Does Faculty Research Improve Undergraduate Teaching? An Analysis of Existing and Potential Synergies

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Abstract

Academicians have been arguing for decades about whether or not faculty research supports undergraduate instruction. Those who say it does—a group that includes most administrators and faculty members—cite many ways in which research can enrich teaching, while those on the other side cite numerous studies that have consistently failed to show a measurable linkage between the two activities. This article proposes that the two sides are debating different propositions: whether research can support teaching in principle and whether it has been shown to do so in practice. The article reviews the literature on the current state of the research-teaching nexus and then examines three specific strategies for integrating teaching and scholarship: bringing research into the classroom, involving undergraduates in research projects, and broadening the definition of scholarship beyond frontier disciplinary research. Finally, ways are suggested to better realize the potential synergies between faculty research and undergraduate education.

Keywords: research-teaching nexus, research, teaching

I. Introduction

Research expectations for university faculty have been rising for over half a century to an extent that research productivity has become the dominant and sometimes the sole criterion for hiring, tenure, and promotion at research universities. This trend has been driven by several factors, including the universities' growing dependence on external research funding to support basic operations and the intense desires of their administrators and faculty members for high national rankings. The consequent pressure on faculty members to increase research productivity is attested to by anecdotal reports [1–4], surveys of faculty and administrators [5], and examinations of faculty reward structures [6]. The pressure has led to increased faculty research activity, not only at research universities but also at institutions with teaching as their primary mission [7], and calls for increased scholarly activity have even been heard at the community college level [8–10].

The emphasis on research productivity in the faculty incentive and reward system is often justified by the claim that research enhances teaching. In a debate that has been raging for decades, most faculty members and administrators support this belief [11–13] and others challenge it [14–19]. In our opinion, the problem is that the two sides are debating different propositions: (1) research has the potential to support teaching; and (2) research has been shown to support teaching in practice. Those who argue that research supports teaching offer evidence in support of proposition 1, pointing out all the ways that scholarship might improve instruction, such as keeping course content up-to-date or modeling for students the intellectual curiosity and critical thinking that characterize good research. Most of those who argue the other way readily concede that teaching and research *can be* complementary but take the negative position on proposition 2, citing numerous studies that have consistently shown negligible correlations between research productivity and teaching performance.

As Rugarcia [18] and Felder [14] point out, research and teaching have different goals and require different skills and personal attributes. The primary goal of research is to advance knowledge, while that of teaching is to develop and enhance abilities. Researchers are valued mainly for what they discover and for the problems they solve, and teachers for what they enable their students to discover and solve. Excellent researchers must be observant, objective, skilled at drawing inferences, and tolerant of ambiguity, and excellent teachers must be skilled communicators, familiar with the conditions that promote learning and expert at establishing them, and approachable and empathetic. Having both sets of traits is clearly possible and desirable but not necessary to be successful in one domain or the other. Moreover, first-class teaching and first-class research are each effectively full-time jobs, so that time spent on one activity is generally time taken away from the other. There should consequently be no surprise if studies reveal no significant correlation between faculty research and effective teaching.

That is exactly what *is* revealed:

- Feldman [20] examined 42 studies and concluded that "the likelihood that research productivity actually benefits teaching is extremely small…the two, for all practical purposes, are essentially unrelated."
- Hattie and Marsh [21] examined 58 studies and explored correlations between such measures of teaching as student evaluations, peer evaluations and self-evaluations and a

number of measures of research productivity including numbers of papers, citations, and grants. Their conclusion was that for teaching and research "the relationship is 0." In a subsequent analysis [15], the same authors sought specific conditions under which research supported teaching, but their analyses failed to reveal a single moderator to the general findings, leading them to conclude that the observed absence of correlation between teaching and research is robust.

- Jenkins [16] reviewed the literature through 2004 and similarly failed to find persuasive evidence that involvement in research improves teaching.

Some authors suggest that the small positive correlations that have occasionally been found between teaching and research indicate an important connection [1], but most analyses come to the conclusion reached by Feldman, Hattie and Marsh, and Jenkins: while research productivity does not preclude quality teaching, the two are unrelated at the individual faculty level. Some professors excel at both teaching and research, many excel at one and not at the other, and some are unexceptional in both. The "Myth of the Superhuman Professor" that underlies the current incentive and reward system is that there are enough people in the first category (world-class at both teaching and research) to populate all university faculties, while the reality is quite different [14].

The claimed synergy between research and teaching is even harder to justify at the institutional level than at the individual faculty level. In his monumental longitudinal study of higher education in the United States, Astin [22] found a significant negative correlation between a university's research orientation and a number of educational outcomes. He concluded that:

> Attending a college whose faculty is heavily research-oriented increases student dissatisfaction and impacts negatively on most measures of cognitive and affective development. Attending a college that is strongly oriented toward student development shows the opposite pattern of effects.

Astin believed that this negative correlation resulted at least in part from hiring faculty with strong research orientations who gave low priority to undergraduate teaching rather than from an inherent conflict between teaching and research.

While the finding that faculty research generally does not promote better teaching frequently provokes calls for more extensive or sophisticated analysis of the data, we agree with Hattie and Marsh [15], who conclude:

> Although we encourage research into different conceptions of teaching and research, we are less optimistic that this will lead to finding the Holy Grail of a high and positive relation. This search appears to assume that the relation between research and teaching is high and positive and that we have been looking for the Grail under a lamplight that is broken and defective. The results of the present study, which are consistent with the preponderance of research on this topic, support the conclusion that there just is no such relation. So, instead of looking for even more mediators and moderators, instead of arguing about the nature of knowledge and how the process of constructing knowledge may have close parallels in teaching and research, we maybe should accept the conclusion that teaching and research (however conceived) are unrelated and move on to ask how we should enhance this relation (of course assuming that we wish to do so).

