 500 institutions and 3,000 individual participants representing all types of higher education institutions. PKal has sponsored many workshops across the nation on disciplinary, interdisciplinary, administrative, curricular, development, and infrastructure issues related to undergraduate science education. The workshops are based on a team model. Institutions send a team consisting of an administrative officer with budget responsibility for the sciences (i.e., president, vice president, director), an academic officer (i.e., provost, dean, chair) and a science faculty member to meet with other institutional teams for three-day working sessions on a theme. These sessions have resulted in the publication of reports such as "What Works: Building Natural Science Communities" (PKal, 1991), a plan for strengthening science education, and "Structures for Science" (PKal, 1995), a guide to designing, financing, and building teaching-laboratories and undergraduate research facilities.

Four years ago, PKal began the Faculty for the 21st Century program under a grant from the Exxon Foundation. In 1994, and each subsequent year, PKal has accepted a class of about 150 junior science faculty members in fields from astronomy to zoology. These participants were nominated by their institutions as campus leaders and "agents of change" in science education. At their time of nomination, the candidates must have had three years of tenure-track experience, but as yet be untenured. They are networked electronically, gather for regional and disciplinary workshops, and annually meet in a national assembly with scientific and academic mentors, professional and governmental leaders, and agency and foundation officers. National assemblies have had themes of "balancing teaching, research, and personal lives," "creating a multidisciplinary undergraduate science curriculum," "conveying the passion for science," and "problem solving and problem solvers." The growing number of participants will continue to be nurtured over a period of years to form a cadre of faculty who can fill positions of local and national leadership in science education and policy. Of the 600 current participants, only 12 are psychologists and 5 are behavioral neuroscientists who orient to psychology rather than biology (PKal, 1998).

Another important organization contributing to the development of science curriculum and programs for supporting science education at teaching institutions has been the Council on Undergraduate Research (CUR). "The mission of the Council on Undergraduate Research is to encourage science and mathematics research involving undergraduate students . . . [and] to strengthen undergraduate science and mathematics education through faculty–student collaborative research combined with investigative teaching strategies" (CUR, 1996, cover). The organization publishes a quarterly journal on science education, awards nearly $200,000 in undergraduate summer research fellowships, holds an annual convention for its membership, organizes a biannual discussion among college representatives and granting agencies, collects and disseminates descriptive statistics on science departments, and cosponsors a national student research conference with about 2,000 participants. The CUR represents nearly 850 institutions and 3,600 individual members in a roster that includes seven divisions: one for various "at large" sciences and six for specialties in biology, chemistry, geology, math and computer science, physics and astronomy, and most recently psychology (Brown, Hallock, & Kraut, 1997).

Joining the Discussion

As individual researchers representing a field, psychologists possibly have been too modest to intrude themselves on the rest of the science community. Given the naturally skeptical conservatism of the scientific perspective, psychologists may have lacked the confidence to join the discussion. However, particularly during the past 20 years, psychology has made almost incredible contributions to the understanding of how people perceive, learn, know, and think; how people relate to their environment and other individuals; and how emotions, motivations, and attitudes interact with cognitive and social processes (Kihlstrom, 1995). Schneider (1996) called on the field of psychology to become more self-confident and take risks. He recommended that psychological research creatively approach the big questions that are central to the wider constituencies of science, academia, politics, and the public. What could be more fundamental to aiding the goals of each of these communities than joining in the debate on science education and policy with the resources scientific psychology can provide?

Indeed we might even have as much experience with student research to contribute. Because of the types of questions asked by psychological science, the field may have been early to adopt the student research model in undergraduate departments. Beyond the ordinary require-

Table 2
Selected Questions Discussed at the National Research Council (NRC) Convocation

