APPENDIX C:

# *Report of the Subcommittee on Physical Sciences*

# *Multidisciplinary Approaches to Physical Sciences and Engineering: Enhancing the Circuit Elements and Integrating the Circuit*

## Subcommittee

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## Executive Summary

The physical science and engineering academic units comprising the Physical Sciences Division have historically made significant contributions to the campus' research, education, and service missions. As we enter the next millennium, the creation and communication of knowledge is changing in extraordinary ways, driven by research developments derived in part from these traditional disciplines. To continue to play an important role in knowledge building and education, we must strengthen these units, metaphorically represented as circuit elements, and more tightly link them to one another and to other areas of scholarship, thereby "integrating the circuit." This report describes opportunities for enhancing the contributions that the Physical Sciences Division can make through its traditional structures and for developing infrastructure and human resources that will better position it to participate in the multidisciplinary research and education environment that we foresee as a characteristic of 21st century science and engineering.

General recommendations that we make to ensure our continuing national and global leadership include:

- Providing resources to improve our competitiveness in attracting leading scholars and students to our campus
- Enhancing the amount of faculty and academic staff time for effective scholarly reflection and professional growth
- Investing in infrastructure that will facilitate communication across campus and with the global community
- Identifying strategies for enhancing diversity and equity, chronically a severe problem in the Physical Sciences Division
- Broadening graduate training to reflect a more varied set of career options
- Creating active learning environments for our students that promote development of teamwork and communication skills
- Exposing all students to research activity, recognizing that the research prowess of the University is a strength for education
- Widening the opportunities for research participation for our majors
- Adding structures and resources for encouraging the Division to play a greater role in the Wisconsin Idea and global community
- Integrating assessment into our research and education programs

Much of our report addresses issues associated with promoting multidisciplinary research and education on campus. To further these efforts we suggest:

- Better recognition by the campus of the importance of professional development and group projects
- Increased support by the Graduate School for small multidisciplinary seed projects
- Establishment of a program through the Graduate School for "in-house" sabbaticals, where participants could serve as bridges between academic units
- Revision of policies associated with joint appointments so as to facilitate their use across campus

- Establishment of a policy of tying student credit hours to their course instructors to promote multidisciplinary teaching initiatives
- Exploration of new options for the master's degrees, including "blended degrees" that merge fields and that would address human resource needs associated with the Wisconsin Idea and our participation in the global community

Finally, we recommend consideration of alternative structures for the Divisional Committee to address these issues in additional depth and with broadened Divisional participation.

### Multidisciplinary Approaches to Physical Sciences and Engineering: Enhancing the Circuit Elements and Integrating the Circuit

## Preamble

Research developments in the physical sciences and engineering have revolutionized our lives, as they have created both the Information Age and Materials Age that define our civilization. The computer provides a compelling benchmark for these developments. For example, we can now place a greater number of electronic components on a silicon wafer than there are people on Earth! [1] While many of the stunning developments shaping our research enterprise have originated from traditional physical science and engineering disciplines, "Many new discoveries are being made on the margins and at the intersections of established fields...Collaborations of persons with expertise in a number of fields is often required to solve different aspects of a complex problem, because no one human being is capable of mastering all the necessary knowledge." [2] Examples of current hybrid fields of scholarship are environmental science, materials science, and biotechnology. In environmental science enormous amounts of geological, hydrological, and meteorological data are easily manipulated with databases and modeled, using tools developed from mathematics and computer science, to enable us to better understand our atmosphere, hydrosphere, geosphere, and their interdependence. Through materials science, we can, with increasing sophistication, calculate properties of materials, build them virtually atom by atom, and incorporate them into devices, representing a confluence of physics, chemistry, and engineering. With biotechnology, the physical sciences and engineering unite with the life sciences to create new biomaterials and bioprocesses.

Established disciplines will remain the foundation of the campus landscape, as they provide well-developed, self-consistent frameworks within which many classes of complex systems and phenomena can be described and understood. This discussion will focus both on enhancing traditional strengths of the campus and on developing a campus infrastructure that recognizes the emerging paradigm of multidisciplinary scholarship. In the metaphor of traditional disciplines as circuit elements, broadening the base of scholarship so as to link traditional disciplines-integrating the circuit-affords the opportunity to make the whole much more than the sum of its parts. As we hope to show in this chapter, such an effort has the potential not only to expand knowledge dramatically, but also to embrace a wider and more diverse population, both as participants in its creation and as beneficiaries of the value it adds to our society. Nurturing such multidisciplinary approaches to the advancement of knowledge thus captures the spirit of both the Wisconsin Idea and of the global community.