Given that expectations for faculty research have risen at the same time that higher education is facing demands for increased public accountability, the advantages of strengthening the connection between research and teaching (or to introduce the term commonly used in this context, the *research-teaching nexus*) seem clear, and several studies encourage a stronger connection [23–25]. Students obviously can benefit from effective linkages between faculty research and undergraduate education; faculty can benefit from the efficiency and satisfaction of integrating their primary professional responsibilities, universities may benefit when their stakeholders perceive that they are not neglecting their educational missions, since a more positive public image may translate into greater financial support from legislative, industrial and philanthropic groups and more student applicants, resulting in a stronger and more selective student body.

In short, there are numerous reasons to strengthen the research-teaching nexus, at both the individual faculty and institutional level. We suggest that this can best be accomplished by testing integration strategies using rigorous scholarship which is consistent with many of the authors previously cited. Toward this end, we examine in this paper three commonly proposed strategies for strengthening the nexus: (1) bringing research into the classroom; (2) involving students in research projects, and (3) broadening the model for academic scholarship. In the sections that follow, we examine the literature to determine whether and how much each strategy has improved teaching in the past, suggest ways to strengthen the research-teaching nexus based on the findings, and identify research questions deserving further investigation.

Before beginning the analysis, let us clarify several points regarding its scope. In principle, the research-teaching nexus relates to ways in which research supports teaching and teaching supports research. In practice, the discussion has been limited almost entirely to the first of these issues, and it will be in this study as well. It is not that teaching does not support research—it can certainly do so under some circumstances. Most teachers have had the experience of gaining deeper understanding of a subject by teaching it, which could subsequently translate to research advances in that subject. Our objective for this study, however, is to examine the validity of the proposition that research activity enhances teaching. We will therefore leave it to others to examine the extent to which teaching enhances research.

Next, let us define exactly what "research supports teaching" and "strengthen the research-teaching nexus" mean in the context of this study. In our view, better teaching is teaching that leads to greater learning or related student benefits such as higher retention in academic programs. A finding that research supports teaching would mean that faculty research activities enhance student learning or related benefits, and "strengthening the research-teaching nexus" means increasing the extent to which research supports teaching in this sense.

A third point concerns graduate education. Colbeck [26] observes that most analyses of the research-teaching nexus do not take into account the responsibility of universities to train graduate students to conduct research. What one concludes about the nexus may depend in large measure on whether or not advising graduate students "counts" as teaching. We agree that research mentoring is

a form of teaching and find it plausible that being involved in research could make faculty better research mentors and perhaps better teachers of relevant graduate courses. The issue we examine in this article, however, is how research affects undergraduate instruction. We are therefore excluding graduate education from our discussion.

II. Bringing Research Into the Classroom

Probably the most conventional argument for how research supports teaching is that faculty with active research programs bring their research into the classroom and use it to inform their teaching. Pocklington and Tupper [27] found that this assumption is frequently unjustified and claim that "current models of integration are inadequate philosophically, they are naïve politically; and they ignore reforms essential to integrating research and teaching." Colbeck [26] observes that it is difficult to bring research into the classroom in "hard" disciplines such as the physical sciences and engineering for two reasons: hierarchical knowledge structures in those disciplines put most research well over the heads of most undergraduates, and rigidly constrained curricula limit opportunities to bring in new material.

The few published claims we could find regarding the benefits of incorporating research in undergraduate classes rely on indirect measures such as self-reports, and show mixed results. Jenkins et al. [28] used data from student focus groups to argue that integrating research can benefit students through "staff enthusiasm, credibility and institutional reputation," and Neumann [29] reported students' opinions that integrating research helped instructors impart a positive and inquisitive approach to learning. Both articles also note, however, that some students they interviewed saw negative effects of research integration, such as inappropriately skewing the focus of courses or detracting from the instructors' interest in or time for undergraduate teaching. The implication is that integrating research into undergraduate courses *may* be beneficial provided that the research illuminates essential course content without distracting from it or confusing more than it clarifies, but at this point the argument that bringing research into the classroom has improved teaching in practice has yet to be demonstrated by the relevant scholarship.

While there is presently little data to support the conventional argument that faculty effectively integrate the *content* of their research into their classes, faculty might link their research and teaching more effectively by introducing students in their classes to the research *process*. A faculty member's research provides experiences that have the potential to enrich instruction by introducing students to the research process and to important research skills. What researchers do routinely is confront open-ended and imperfectly defined problems, figure out what they need to know and how to find it out; search out sources of missing information; hypothesize and test possible solutions; arrive at final results; and defend them. The traditional lecture-based teaching model, in which instructors present perfectly organized derivations and examples on the board or in PowerPoint(tm) slides, and then ask students to reproduce and/or apply the information in assignments and tests, bears little resemblance to the research process.

An instructional strategy that comes much closer to emulating research is *inductive teaching*. In this approach, the students are first presented with a challenge of some sort—a question to be answered, a problem to be solved, or a set of observations or experimental results to be explained—and learning takes place in the context of the students' attempting to meet the challenge. Variations of this approach include inquiry-based learning, problem-based learning, and project-based learning. Prince and Felder [30, 31] compare and contrast different inductive methods, summarize the research that attests to their effectiveness, and provide guidance in identifying and applying the method best suited for a particular course and instructor.