- How can successful models in recruiting and retaining underrepresented groups in science education be extended to all students?
- Should the same introductory courses serve both future majors in science as well as arts and humanities students?
- Should students be expected to have a breadth of understanding in science or should their experiences allow them to encounter subjects in depth, or both?
- How can faculty in different departments be encouraged to work together so that students see the connections among subjects that are an inherent part of those subjects?
- What are the best ways for faculty and administrators of science departments and education departments to work together to integrate the education they provide future teachers?
- What are the best avenues for professional development for faculty who are involved with educating future members of the technical workforce?
- How can majors in science best combine breadth of exposure with the disciplinary rigor required for an undergraduate degree?
- What are the best ways for science faculty to incorporate historical, social, and ethical issues into courses for undergraduate majors?
- How can science departments accommodate students who arrive at majors through unconventional routes, such as beginning course sequences later in a college career or after a period away from academic study?
- How can curricula be developed to provide students with a broad and integrated view of science? What new curricular tools can be developed to enhance science literacy?
- What kinds of faculty rewards and development are needed to drive curricular reform?
- How can science departments be encouraged to create introductory courses that act as pumps rather than filters, especially for women and minorities?
- How can faculty create active learning experiences for all students? How should science be set in the appropriate contexts?
- Which students can benefit from research experiences? To what extent should the electronic simulation of laboratory experiences be encouraged?
- What are the implications of information technology for the development of communities of learners?
- What training should be provided to graduate students who intend to pursue teaching careers at colleges and universities?
- What development opportunities should be provided to faculty at colleges and universities to enhance their teaching and advising skills?
- How should faculty development efforts be promoted, recognized, and rewarded at the departmental and institutional levels?
- How can we cultivate institutional environments in which educational issues are viewed as a professional responsibility and as a prominent cross-disciplinary area of intellectual and philosophical inquiry?
- To create active learning environments, what is required in terms of class size, instructional lines, classroom space, office space, and study environments?
- What new models of teaching, facilities, and technology are needed to plan for education in the 21st century?
- What is the appropriate design of lifelong education programs, and what should be the relation of these programs to the undergraduate curriculum?
- What institutional changes are needed to make science learning and teaching more central and important to postsecondary education?
- Are there indicators of quality in science education that transcend the great diversity of our undergraduate institutions, populations, and student aspirations?
- What responsibilities must colleges and universities assume to achieve and sustain undergraduate instruction in science that is personal, active, hands-on, enmeshed in communities of learners, and strongly connected to contexts?

ments of laboratory courses, a trend toward independent data collection as an instructional device for the training of undergraduate psychology students had already been identified in the higher education literature as early as 1973 by Kulik and colleagues (cited in Kierniesky, 1984). In exchange, participation with other disciplines could gain us perspective on issues more recently facing psychology such as the growth of the discipline, the misperceptions of the public, the cooperation of our subfields, the structure of the scientific psychology curriculum, the identification of our educational priorities, the students' perceptions of the field, and the evaluation of our educational outcomes.

Benefits to Psychology

The psychological community as a whole has become more directly interested in its own undergraduate education over the years. The American Psychological Society has included an annual Institute on the Teaching of Psychology with its national convention and is planning a new journal on the subject. Its journal will join one on the "Teaching of Psychology" produced by the American

Psychological Association's (APA) teaching division, which has examined educational issues for 50 years and has recently reorganized as the semi-autonomous Society for the Teaching of Psychology. A taskforce of this new organization has been working to redefine scholarship in psychology to include pedagogical research and teaching (Halpern et al., in press). However, as related to the kind of issues now being considered by the science community, the stated goals of the entire psychological field seem somewhat inconsistent or even contradictory.

Oakland (1994) reported on the priorities of the members and leaders of the APA. Among the most important issues, he found psychology's public image ranked 2nd, public understanding of the applications of psychological research and knowledge ranked 3rd, interests and values important to science ranked 4th, interests and values important to education ranked 9th, and interests and values important to the public interest ranked 10th. These are subjects directly related to the new national goals for science education. Yet, the APA's specific educational concerns demonstrate the reverse of what would be necessary to achieve that desired public awareness, understanding, and support of psychological science. Among all the priorities of APA leaders and members, curriculum and program quality at the doctoral level is ranked 1st, followed by education at the masters level ranked 12th, education at the undergraduate level ranked 21st, and psychology education at the secondary school level ranked 32nd at dead last. To achieve the fine-sounding public goals, reality must force a change in these educational priorities.

The field of psychology has experienced tremendous growth in the number of undergraduate majors since 1985. In the United States, college students graduating with degrees in psychology increased from 39,900 to 63,513 during the seven years ending in 1992 (McDonald, 1997). McDonald surveyed 19 research universities regarding the 1994–1995 academic year. Those schools reported a total of nearly 17,000 undergraduate majors and a number of mechanisms for dealing with the influx of students. Some departments instituted admissions standards for the major such as a minimum GPA in a set of premajor courses, a departmental essay addressing educational goals, or prerequisite courses in the physical and life sciences. Other departments introduced graduation standards, created separate bachelor of science and bachelor of arts tracks, increased performance requirements for "hurdle" courses in statistics and experimental methods, or required completion of a capstone course in the senior year. A few departments simply limited enrollments or increased prerequisites in upper-level courses to exclude nonmajors.

These methods of reducing enrollments are what other sciences are now working to end. These methods are exclusive and not consistent with society's new educational goals. These methods obscure programmatic successes by confounding educational achievements with selection biases. And, these methods ultimately reduce the reservoir of scientific talent. Stated succinctly, "we [must] reject models that conceive of learning as a constant test put to isolated and beleaguered individuals who are winnowed so that only the strongest and brightest remain. An able scientist becomes that not because of endowments conferred at birth, but because others cared enough to nurture and inform that person" (PKal, 1991, p. 37).