The principal themes that we believe can contribute to this vision of multidisciplinary research and education are associated with infrastructure and human resource development. There are many ways, we believe, in which our institution can foster multidisciplinary partnerships by modifying its structures and values. We explore strategies for ensuring that faculty and academic staff who wish to participate in such partnerships as an integral part of their professional development have the encouragement and resources for efforts of high quality. For our students, we identify mechanisms for providing a less compartmentalized, more flexible education. A promising approach for achieving these objectives may be the master's degree, which we feel has the potential to be a powerful tool for forging new partnerships across disciplines, making our students more marketable, and increasing access for underrepresented groups. Collectively, the initiatives that are described in this document address our campus vision priorities: They will enable us to retain our research pre-eminence, reconceptualize undergraduate education, contribute to the modernization of the Wisconsin Idea, and integrate our efforts into the global community.

**Demonstrations that research improves the quality of our lives, our competitiveness, and our future prospects are often found in multidisciplinary research efforts such as those leading to the banning of chlorofluorocarbons (CFCs) to protect the ozone layer, the creation of ever more powerful and affordable computers, and the exploration of space.**

## Introduction

Reliance on individual research programs, conducted in traditional physical sciences and engineering disciplines, will always continue to be a strength of our institution. Many of our departments are highly ranked nationally, and there is a rich tradition of research leadership emerging from the work of individual principal investigators (PIs) and their co-workers. There is an increasing contribution to the research enterprise of multidisciplinary, collaborative work that bridges our strong, traditional physical sciences and engineering disciplines. Indeed, scholarship in fields like drug design, neuroscience, and biomedical engineering also embraces the life sciences as part of a developing multidisciplinary research culture. In this section we describe some of the drivers for this trend and its appeal to individual investigators.

A principal impetus for multidisciplinary research is societal. Our society is concerned with a multitude of intrinsically multidisciplinary scientific and technical issues, including environmental quality, national defense and security, energy, health, and the economy. The physical sciences and engineering have historically made significant contributions to all of these arenas. While our society celebrates these contributions, there is an understandable need to justify the use of scarce tax dollars to support the basic and applied research leading to progress in these areas, and a trend toward increasing accountability for how effectively the funds have been spent. Demonstrations that research improves the quality of our lives, our competitiveness, and our future prospects are often found in multidisciplinary research efforts such as those leading to the banning of chlorofluorocarbons (CFCs) to protect the ozone layer, the creation of ever more powerful and affordable computers, and the exploration of space. Furthermore, multidisciplinary research may be needed to evaluate long-term effects of new technologies, as illustrated by CFCs.

Sources of federal funding, which support the majority of our university and our national academic research expenditures, have recognized the need to diversify their portfolio beyond the traditional individual principal investigator grants. The National Science Foundation, for example, has initiated competitive programs like the Engineering Research Centers (ERCs), the Materials Research Science and Engineering Centers (MRSECs) , the Science and Technology Centers (STCs), the Integrative Graduate Education and Research Training Program (IGERT), and the National Institute for Science Education (NISE). Similarly, the National Institutes of Health has introduced Biotechnology Training Grants and Molecular Biophysics Training Grants. In each case, the intent is to provide comparatively large sums of funding to encourage groups of investigators from different disciplines to work together on multidisciplinary projects and to train students to work in such hybrid fields. Staff from the Colleges of Engineering, Letters & Science, and Agriculture and Life Science and from the School of Education have collaborated effectively through many of these programs. Additional benefits include broadened training experiences for undergraduate, graduate, and postdoctoral students, and resources to acquire equipment that would likely be beyond the reach of individual PIs.

An important perspective on multidisciplinary research is provided from campus funding trends. One metric is the percentage of multi-PI awards on the UW–Madison campus and the percentage of total research dollars that they represent. As Figure 1 illustrates, the percentage of multi-PI awards is relatively small and has remained roughly constant at less than 10% of all awards. However, the dollar value has increased substantially over the past decade, from less than 10% to almost 15%. In many respects, multi-disciplinary projects, involving multiple PIs from the same or different departments, represent an area of substantial potential growth for campus research. While this report emphasizes strategies for positioning ourselves to take advantage of this trend, we also underscore the need to enhance our traditionally strong disciplines, which account for the substantial majority of campus research activities.