It is certainly reasonable to hypothesize that faculty could capitalize on their research experience in the classroom using inductive methods. For example, skilled faculty researchers could take the methods they use in their scholarly activities and translate them into an inductive teaching environment by borrowing elements of their own research or choosing challenges more appropriate to the subjects and levels of the courses they are teaching. The faculty's research knowledge and experience, including their knowledge of the relevant literature, familiarity with current information finding strategies, knowledge of modern laboratory techniques, experience supervising research students, awareness of colleagues doing related work in the field or simply their intimate familiarity with the research process itself, could all be brought into their teaching and thereby enrich student instruction in this classroom environment. Students taught in this manner would get excellent training in the skills required for graduate study and research careers. More importantly, it would help students to develop critical thinking and problem-solving skills that will serve them well in any career path they undertake. In addition, if students are taught inductively as freshmen and sophomores, it could induce many of them to seek research experiences later in the curriculum, the educational benefits of which are discussed in the next section of this paper.

Others have similarly called on universities to capitalize on their research activity for educational purposes in this way. Beginning in 1995, a major study of education at research universities was carried out by a distinguished group of scholars under the sponsorship of the Carnegie Foundation for the Advancement of Teaching. The group (later called the Boyer Commission to honor Ernest L. Boyer, the president of the Foundation who initiated the study) proposed that research universities should make the research-teaching nexus central to their instructional mission and offered persuasive evidence that they have seriously failed to do so. The final Boyer Commission report had as one of its primary recommendations that research institutions should move to an inquiry-based approach to teaching.

> The experience of most undergraduates at most research universities is that of receiving what is served out to them. In one course after another they listen, transcribe, absorb, and repeat, essentially as undergraduates have done for centuries. The ideal embodied in this report would turn the prevailing undergraduate culture of receivers into a culture of inquirers, a culture in which faculty, graduate students, and undergraduates share an adventure of discovery. In a setting in which inquiry is prized, every course in an undergraduate curriculum should provide an opportunity for a student to succeed through discovery-based methods [23, pp. 16–17].

As the Boyer Commission envisioned it, repeated exposure to inductive teaching throughout the curriculum would equip

students to function effectively as researchers by the time they graduate.

> As undergraduates advance through a program, their learning experiences should become closer and closer to the activity of the graduate student. By the senior year, the able undergraduate should be ready for research of the same character and approximately the same complexity as the first-year graduate student; the research university needs to make that zone of transition from senior to graduate student easy to enter and easy to cross. For those who do not enter graduate school, the abilities to identify, analyze, and resolve problems will prove invaluable in professional life and in citizenship [23, p. 17].

Additional authors have issued similar calls for a change in the dominant mode of undergraduate instruction, in part as a way to strengthen the connection between teaching and research. Badley [32] proposes that research and teaching might both be envisioned as forms of inquiry if one gets away from the traditional model of teaching as transmitting information and turns instead to any of several inductive teaching approaches. Elton [33] and Brew [34] similarly conclude that a positive research-teaching link depends primarily on the nature of the students' learning experiences and also propose that student-centered teaching (as exemplified by inductive approaches) provides the type of experience that enhances the connection.

In summary, integrating research into the classroom in the way integration is normally conceived—i.e., instructors discussing the content of their research—has not been shown to occur frequently or to improve learning. An alternative way to integrate research into the classroom, and one with much more empirical support in terms of improving students' learning, is to teach in a manner that replicates the research process, e.g., by using an inductive teaching approach such as inquiry-based or problem-based learning. The potential for inductive methods to achieve the benefits frequently claimed for bringing research into the classroom (e.g., the ability of faculty to share their research experiences in ways that enhance their own and their students' enthusiasm, the development of students' research skills, and the motivation and training of students to pursue research) seems clear. However, the effectiveness of inductive methods at achieving those outcomes in practice, and whether a faculty's research experience truly provides a depth of experience that can enhance their ability to implement these methods, remains to be demonstrated. In addition, there are challenges in persuading faculty to adopt inductive teaching methods and equipping them to implement the methods successfully, a point we return to in the recommendation section.

III. Undergraduate Research

Engaging students in research projects is frequently cited as an effective way to link faculty research and undergraduate teaching, a major goal of this study. Sabatini [35] cites several examples of how undergraduates and high school students can be involved in engineering research, and the NSF Research Experience for Undergraduates (REU) program [36] promotes and supports research involvement. While this activity clearly has the potential to benefit students (proposition 1), determining whether undergraduate research strengthens the research-teaching nexus in practice (proposition 2) requires an analysis of how much undergraduate research programs have benefited students and what percentage of students have reaped those benefits. It is also worthwhile to examine how programs should be structured to maximize any benefits and extend them to a broad spectrum of the student body.

Pascarella and Terenzini [37], drawing on an extensive literature base, note several positive outcomes for students who participate in undergraduate research programs, including greater retention in the curriculum and greater likelihood of enrolling in graduate school. On the other hand, Seymour et al. [38] question much of the literature in this field, arguing that most studies of undergraduate research did not include proper control groups, used biased samples, inferred causation from correlation or failed to provide sufficient details of their evaluation methods. The sections that follow contribute to the scholarly analysis of this question by providing an overview of the relevant research, keeping Seymour's cautions in mind, and organizing the major findings in terms of the types of student benefits reported.