The importance of mentors and role models in the definition of what makes a great university and college has been frequently lauded both for graduate training and undergraduate education (Malachowski, 1996; Willis & Diebold, 1997). We also must avoid making introductory courses unpleasant for the majority of nonmajors if we wish to maintain the goodwill of the future leaders and citizenry of our society. For example, during the 103rd U.S. Congress, the chairman of the House Science Committee advocated the elimination of the Social, Behavioral, and Economic Sciences Directorate of the NSF because it was included among the sciences on the basis of political correctness. Such a misunderstanding could not have occurred if Chairman Walker had received a positive collegiate experience in a scientific, discovery-oriented introduction to psychology that was integrated with other science courses (Newman, 1995c).

As the traditional fields of science have gained more understanding of psychology through their enterprise to improve science education, psychology has gained legitimacy in their eyes. At the same time, the teaching of psychology is changing and beginning to confront the problems of older fields in science education. Those fields are responding to change by broadening participation and increasing access to investigative, experiential learning. As a reflection of contributing its knowledge to improve education in other sciences, psychology should begin adapting successful teaching techniques from other fields. Through collaboration with other disciplines and among various kinds of institutions, we can enhance education in psychology. However, we also must be willing to take our own advice and engage in quality assessments of the education programs developed.

Focus editions of the *CUR Quarterly* (Kolmes & Reggio, 1997) on "assessment and evaluation of the undergraduate research enterprise" and the *American Psychologist* (Greenwald, 1997) on "student ratings of professors" have most recently recalled our attention to the need for measurement. Only about 32% of psychology departments engage in any form of program evaluation or assessment. Most surprisingly, it is the best liberal arts colleges with national reputations that show the lowest frequency of 19% investigating student outcomes (Jackson & Griggs, 1995). To many, this might seem an incongruous statistic; however, those programs may be resting on their laurels as measured by the production of future graduate students. How do those flagship liberal arts programs meet the goals proposed for a broader general science education?

Student participation in research has long been a trademark of psychology education for the elite student and the elite institution. But, widely adopting a research-rich model of higher education in psychological science at the undergraduate level is not simple (Newman, 1995b). Broad adoption of such a program requires answers to four interrelated questions and must deal with some issues peculiar to psychology as a science: How does one obtain support for a discovery-oriented curriculum? How does one structure such a program departmentally and institutionally for the nonmajor courses *and* a major course of study that contains laboratory courses, statistics, research methods, and student involvement with research projects? What kind of research experience, apprenticeship on a faculty project or a self-conceived student project, is best for which students and when in their course of study? And, how does one encourage the necessary interests and enthusiasm in individual students for individual projects and in successive generations of students for stable programmatic research?

Additionally, as in any other science, there are special considerations in the planning and construction of psychological teaching-laboratories (Newman, 1995a). The new kind of hands-on interactive science instruction being developed and the increased centrality of student research as an educational tool will necessitate a new kind of lab-classroom (Narum, 1996). Administrative commitment to provide the means, motive, and opportunity for undergraduate research has been critical to the success of such programs in psychology departments and campus wide in other sciences (Friedenberg, 1995; Ramey, 1995).

A special difficulty for teaching scientific psychology through a research participation model is that the field is often not initially recognized as being a science (Newman, 1995b). The perception of psychology as strictly a helping profession or a less than "natural" science may affect the structural support for the complexities of a research-based curriculum. Further, typical psychology students at many institutions of higher education choose the major because they "like talking to people" and they "don't like math." For most students, their first exposure to psychology as a science is in college; therefore, at the earliest, the major course of study begins in the sophomore year. It would be difficult for a lab-based introductory course to function in the freshman year, and student research interests do not usually develop until the junior year, after statistics and methods coursework. How can a lab-based, research-rich curriculum be designed, function, and grow with these limitations? Must we always work within such limitations or can we ultimately modify the antecedent conditions by influencing K–12 instruction and public understanding through research-enhanced undergraduate education in psychology?

Implementing this kind of discovery-oriented program is fraught with the previously noted difficulties, and these are compounded at small departments. A solution for the small department can be closer ties to the research university. The ability of psychology departments and individual psychological scientists at smaller colleges to provide this kind of science-based opportunity to students is enhanced through collaborations with scientists at research universities (Waddill & Einstein, 1996). At small undergraduate departments, being the only faculty member in a specialty area makes it difficult to generate the stimulating research ideas around which to build a research program that can capture the interest of the students. On the other hand, the experience that liberal arts colleges have with providing research-rich education for all levels of students is of value to the university considering this kind of curriculum. Both the liberal arts colleges and the research universities have contributions to make and benefits to gain from interaction.