What causes researchers to work collaboratively across disciplines, despite the difficulties inherent in doing so? Part of the drive is that there are exciting challenges and opportunities that build upon traditional discipline-based knowledge. An illustration is provided by the scanning tunneling microscope (STM), whose invention was recognized by the 1986 Nobel Prize in physics. The basis for this invention is the understanding of tunneling that emerged from quantum mechanics. With the STM and related tools, multidisciplinary teams can now image biologically important molecules and construct matter on an atom-by-atom basis.

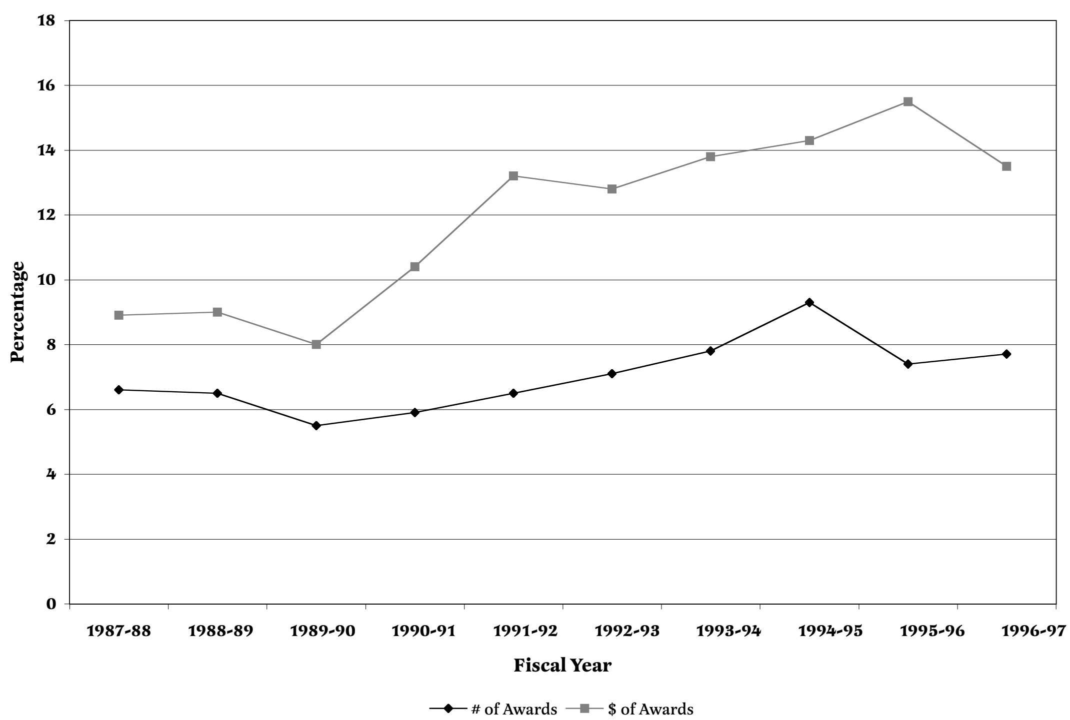


**Figure 1:** "Percent of Awards and Dollar Amount of Awards" Source: Office of Budget, Planning and Analysis

The opportunities provided by multidisciplinary research have parallels in undergraduate and graduate education. Increasingly, the educational enterprise is being recognized as the same kind of moving target as the research enterprise. At the undergraduate level, the National Science Foundation, National Research Council, and Carnegie Foundation for the Advancement of Teaching have all recently advocated fresh approaches to the teaching of science, mathematics, and engineering at research universities that emphasize inquiry-based instruction, collaborative learning methods, integration of research experiences, and promotion of multidisciplinary educational approaches. [3–6] The broadened perspectives provided by a multidisciplinary curriculum can help to recruit a talented, diverse group of students to technical careers as well as enhance science literacy and numeracy for all students: The solution of multidisciplinary technical problems of relevance to society is of keen interest to many students and staff. By widening our definition of scholarship to be more inclusive, we may increase student and staff participation and public interest, enhancing equity in the process. At the graduate level, the National Academy of Science's Committee on Science, Engineering, and Public Policy (COSEPUP) has called for a broadening of traditional doctoral training, including exposure to multidisciplinary approaches to research. [7] The master's degree may provide new opportunities for multidisciplinary graduate education and stimulate market demand for students trained in this way. [8] This degree allows for considerable curricular experimentation, including the blending of different traditional disciplines such as science with teacher preparation, or engineering with business training.