A. Retention of Students in Academic Programs

Astin [22] looked at data from over 24,000 students on over 300 college campuses and found that undergraduate student research involvement correlated positively with the students' attainment of the bachelor's degree, commitment to the goal of making a theoretical contribution to science, and self-reported growth in preparation for graduate or professional school. He also found positive correlations between research involvement and a broad range of self-reported growth measures and satisfaction with many aspects of the educational experience. Results similar to Astin's are reported by Heath [39], who used Astin's stepwise multiple regression approach to analyze data on over 26,000 students.

Nadga et al. [40] examined the effect of participating in the University of Michigan's Undergraduate Research Opportunity Program (UROP) in a study that included over 1,200 students in matched control groups. Students who participated in the UROP program had higher retention rates than those in the control groups, even when the contributions of prior grades, standardized test scores, and ethnicity were factored out; however these findings were only statistically significant for African-American students (10.1 percent vs. 18.3 percent, $p < 0.03$). The average attrition rate for Caucasian students in the UROP program was about half of that for the matched control group (3.2 percent vs. 6.1 percent), although the difference was not statistically significant, and Hispanic students in the UROP and control populations had almost identical attrition rates (11.6 percent vs. 11.3 percent).

The critical elements of UROP are worth mentioning in view of the program's success. Those elements were early student recruitment, peer advising, formation of peer research interest groups, active recruitment of faculty, mutual selection of students and faculty advisors, opportunities for research presentations, and student choice of the academic credits assigned to the research course and the type of assessment to be used. Nagda et al. [40] observed that the study provided little basis for determining which components of UROP were especially effective in promoting student retention, but they speculate that regular faculty contact and peer mentoring were significant factors. In separate studies, Lopatto [41] and Alexander et al. [42] reached similar conclusions about the importance of faculty establishing a good mentoring relationship with their advisees. Lopatto also speculated that the relative ease of doing so at smaller

institutions explains why programs lacking the impressive research facilities of larger schools still produce higher proportions of students who go on to graduate study. The identification of good mentoring relationships as a key component of the programs raises an interesting research question as to whether many of the student benefits of mentored research stem primarily from close student-faculty interactions that might be achievable in other ways that might be less resource-intensive.

B. Pursuit of Graduate Study

Several articles suggest that involving students in undergraduate research promotes their subsequent pursuit of advanced study. Even if this outcome were confirmed, it would not guarantee that the research involvement led to the acquisition of greater knowledge or skills, but most faculty members would consider it a positive effect and so we will summarize the relevant evidence.

Heath [39] found a significant positive correlation between undergraduate research involvement and pursuit of graduate study for both Caucasian and African-American students, with the effect being stronger for the African-Americans. Fitzsimmons et al. [43] similarly found that participation in the NSF-sponsored REU Program had a positive effect on students' plans for graduate study. Of almost 2,000 students surveyed, 75 percent anticipated pursuing a graduate degree before participating in the program and 92 percent reported their intention of doing so after participating. Also, 80 percent of the students reported that participating in the program increased their interest in science and engineering. Kremer and Bringle [44], using nonrandomized but comparable control groups, found that participation in a summer research experience positively influenced students' likelihood both to work in their major field of study and to attend graduate programs that were more highly ranked with respect to research productivity.

However, not all studies show the same impact of research involvement on the decision to pursue graduate study. Lopatto [45] surveyed over 1,000 student participants in research programs at 41 institutions. More than 83 percent of the respondents reported that the experience did not affect their prior decisions about pursuing graduate study; only 3.5 percent of the respondents reported that the experience changed their mind positively about attending graduate school; and 4.5 percent had planned to attend but decided not to do so as a result of their research experience.

The strongest support for the hypothesis that research involvement positively influences the choice to go to graduate school comes from programs designed for African-American students. Seymour et al. [38] note that such programs often differ from other research programs in that they tend to engage students early in their academic careers, perhaps as early as high school, and generally extend over two summers of research experience. In a continuation of the previously cited studies by Nagda et al. [40], Hathaway et al. [46] carried out a controlled study comparing students who participated in research with non-participants. Both the research and non-research groups were randomly drawn from a population of students who applied to participate in the research program, so self-selection bias was not an issue. There were no statistically significant differences in subsequent graduate school attendance between Caucasian or Asian-American participants and non-participants; however, roughly 80 percent of African-American participants attended graduate school while only 57 percent of the non-participants did so, a statistically significant difference ($p < 0.01$). Less rigorous studies reported by Foerstch et al. [47] and Alexander et al. [42] led to similar conclusions: research program participants stated that their involvement made them aware of research as a viable option, gave them the confidence to pursue graduate school, and led them to pursue graduate school in numbers significantly higher than the national average.

C. Cognitive Learning Gains

While many authors claim or imply that participating in research promotes significant knowledge gains and other cognitive benefits, empirical evidence for such claims is thin and sometimes contradictory. Fitzsimmons et al. [43] report, for example, that faculty advisors of REU projects claimed that the experiences helped their advisees acquire substantive knowledge of the field but the advisees themselves did not fully agree.

We found only two studies that provide support for claims that research promotes cognitive gains. Rauckhorst [48] studied the impact of a summer research experience on students' intellectual development, using the Baxter Magolda epistemological reflection model [49] as the basis of his assessments, and found that the student researchers were more likely to make the transition to independent knowing than were students in a control group. Ishiyama [50] examined the impact of research participation on the performance of political science students taking the Major Field Aptitude Test. He found that students who presented collaborative conference papers performed better on this test than students who did not, even adjusting for "raw ability" as measured by their incoming ACT scores. Such studies suggest that involving students in research may result in learning gains or other forms of cognitive development, but more extensive studies are needed to draw firm conclusions.