A few models for programs that appear to successfully emphasize a course of study in discovery-oriented scientific psychology do exist. Those curricula have been proposed as solutions to the high attrition among declared psychology majors and recognized for successfully attracting students with scientific talent to the psychology major (Bahrick, 1994; Bill, 1995). In such programs, the perception of psychology as a science among junior and senior majors is positively correlated with their interest in course material and ratings of teacher performance and, among "introductory" students, with their test performance and appreciation of research participation as subjects (Friedrich, 1996). At first blush, these are comforting statistics. However, that correlation pattern is also just what one would expect from the filter model of science education. If the field of psychology is to truly apply its high standards for scientific rigor to improving education in psychology while also assisting other sciences in educational projects, there is much remaining to consider and to accomplish.

The Mandate

What has been laid out in this article is a convergence of interests among research universities, liberal arts colleges, and psychological science and other science departments. The changing nature of undergraduate education, professional careers in science, and the needs of society has created the necessity for a mutual dialogue. Such a discussion has begun within the traditional undergraduate science education community and at the national level within science policy organizations. Psychological knowledge has become a central component of the content being discussed, and it has done so without wide participation by psychological scientists. The lack of involvement by psychologists has been unfortunate. Frankly, as one of the few psychologists involved, I have found the openness to psychologists and the cooperation between liberal arts colleges and research universities to be very encouraging.

Vigorous Dialogue

Psychology departments should begin internal discussions of undergraduate science education. Questions such as those engaged by the NRC convocation (Table 2) need to be explicitly addressed within academic departments at all levels of higher education in psychology. The usefulness of the discovery-oriented, research-rich curriculum and teaching-laboratory seems reasonably well established in liberal arts colleges and for honors students at research universities. However, we need to ask the question "Can and should such a program be more broadly applied and what forms would be effective for different kinds of students?" The best educated of psychology students often have graduated from research-rich programs, but it would be good to determine whether such an experience is effective for all psychology students before making an expensive correlational error. Further, in developing such a program can we aspire to making it congruent with greater, or even universal, literacy in psychological science and science in general? During such deliberations, the special problems of a curriculum for psychology as a science will need to be reconciled. In so doing, perhaps the relationship to teacher training and high school psychology could receive needed additional attention.

Disciplinary Alliances

It is time for psychology departments to form closer ties with the broader science education community. More psychologists should become involved in conversations regarding interdisciplinary cooperation, integrated science education, and mutual support. This can be achieved both at the campus level and at the national level by becoming more active in organizations such as PKal and the CUR. From such conversations, we can gain an understanding of the science education solutions developed in other fields. We also should make available our expertise in psychological processes that affect science education: learning, assessment, group processes, ergonomics, and so forth. A beginning can be made by simply offering what each of us considers our personal professional strengths in support of the projects of colleagues and programs in the other science fields. Remember that your colleagues across campus may not have any more knowledge about psychology than what they gained from an introductory class 30 years ago, if that. Pick up the phone and make some calls.

Further, there are a multitude of opportunities to include psychological content as part of the multidisciplinary science courses being developed within the integrated science education movement. Possibilities go beyond the obvious links with chemistry and biology through brain mechanisms to concepts of psychoneuroimmunology and stress and disease (Andersen, Kiecolt-Glaser, & Glaser, 1994; Maier, Watkins, & Fleshner, 1994). Possibilities extend beyond psychology's ties with math, computers, and engineering through artificial intelligence and robotics to theories of chaotic and dynamic and self-organizing systems (Barton, 1994). There are many creative connections as far ranging as linking perception and astronomy or behavioral ecology and geoscience. The discipline of psychology must become an active part of the inter- and multidisciplinary science curriculum initiative for our own good, possibly obtaining allies in an increasingly competitive and often seemingly hostile policy environment.

Institutional Partnerships

Research university and liberal arts college departments should increase cooperation. This might begin with greater participation of university faculty in teaching organization activities. It may be an uncomfortable but hardly radical hypothesis to think that colleges may have the same ratio of teaching–research expertise as universities have in research–teaching expertise. Further, a new orientation toward investigative learning strategies certainly would change the conflict of how to balance research and teaching duties into a more harmonious challenge of how to teach through research. Cooperation might also be advanced by opening research organization activities, commissions, and committees to greater representation by the nationally recognized liberal arts colleges. Once institutional connections are formed, a number of profitable avenues exist to investigate: science career track successes at both kinds of institutions; liberal arts strategies in general education, values, and mentorship; and university research collaborations with liberal arts college faculty and their students. Eventually this partnership could be evaluated with an eye toward incorporating two-year and comprehensive institutions.

Coda

Other considerations for the future should probably include more explicit collaboration in education research with education departments. Certainly, the changes in information technology and electronic networking capabilities will require continued attention. And, of course, technological and general educational policy considerations will have a tremendous effect on colleges and universities for which psychology should prepare itself. We will be more successful at anticipating the future, readying ourselves, and achieving our ends if we do so in cooperation with colleagues who are facing similar challenges.

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