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**Assessment.** An overarching theme associated with forthcoming initiatives in higher education is the need for assessment. The demand for accountability, particularly at public institutions such as UW–Madison, means that as curricular and programmatic changes are instituted, benchmarks are needed to assess their impact. In many respects assessment efforts are experiments in progress, and the tools for conducting them are rapidly evolving. For instructors, guidelines for assessing the scholarship of teaching have recently been published by the Carnegie Foundation for the Advancement of Teaching. [9] At the classroom level, we will likely soon have "point and click" capability so that, with appropriate security measures, instructors will be able to use the web and powerful databases to follow groups of students through the curriculum. A variety of tools for classroom assessment are being developed and shared using the web. [10] Instructors will thus be able to evaluate their effectiveness on the basis of student achievement, persistence, and attitude, past and subsequent performance, and differential impact, i.e., determining whether all population groups are equally successful. At the department and program level, undergraduate majors and graduate students can be surveyed while in school and afterward, from their broadened perspectives as alumni, to assess the strengths and weaknesses of the programs. Likewise, employers will be asked how effectively students were prepared for their work. Assessment will thus provide an increasingly sophisticated set of tools for informing curricular and programmatic innovation.

## General Recommendations—Enhancing the Circuit Elements

Our campus is justifiably renowned for its pre-eminence in research, the outstanding education it provides, and its multifaceted contributions to the State of Wisconsin and the global community. Through its traditionally strong departments, the Physical Sciences Division has been and will continue to be integral to the campus' success in these areas. In this section we identify issues that we believe need to be addressed to strengthen our departments if we are to continue to provide state, national, and international leadership.

**Professional Development.** We believe that a more holistic view of the professional development of our faculty and academic staff is needed that recognizes the challenges and opportunities associated with various career stages. Exploring a new research field, innovating in a course, and nucleating an outreach activity are examples of professional development that are energizing, and this vitality is shared with our students and with the broader society served through the Wisconsin Idea and global community. For professional development to thrive, however, we believe that the campus needs to recognize more explicitly both the many pressures on limited staff time and the multi-dimensional contributions that staff can make in research, teaching, and service over the course of their careers.

For faculty members beginning their careers, we advocate establishment of a mandatory, intensive orientation program of several days length that might take place within the first year of a faculty member's arrival. Modeled after our NSF-funded Engineering Education Scholars Program for graduate students contemplating faculty positions, the orientation might include presentations by successful faculty role models on such topics as grant writing, supervision of co-workers, new instructional methods, equity, and ethics. Such an immersive, concentrated program would both connect these individuals to one another and "calibrate" faculty as to campus culture and expectations. Moreover, it could provide a forum for discussing a variety of other issues bearing on tenure, including pre-tenure research collaborations, the scholarship of teaching, and characteristics of service, with administrators and Divisional committee representatives.

In later career stages, we believe that sustained staff productivity is critically dependent on providing adequate time and resources so that new research, teaching and service directions can be thoughtfully identified and productively pursued. Our campus sabbatical program is an established, effective mechanism for professional growth that merits additional resources. We encourage the Graduate School to use more of its resources for mid-career faculty who wish to explore new research directions. The recently instituted post-tenure review process provides an excellent opportunity to provide faculty with periodic constructive peer feedback on their professional goals.

**Research.** Maintaining our research pre-eminence in the physical sciences and engineering will continue to require a substantial investment in staff and students, for which there is stiff national competition from our peer institutions. The "graying" of the faculty is a major issue in the Physical Sciences Division, as a third of the faculty is predicted to retire in the next ten years, [11] and start-up packages are costly. Over the past 20 years, market forces have caused start-up packages in the Physical Sciences Division to rise by an order of magnitude, so that they are now often in the range of $250k to $500k for junior faculty and $1M for senior faculty with experimental programs. A cross-campus discussion of the best way to finance these packages from Graduate School, College and Department funds is needed, as there is concern over whether the current financing structures are sustainable. Similarly, market forces have sharpened competition for the best graduate students. If we wish to remain a "national" university in the eyes of prospective faculty and graduate students, strategies for effective recruitment need to be re-evaluated. We applaud the recent commitment of the Graduate School to help raise substantial funds for graduate recruitment.

We urge the sustained development of mechanisms that facilitate acquisition of resources for our campus. For example, the electronic COS Funding Alert provides timely identification of funding opportunities to which PIs can respond. The campus is urged to continue to streamline mechanisms for applying for funding and for providing the necessary accountability associated with awarded funds through web-accessible resources and adequate support personnel. The College of Engineering provides excellent models of resource development and grant administration.