D. Acquisition of Research Knowledge and Skills

Several studies examine how well involving undergraduate students in research promotes the acquisition of research-related skills. Kremmer and Bringle [44] note that students who engaged in an intensive ten-week summer research experience reported greater increases in research skills than did students in a control group. Kardash [51], Seymour et al. [38], Lopatto [45], Kardash [51], and Zydney et al. [52] present similar self-reported gains in research skills resulting from research experiences. Ryder, Leach, and Driver [53] report that research experiences enhanced students' understanding of the nature and development of scientific knowledge, while Seymour et al. [38] report student claims that research helped them "think like a scientist," and Lopatto [45] reports students' self-assessed gains in understanding the research process as a result of their own research experiences. While these claimed benefits of research involvement are plausible, they are all based on self-reports rather than direct assessment of gains in research skills. A study that involves such an assessment would be a worthwhile contribution to the literature.

E. Affective Outcomes

One of the strongest and most consistent findings regarding student involvement in undergraduate research is that students (and faculty) overwhelmingly find it to be a positive experience. Bauer and Bennett [54] surveyed 986 alumni (59 percent of whom had majored in engineering or the sciences) and found that students who participated in undergraduate research reported greater overall satisfaction with their undergraduate experience and more positive perceptions about whether their education enhanced their

"ability to develop intellectual curiosity, acquire information independently, understand scientific findings, analyze literature critically, speak effectively, act as a leader, and possess clear career goals." The statistical analysis that led to this conclusion took into account the students' entering grade-point averages. Seymour et al. [38] interviewed 76 students who participated in summer research programs and found that 91 percent of their statements about their research experience related to gains, lending "substantial support to the proposition that undergraduate research is an educational and personal-growth experience with many transferable benefits." Similar results are reported by Rauckhorst [48] and Lopatto [45].

F. Limitations of Undergraduate Research

While students clearly benefit from being involved in research, the benefits generally reach only a limited subset of the student population, with the participants being mainly top students. Of the 91 research institutions surveyed by Katkin [55], only seven reported having a research requirement for all graduates, 16 percent involved 75 percent or more of the students in research, and 48 percent involved fewer than 25 percent of them. Research is a resource-intensive activity, requiring laboratory space, specialized equipment, and considerable faculty time. Undergraduate research may thus consume valuable resources to benefit a relatively small number of students-resources that might instead be directed to instructional activities that could benefit most students. It would be worthwhile to study the costs and benefits, both educational and with respect to enhanced research productivity, of involving undergraduate students in ongoing research programs.

Most universities do not have the resources to provide research opportunities to all undergraduate students, and some question the wisdom of trying to do so [55]. The major limitations are resources and the rising expectations for faculty research productivity. This latter restriction is increasingly addressed by relying on doctoral students and research staff to provide undergraduate research supervision and mentoring. A discussion of the different challenges in stimulating and sustaining increased undergraduate research at both public and private institutions is provided by Merkel [56].

In summary, the answer to the question "Has undergraduate research been shown to strengthen the research-teaching nexus in the sense that it produces better learning?" is a qualified yes. Involvement in research has been shown to correlate positively with student retention, with the greatest observed effects being seen for African-American students, and most participants in undergraduate research programs report that their experiences were both instructive and enjoyable. Research participants also report gains in research-related skills, although direct measures of these gains is currently lacking, and there is very little evidence that undergraduate research has much of an effect on students' content knowledge. Research involvement may also have a positive effect on students' plans to pursue graduate study. Finally, undergraduate research at most universities is limited primarily to relatively strong students who constitute a small percentage of the student population, so that the impact of whatever benefits may exist is similarly limited.

IV. Broadening the Definition of Research

Another potential strategy to strengthen the connection between faculty research and undergraduate teaching is to broaden the definition of research to include forms of scholarship other than conventional frontier research, such as research on teaching and learning. If faculty members study innovative instructional methods, evaluate the extent to which the methods improve knowledge acquisition and skill development, apply the outcomes to their own courses, and publish relevant findings that can be used by other instructors to improve their teaching, it is reasonable to hypothesize that improved learning should result.

Educational research is a component of a model for academic scholarship that originated in 1990 with the publication of Ernest Boyer's seminal *Scholarship Reconsidered* [57]. Boyer, then Head of the Carnegie Foundation for the Advancement of Teaching, proposed that the traditional definition of acceptable scholarship as research intended to advance the frontiers of knowledge of a discipline was too limited. He affirmed that frontier research (which he called the "Scholarship of Discovery") is a vitally important function of research universities, but no less so than scholarly efforts to extend new discoveries to broader contexts or across disciplines (the "Scholarship of Integration"), to apply the new knowledge to problems with far-reaching public impact (the "Scholarship of Application"), or to better understand and improve the educational process (the "Scholarship of Teaching," later modified to be the "Scholarship of Teaching and Learning"). The definitions of the four scholarships were elaborated and protocols for assessing them were set forth in a subsequent Carnegie Foundation monograph, *Scholarship Assessed* [58]. In recent years, many institutions have broadened their views of what constitutes acceptable scholarship, most using the Carnegie model as their framework [25, 59, 60].

In examining the existing and potential impact of broadening the definition of research on the strength of the research-teaching nexus, we consider three propositions, the first two being those we have considered throughout this paper: broadening the definition of research (1) has the potential to support teaching (i.e., to improve learning); (2) has been shown to support teaching in practice; and (3) increases the faculty's integration of teaching and research activities.

The third of these propositions has been investigated by Colbeck [26], who examined faculty activity reports at two institutions, one holding a traditional view of scholarship as frontier research and the other accepting a range of scholarly pursuits that corresponded to the four Carnegie forms. She found that faculty members carried out integrative activities significantly more often at the institution that adopted the Carnegie model, and concluded that "the broader the university definition of what counts for research, the more faculty are able to integrate research and classroom-oriented teaching." Based on this result, Colbeck argued that research universities should specifically collect information on integrative activities in faculty performance assessments and should view such activities positively when making personnel decisions. Similar points about the desirability of broadening the definition of research, particularly in faculty performance evaluation criteria, have been made by Brew [32], Zubrick et al. [25], Schön [61], Scott and Awbrey [62], and Weimer [63]. Greater integration of teaching and research may not automatically translate to improved teaching (proposition 2), but it surely increases the potential for it (proposition 1).

Having shown how promoting broader forms of scholarship can in principle lead to strengthening the research-teaching nexus, we now examine the evidence for whether it has been shown to strengthen that nexus in practice. We do this by first examining the evidence for the Scholarship of Teaching and Learning, which has a

more explicit connection to teaching, and then examining the evidence for the Scholarships of Integration and Application.

A. The Scholarship of Teaching and Learning

By its nature, the Scholarship of Teaching and Learning (SoTL) is arguably the Carnegie scholarship most likely to achieve the elusive synergy between teaching and research. It is often defined in relation to three types of knowledge that teachers may possess [64]: (1) *content knowledge*—knowledge of the facts, principles and methods in the discipline that is being taught, (2) *pedagogical knowledge*—understanding of the learning process and the conditions that facilitate and hinder it, independent of the discipline in which the learning takes place, and (3) *pedagogical content knowledge*—a term coined by Lee Shulman [65] to denote knowledge and understanding of the learning process in the context of a particular discipline. SoTL encompasses studies intended to advance pedagogical content knowledge that are made available for peer evaluation in the professional community [64].

That educational scholarship and education are connected is tautological-if one is engaged in research on teaching and learning, then the research is by definition linked to teaching and vice versa. Whether promoting SoTL on college campuses results in real educational benefits for students is not as self-evident, but it is reasonable to hypothesize that determining the effectiveness of instructional methods within a discipline and publicly disseminating the results of proven-effective methods through peer-reviewed scholarship should lead to improved teaching and learning. Within the engineering community, for example, journals such as *the Journal of Engineering Education*, *Advances in Engineering Education*, *IEEE Transactions on Education* and related publications are no doubt founded in part of this hypothesis. It is also reasonable to hypothesize that faculty engaged in the scholarship of teaching and learning will acquire a broader and deeper appreciation of educational issues that might translate into better teaching, and that by focusing their scholarly work on SoTL they might also be more inclined and able to test innovative instructional strategies that are better grounded in the educational literature. Therefore, promoting SoTL may lead to better penetration of educational research findings into actual classroom instruction. As with the other potential synergies examined in this paper, it remains to be seen whether this potential is realized in practice.

Some support for the validity of this hypothesis is provided by Huber and Hutchings [66], who surveyed 137 CASTL (Carnegie Academy for the Scholarship of Teaching and Learning) scholars about their experiences and received responses from 83 percent of them. Of the respondents, 98 percent reported investigating questions related to their own classroom teaching, and most of them reported changing their course designs (93 percent) and learning assessment procedures (92 percent), expecting more from their students (92 percent) and from themselves (87 percent), experiencing greater excitement in their teaching (98 percent), seeing improvements in their students' learning (87 percent), and documenting such improvements (81 percent). Moreover, many of the respondents reported that their SoTL had a positive influence on teaching in their departments beyond their own practice (72 percent) and influenced colleagues outside of their departments (80 percent).

Additional support for the positive impact of SoTL on teaching is provided by Ciccone and Meyers [67], who surveyed 245 faculty engaged in educational scholarship. Not only did most respondents become more interested in teaching and learning issues and come to value this form of scholarship more, but over 90 percent of them incorporated results of their research in their courses, showing clear integration of SoTL and classroom teaching. In other studies, O'Meara [60, 68] examined the effects of promoting educational research at the institutional level. She found that relative to institutions that encouraged and rewarded only traditional disciplinary scholarship, institutions that promoted SoTL reported a stronger connection between faculty priorities and their institutional missions, a heightened campus focus on the quality of undergraduate learning, and greater gains in the value attached to teaching in tenure and promotion decisions.

While the studies just cited are suggestive of a positive linkage between educational scholarship and teaching, they are largely based on self-reports. What is still needed is rigorous research demonstrating the existence and strength of the connection between educational scholarship and student learning. In other words, educational scholarship is the only way to determine the effectiveness of educational scholarship or any of the other proposals to strengthen the research-teaching nexus discussed in this paper. More generally, promoting a more rigorous and public analysis of educational practices through SoTL has been recognized as a potentially effective mechanism for addressing a range of issues facing higher education today [69].

B. The Scholarships of Integration and Application

Although the Scholarship of Teaching and Learning has the clearest potential of all four Carnegie scholarships to improve teaching, possibilities also exist for linkages between teaching and the Scholarships of Integration and Application. It seems likely that many engineering undergraduates would find problems in these contexts more accessible and relevant to their interests and career goals than typical frontier research problems tend to be. In principle then, faculty engaging in these forms of scholarship might motivate and engage a subset of students in ways that could lead to more widespread student involvement and perhaps greater learning.