**Undergraduate Education.** We support the shift in undergraduate education to learning environments in which students are more active participants: students in our courses have a right to expect stimulating, inquiry-based instruction that recognizes a diversity of learning styles, illustrates the research process and includes cutting-edge exemplars. [3–6] There is also considerable evidence that student performance, persistence, and attitudes are greatly enhanced by use of cooperative learning methods. [12,13] Exposing all undergraduates to user-friendly, engaging courses at the introductory level that include exposure to current research ideas and methods will enhance science literacy and numeracy and produce citizens better able to participate in decisions involving technical issues. A critically important segment of our undergraduate audience, prospective pre-college teachers, will particularly benefit from this approach, elements of which can be imported into their classrooms. We need to view our courses as pumps, not filters.

For physical science and engineering majors, coursework should build communication and teamwork skills and develop an understanding of professional ethics, along with technical skills. We endorse the notion that participation in a research project, such as is afforded by the Hilldale fellowships or an industrial internship, should be an integral part of the undergraduate experience. We encourage experimenting with new strategies for integrating research with undergraduate education. One possible mechanism that would also help keep the curriculum current is to have undergraduates assist in the creation of new laboratory experiments, demonstrations, text, software, and multimedia products from current research as part of courses in which they are enrolled (see below). A second strategy is to make increased use of service learning. Undergraduates might, for example, conduct research of value to local communities or industry with supervision from graduate student teaching assistants (TAs), staff and faculty; or they might participate in projects in cooperation with K–12 teachers.

**For physical science and engineering majors, coursework should build communication and teamwork skills and develop an understanding of professional ethics, along with technical skills.**

**The Wisconsin Idea and the Global Community.** Sharing our expertise with individuals outside of our campus is a hallmark of the Wisconsin Idea and our participation in the global community. We urge more involvement by more members of the Physical Sciences Division in pre-college education. The national standards developed by the National Council of Teachers of Mathematics, American Association for the Advancement of Science, and the National Research Council [14–16] for K–12 education promotes a less compartmentalized view of science and technology that embraces all of our traditional disciplines. Individuals and teams from a variety of campus departments are to be commended for helping to develop these standards. The campus needs to encourage continuation of such participation, as we all have a stake in high quality pre-college education, but there is currently little in the way of an infrastructure, resources, or incentives to facilitate the involvement of Divisional staff. Partnerships with state policymakers and with the private sector through internships, technology transfer, and consulting represent other connections that can potentially be strengthened by involving staff and students and working with the campus' University-Industry Relations office and with WARF. Our alumni represent a largely underutilized resource for helping us integrate our activities into the state and global communities, and we urge the development of stronger ties with our graduates. Faculty and staff have traditionally contributed to outstanding outreach efforts such as the biannual Engineering Expo, Geology Museum, Space Place, the WhyFiles website [17], and annual special lectures for the community from staff in the Chemistry and Physics Departments. The campus needs to encourage more faculty and staff to become involved in outreach activities. At the Divisional level this requires recognition that such contributions are valued.

**Infrastructure.** Many of the initiatives described above can be facilitated by high-speed communication technologies, including site-to-site video linkages. These technologies can, for example, permit remote consultation and use of equipment in real time. They can make it possible to share our expertise with individuals anywhere in the world, promoting distance learning possibilities. While the introduction of this infrastructure represents a sizeable investment, it offers many creative possibilities for breaking down barriers to communication among individuals. We urge the campus to invest heavily in this infrastructure, not only as a mechanism for promoting more effective campus research and education, but as a means to further the objectives of the Wisconsin Idea and the global community by making the campus more accessible to individuals who are outside of its physical boundaries.

**Diversity and Equity.** A critical concern for the Physical Sciences Division is that it is woefully imbalanced in terms of gender, racial and ethnic representation among its faculty, academic and administrative staff, and students. Such an imbalance impairs our ability to recruit and train a diverse group of talented students, to apply our research strengths to meet the needs of the state and the global economy, and to serve as an attractive environment for investment. Several major companies that recruit from the physical sciences and engineering fields have expressed their frustration over the campus' lack of diversity. [18] A strategy for addressing this problem is to examine processes and structures in the university that might serve as disincentives to achieving diversity. An example that would be worth studying is the current tenure process, which may serve as a disincentive to faculty diversity, by demanding that young scholars spend their 30's juggling the dual demands of career establishment and family growth. Student recruitment could be improved by identifying what prevents talented students from underrepresented groups from attending UW–Madison and working with campus and state colleagues to remove barriers to enrollment. Like recruitment, retention strategies need to be critically examined. Faculty, staff and students from underrepresented groups must be made to feel that they are valued participants in the life of the Division and that their opportunities for professional development are well served by the Division.