Zubrick et al. [25] outline experiences at the University of Ballarat, a regional Australian university that explicitly adopted the four Carnegie scholarships as a basis for strengthening the research-teaching nexus, placing particular emphasis on the Scholarships of Integration and Application. Encouraging pursuit of those forms of scholarship strengthened partnerships between different disciplines within the university and between the university and local government and business entities, induced some faculty members with little interest in the Scholarship of Discovery to become involved with research, and provided the students with a broader range of learning opportunities. No information is given regarding actual learning outcomes except for some faculty members' informal comments about how much the students learned, so the true extent of benefits from expanding the definition of scholarship in this way remain to be determined.

To summarize the evidence that promoting broader definitions of scholarship strengthens the connection between research and teaching, there is limited but encouraging evidence that promoting the Scholarship of Teaching and Learning leads to both better integration of faculty research and teaching on college campuses and to positive impacts on faculty teaching and student learning. Additional research is necessary to determine the nature and strength of the synergies promoted by any of the Carnegie scholarships examined in this section, especially for the Scholarships of Integration and Application where the evidence that adopting these forms of scholarship enhances student learning is both indirect and very limited.

In addition, promoting alternate forms of scholarship as a strategy for strengthening the research-teaching nexus has limitations. Just as all faculty will not choose to adopt inquiry-based methods in their courses or to serve as undergraduate research project advisors, many engineering faculty will not choose to pursue SoTL, which requires a significant departure from their traditional research focus and training. However, in this study we are not advocating a one-size-fits-all approach for either faculty or institutions seeking to strengthen the linkages between faculty research and undergraduate teaching. Instead, we recommend that individual faculty members and institutions should choose from a variety of strategies which have the potential to strengthen the research-teaching nexus, basing the choice on their strengths and priorities as well as on the strength of the empirical evidence for each strategy, which this study seeks to provide.

V. Summary, Conclusions, and Recommendations

The research vs. teaching debate has been raging for a long time, and there is much to justify Weimer's [63] characterization of it as "old, tired, boring, and…not productive." A large part of the problem is that those who claim research supports teaching generally argue that synergies between research and teaching can occur in principle (proposition 1), while their opponents debate the different proposition that synergies occur in practice (proposition 2). The preceding sections of this paper review the research regarding proposition 2. In the next section we summarize the principal findings, and in the following one we offer recommendations for how the research-teaching nexus can be strengthened.

A. The Current State of the Nexus

There can be little doubt that potential synergies exist between faculty research and undergraduate teaching, but empirical studies clearly show that the existing linkage is weak. Several meta-analyses of the literature on the research-teaching nexus discredit the notion that faculty research productivity improves students' educational experience. Faculty research is not widely and effectively integrated into undergraduate courses. There are barriers to doing so in engineering and the sciences, and when integration does occur it may have both positive and negative effects on the quality of instruction. Undergraduate research produces several documented educational benefits: some studies show that research involvement improves student retention (notably that of African-Americans) in academic programs and influences students to pursue graduate study, but there is little direct evidence that it enhances learning and skill development (although several studies report indirect measures of improved research skills) and the benefits of research normally reach only a limited subset of the student body. Potential synergies between teaching and the Scholarships of Integration, Application, and Teaching and Learning are plausible, and for SoTL have been documented through preliminary studies, but so far the evidence that adopting the full range of Carnegie scholarships improves teaching and learning is limited, and it is unclear how extensively these models for scholarship will be adopted by engineering faculty.

B. Strengthening the Nexus

The case for strengthening the research-teaching nexus is made eloquently in the final Boyer Commission report:

> We believe that the basic direction of change is clear: undergraduates need to benefit from the unique opportunities and resources available in research universities; clumsy adaptations of the practices of liberal arts colleges will no longer serve. The research universities need to be able to give to their students a dimension of experience and capability they cannot get in any other setting, a research experience that is genuine and meaningful. They should turn out graduates who are well on their way to being mature scholars, articulate and adept in the techniques and methods of their chosen fields, ready for the challenges of professional life or advanced graduate study. Research universities have unique capabilities and resources; it is incumbent upon them to equip their graduates to undertake uniquely productive roles. [23, p. 38]

We believe that the situation in engineering education may have improved somewhat in the decade since the Boyer Commission report was issued, but clearly there is still much to be done if universities hope to encourage and support strong linkages between faculty research and undergraduate education. Following are our suggestions for measures that could move universities in this direction.

1. *Formally recognize and reward faculty members who successfully integrate their teaching and research:* Most faculty members adhere to the natural human tendency to pursue activities that are recognized and rewarded. As Colbeck suggests, one way to promote integration of teaching and research is to ask faculty members to explicitly list integrative activities in their annual activity reports as opposed to forcing them to sort all activities into one or the other domain [26, 69]. Flexible criteria for assessing integrative activities should be adopted, perhaps using NSF guidelines for integration strategies [71] as a model. If linkages of teaching and research are assessed in this manner and the outcomes are used to inform decisions regarding tenure, promotion, and merit raises, a growing number of such linkages would be the inevitable outcome.
2. *Establish faculty development programs in both teaching and research at the school or college level, including ways to integrate the two domains:* Most faculty members begin their academic careers with little or no training in either teaching or managing a research program, let alone in how to integrate the two. Giving new faculty some early guidance via workshops and/or mentorships could significantly strengthen the research-teaching nexus, and it would also go a long way toward enhancing both the institution's research productivity and the effectiveness of its teaching programs [72].
3. *Promote involvement in research for a broad spectrum of undergraduates, and make sure there is meaningful contact between the researchers and their advisors:* If involvement in undergraduate research is restricted to a small elite percentage of the student body, as our analysis shows is generally the case, the impact of the research on teaching is similarly limited and the faculty time and department resources that support the research may come at the expense of the mainstream undergraduate teaching program. On the other hand, research that is part of the undergraduate experience for most students has the potential to make a positive contribution to the department or school instructional program. While not all universities have the re-

sources and culture to support inclusive undergraduate research programs, many do [56].

Simply getting students to do research is not enough, however: for undergraduate research to yield the benefits it has been alleged to provide, the faculty must play an active mentoring role. In his study of the NSF REU program, Fitzsimmons [43] observed that "the more contact that students…had with their REU advisor, the greater the likelihood that they felt that their objectives in attending had been met."

4. *Recognize and reward faculty performance in all four Carnegie scholarships and apply the same performance standards to all of them:* Colbeck [26] found that faculty integrated their teaching and research activities to a greater extent when the institution's stated expectations for research permitted activities in all four of the Carnegie scholarships than when the expectations were limited to the Scholarship of Discovery. Moreover, the wide range of multidisciplinary and socially relevant projects that might become available if the definition of scholarship were broadened could attract many undergraduate students with minimal interest in frontier disciplinary research, and their interest in the work and motivation to engage in it could lead to learning gains at a level that has not been observed for traditional undergraduate research. A supporting recommendation to promote all four Carnegie scholarships, and guidelines for doing this within an engineering context, are provided by the American Society of Civil Engineers [73]

Doing research on teaching (the Scholarship of Teaching and Learning) and integrating successful innovations into classroom practice clearly have the potential to improve teaching and learning. Recognition of this within the engineering community is reflected by a recommendation to promote and reward educational research by the National Academy of Engineering [74]. We recommend, however, that additional studies should be conducted that document the impact of promoting broad scholarship models on student outcomes, preferably using direct measures rather than relying on self-reports as most existing studies do.

Suggestions to legitimize forms of scholarship other than the Scholarship of Discovery are troublesome to many administrators and faculty. A key to overcoming resistance to the idea is to ensure that products of non-traditional scholarship are held to the same evaluation standards of quality and peer-review as those traditionally applied to frontier research.

5. *Encourage faculty members to use inductive teaching methods (e.g., inquiry-based, problem-based, and project-based learning); provide faculty development programs that prepare them to do so; recognize and reward those who use the methods effectively; and assess the effectiveness of the methods for integrating research and teaching:* Integrating research into the undergraduate classroom may be better done by teaching in a manner that emulates the research process than by simply describing one's own research findings. Inductive methods, which involve such emulation, have been shown to improve a number of learning outcomes, so adopting this recommendation is quite likely to lead to positive learning results. Still speculative, however, are hypotheses that adopting inductive methods will better enable faculty to integrate their research experiences into their classes, encourage students to pursue independent research experiences of their own, or that inductive teaching effectively promotes development of the skills and attitudes that characterize expert researchers. Testing these hypotheses will be necessary to validate inductive teaching as a strategy for strengthening the research-teaching nexus.

Achieving widespread faculty adoption of inductive methods is not a trivial undertaking. It is difficult to motivate faculty to adopt unfamiliar instructional approaches because of the time it takes to learn and implement those approaches, fear of student resistance, and a natural human tendency to remain in one's comfort zone. Moreover, the fact that a professor has research skills does not automatically mean that he or she can effectively equip students with those skills. To promote the successful adoption of inductive methods, institutions should provide training in the methods and recognize efforts to adopt them in annual faculty performance evaluations [55].

6. *At the institutional level, recognize and reward academic departments and programs that adopt some or all of the preceding measures:* Departments, like individuals, respond to recognition. If a dean's goal is to promote the integration of teaching and research and departments take steps in that direction, acknowledging and rewarding those departments would provide incentives for other departments to do likewise.
7. *At the national level, government and philanthropic research funding agencies should stipulate in their proposal evaluation criteria that a subset of the projects they fund must have measurable impacts on undergraduate education:* The National Science Foundation has made excellent strides in this direction, particularly in its REU (Research Experiences for Undergraduates) and CAREER Award programs. We encourage an expansion of these efforts as well as expanding and funding studies of the extent to which these programs truly strengthen the research-teaching nexus.

This paper highlights the importance of promoting a strong link between faculty research and undergraduate teaching, while demonstrating that—despite widespread opinion to the contrary—the evidence for the existing link is weak at best. The state of the research-teaching nexus affects the quality of the education provided by universities across the research spectrum. The failure of research universities to forge strong links between teaching and research caused the Boyer Commission [23] to conclude that "Research universities have failed, and continue to fail, their undergraduate populations." Weak linkages between teaching and research are also an issue at colleges with strong teaching missions, since expectations for research have been rising steadily there as well.

We believe, however, that research has a clear *potential* to make significant contributions to the quality of undergraduate education, and we also agree with the Boyer Commission that universities have an obligation to make the research-teaching nexus as strong as it can be. The question is, how best to do it? The driving forces behind the heavy emphasis on research in the academic priority system—the quest for research dollars and the high institutional rankings that those dollars make possible—are unlikely to change significantly in the near future. University research also plays a vitally important role in its own right. Therefore, rather than lamenting the rising expectations for research, we think it more productive to seek ways to improve undergraduate education that work *with* the prevailing trend.

The strategies we have recommended in this paper are intended to do exactly that. They rely on the continued vitality of research on our campuses and seek to make better use of its presence than has been made in the past. Using a scholarly approach to test potential integration strategies can only increase the chances that the

synergies between teaching and research that now exist in primarily in principle will finally be realized in practice.

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