**Citizenship.** The Committee reaffirms the importance of campus citizenship. At the individual level, *all* colleagues should contribute some form of campus service, such as participating on a university-wide committee, serving in the Faculty Senate, or chairing a department or program. Divisional members have a responsibility as university citizens to share their expertise by providing prompt, courteous responses to requests for information from citizens and the media. At the level of academic units, good citizenship is reflected in such efforts as working together on spousal hires and joint appointments.

## Promoting Multidisciplinary Activities—Integrating The Circuit.

**Professional Development.** A major strength of multidisciplinary initiatives is the opportunity they provide for ongoing professional development for the staff of our institution. The campus can help to promote these initiatives by recognizing outstanding efforts by groups of individuals, either within or across departments and programs, in the areas of research, teaching and service. We recommend that the campus re-evaluate its recognition structures so as to ensure that they will enhance our campus by enabling our staff to contribute more broadly to the campus missions through teamwork.

**Research Infrastructure**. Multidisciplinary initiatives can be substantially advanced by a physical environment that supports co-locality. Our industrial colleagues often physically co-locate teams working on a common project. Venture research and development efforts in the commercial sector are frequently started in "incubator" settings, where temporary allocations of minimal amounts of shared space allow a multidisciplinary project to be initiated, and universities have begun to provide and market this service. [19] Although co-location of university personnel is not always feasible on our campus because of the expense involved, campus allocations of building space need to be flexible enough to provide centrally-coordinated space for new research centers, programs, and institutes on short time-scales without disrupting other productive campus activities. Likewise, flexibility in parking assignments can allow collaborators to meet in person as the need arises. The investment in infrastructure for enhancing electronic communication that we advocate (see above) would pay substantial dividends in promoting multidisciplinary research.

Facilitation of proposal submission is also important for encouraging collaborative research. Ideally, it should be as easy to submit a proposal and manage a project involving multiple investigators from different colleges as for a single PI from a single college. The Graduate School has customarily supported efforts to attract large multidisciplinary Centers to the campus through generous matching funds, a tradition we enthusiastically endorse. At the same time, we urge the Graduate School to lend its support to smaller collaborative efforts by allocating part of its resources to funding start-up multidisciplinary projects (and providing insurance support for them when they are submitted for extramural support) through the annual campus Research Committee competition.

**"In-House" Sabbaticals.** In the same spirit, we urge the Graduate School to provide funds for "in-house" sabbaticals, wherein staff would have the opportunity to spend a semester or a year as part of another department on campus. This would be particularly appealing to staff members for whom physically relocating for a sabbatical is a hardship because of, e.g., family considerations. At the same time, we view in-house sabbaticals as a mechanism for broadening perspectives of both the donor and acceptor academic units and perhaps even as a tool for enhancing diversity awareness, if members of underrepresented groups participate in such a program.

**"Cluster Hires."** The campus can also help catalyze multidisciplinary research. The so-called "cluster hires" initiative was enthusiastically received and led to nearly 100 multidisciplinary proposals across campus. Several of the successful proposals, including genomics and nanoscale materials, were led by scientists from the Physical Sciences Division. By adding faculty in these areas, we envision stronger connections among participating academic units around the campus and greater potential for promoting multidisciplinary research and education. Departments, too, are encouraged to broaden themselves as they recruit. By recruiting new staff who push the boundaries of their discipline, departments reaffirm their intention to be "living" units that reflect intellectual frontiers. Several physical sciences and engineering departments have also used such hires as an opportunity to increase the number of faculty from underrepresented groups on their staff.

**Joint Appointments.** Faculty appointments that result from efforts like the "cluster hires" initiative represent an opportunity for faculty to participate in two or more departments to the mutual benefit of the departments and the faculty member. Because these appointments contribute substantially to the multidisciplinary culture of the campus, it is important that existing University structures adequately accommodate them. Presently, faculty who hold joint appointments typically must go through a review committee for each department and have to establish detailed accounting procedures for each department, which are labor-intensive processes. Moreover, if each home department has a tendency to view the individual as a full-time member, then the efforts of the individual will be evaluated as less than satisfactory by each department. Collectively, these are disincentives to individuals contemplating such a joint appointment. A possible solution to this problem rests in appointing a review and merit committee comprising members from each of the home departments. Refining the University financial model to facilitate sharing of grant funds or indirect cost recovery by two or more departments is needed.

**Exposure to multidisciplinary research perspectives should be an integral part of the graduate experience.**

**New Research Structures.** Large, complex, multidisciplinary units like Centers raise several key issues. Their management places unusual demands on the PI, reflecting not only scientific, but legal and ethical issues as well. We urge the campus to develop an infrastructure that adequately prepares PIs to manage such units. This includes developing streamlined management procedures that are common to such Centers (including making available a knowledgeable administrator), acquainting the PIs with relevant case studies, and linking PIs to other experienced, successful Center directors. Every effort should be made in establishing such Centers to recruit and retain a diverse group of participants, including individuals who are at early stages of their careers. The participation in multidisciplinary activities of untenured faculty members has historically been problematic, as the granting of tenure requires evidence of independent scholarly achievements. Yet these new faculty members bring fresh ideas and energy that can nourish multidisciplinary efforts. The Committee believes that some participation by untenured faculty members in collaborative projects should be encouraged so long as their individual contributions to the project can be documented, as should be the case for all participating faculty. Advantages of such participation to a new faculty member include more facile access to campus expertise and to human and capital resources, which can ultimately enhance the quality of their tenure documentation with regard to research, teaching, and service, since many multidisciplinary projects now include initiatives in all three of these traditional components of university life.

New program and departmental structures can grow out of multidisciplinary efforts, but require administrative nurturing to do so. It is important to provide incentives during the nascent stages of these units when they are most vulnerable. A program like Biomedical Engineering, for example, has great promise for uniting engineering with the life sciences, but may face substantial challenges to establishing its funding lines and support services without a supportive campus commitment.

**Doctoral Graduate Education.** Graduate education is at a crossroads and the focus of recent national conferences [7]. Discussion has centered on how to broaden the doctoral experience to train students for a wider range of career options, while changing faculty culture to support such a shift in training objectives. The NSF has recently unveiled the IGERT program, designed to promote a more multidisciplinary approach to graduate education. [20] Campus graduate enrollments have declined about 20% over the past decade and prompted concern about such issues as the nature and quality of career preparation that graduate training provides, the effectiveness of mentoring, and the length of time required to obtain a doctoral degree. Consideration should be given to alternative models that promote a more student-centered graduate experience. This committee believes that exposure to multidisciplinary research perspectives should be an integral part of the graduate experience and that this represents an updating of the philosophy behind the campus' so-called "minor requirement." In this spirit, we advocate assigning to each student a faculty advising team, ideally drawn from several academic units, that works with the student throughout his or her tenure at UW–Madison to develop a sound professional development plan and to closely monitor the student's progress so as to ensure timely completion of degree requirements. Additionally, we believe that there should be a greater emphasis placed on developing communication skills, both through formal coursework and research presentations to a variety of audiences. Participation in the development of new multidisciplinary curricular materials, as described below, would represent one such communication vehicle.

Nationally, there are discussions within certain disciplines regarding changing doctoral-level training in which our participation is crucial. For example, the American Astronomical Society is moderating a national debate within the astronomy community as to whether the master's degree should be a prerequisite for doctoral study at all U.S. universities. [21] Proponents argue that an enhanced M.S. degree could provide staff and students with an opportunity to "pause and reflect" on student career paths while enhancing skills that would be useful in a wide variety of technical careers. Such a staged degree path might attract a more diverse group of students for whom the substantial commitment of time to a doctoral program is unappealing for personal and/or financial reasons. Once exposed to a stimulating graduate environment, some of these students might in fact eventually obtain doctorates and take positions in academia. Concerns expressed with making the M.S. degree a prerequisite include additional time that may be needed to obtain a doctoral degree and possible negative impact on particular institutions.

**Undergraduate Education.** As discussed in the Introduction, there are major changes taking place in undergraduate education. Multidisciplinary courses like the popular "Ways of Knowing" and a planned symmetry-based course offer broad perspectives of value to all students. In this spirit, the Division is encouraged to consider instituting additional courses that illustrate the connections between science, engineering and technology. We believe that having undergraduates develop new instructional materials for college science, mathematics and engineering courses (see above) based on multidisciplinary research is worth exploring. This experience would provide an opportunity for undergraduates to work under the supervision of teams of graduate students and staff from a variety of departments, who have an interest in curriculum development. Such a design not only has the potential to freshen the curriculum perennially, but also to communicate the vitality and unbounded nature of the research enterprise to students. Examples of current multidisciplinary research that lend themselves to the development of instructional materials might include ferrofluids, linking chemistry, physics, chemical engineering, and life sciences; and chaotic systems, spanning mathematics, computer science, astronomy, physics, chemistry, and engineering. Products that are developed can potentially be used in a variety of courses on our campus and elsewhere. Furthermore, if an infrastructure can be developed to market some of these products and create a revenue stream, this mechanism for integrating research and education could become self-sustaining.

Many aspects of interdisciplinary teaching have recently been examined by the Physical Sciences Divisional Committee. [22]. We support the Divisional Committee's recommendation for a structure that better accounts for faculty time and student credit hours across colleges, schools, and departments. For example, if a faculty member contributes 10% of his or her effort to a course in another department, then 10% of the student credit hours are returned to the department. Existing accounting systems that do not disclose the amount of effort or student credit hours generated in collaborative teaching efforts should be replaced by this effort-accounting model, which can be summarized as "credit follows the instructor." We believe that this bookkeeping change alone will remove many obstacles to multidisciplinary teaching initiatives and lead to more experimentation and flexibility in our instructional efforts. Outstanding efforts along these lines should be acknowledged and rewarded, and these activities should be built into the departmental and college missions and cultures.

**Master's Degrees. New Perspectives on the Wisconsin Idea and the Global Community.** The University of Wisconsin is a premier research university, and at the graduate level in the physical sciences, generally the emphasis has been placed on the Ph.D. degree. This emphasis is discipline-specific; in some engineering fields and in computer science, for example, the M.S. degree is a sought-after professional degree and may even be more common than the Ph.D. Enrollments of graduate students (both M.S. and Ph.D) in the physical sciences and engineering decreased 5% to 9% from 1992 to 1995, the last year for which statistics were available from NSF. [23] This trend is striking in light of the increasingly technical nature of the workplace.

There has been considerable interest nationwide in revitalizing master's degree programs, which have been described as a "silent success," owing to their lack of visibility in some fields. [24] Recently, there has been a call for universities to take the lead in developing programs to train a "new breed" of science-trained professionals: persons whose jobs encompass science- or technology-based problem-solving, and persons conversant with science and technology but destined to work in allied fields such as patenting, technology management, policy, or education. [8] These educational programs are likely to be predominantly at the master's level. From a student's perspective, the master's degree can offer an excellent value in higher education in terms of lifetime earning enhancement relative to the time invested to acquire the degree, and there are many kinds of master's programs from which to choose. [24] Master's programs thus could be used to recruit a diverse group of students, including many with valuable work experience, and to prepare them for a wide variety of career opportunities. This degree program also typically produces revenue for the campus.

The position of the UW–Madison with respect to master's degrees is in flux. A recent survey released in 1997 indicates that our campus offers an "excess" number of master's degree programs compared to peer institutions, and enrollment in many of these programs is very low, [25] suggesting that such programs need to be reviewed periodically and phased out if they are no longer viable. At the same time, several new master's degree programs are in various stages of planning on campus.

This committee endorses development and/or expansion of master's programs at the UW–Madison campus that meet the needs of the state and the nation in educating a new generation of "knowledge workers." [8] These master's degree programs should be regarded in terms of meeting the teaching mission, not the research mission, of the University, and thus play a role distinct from traditional Ph.D.-oriented graduate programs. Examples of such programs include:

*Multidisciplinary programs*. The master's degree provides an important conduit for a student moving into a field that interfaces with two or more science/mathematics/technical disciplines. The establishment of the new Biomedical Engineering Degree program is one such example, where students are expected to be conversant in basic biology and medicine but also to have a strong background in one of the traditional engineering disciplines. Other examples, represented by recent master's degree proposals to the Sloan Foundation, are Computational Sciences, Bioinformatics, and Environmental Technology.

*Science educator programs*. We should make use of the opportunity to introduce future teachers to the experience, excitement, process, and culture of research. A Master's of Science and Education would meld pre-service training, science and engineering courses, and a research project, which could involve the creation of new instructional materials as described above. Recipients would be certified to teach science in secondary schools. This may prove to be a particularly attractive track for science majors not wishing to pursue research careers. Ultimately, an attractive master's program would increase the pool of superbly trained secondary school science teachers. Perhaps a similar program could be designed to combine science with journalism, for individuals who will communicate scientific and technological issues to various audiences.

*Technology/science management programs*. Clearly, technical expertise is an invaluable skill in the business world of the next millennium. We have the opportunity to combine the research prowess of the University with a strong Business school to produce MBAs with outstanding technical backgrounds. A three-year joint master's program would combine the standard MBA program with a master's in a science or engineering department.

This committee also endorses the concept that the University of Wisconsin's graduate education should retain its strong focus on scholarly research and PhD education. Extreme care must be taken if any re-allocation of faculty time or financial resources occurs in an effort to expand offerings at the master's level, lest this tradition of excellence in academic research and PhD education is damaged. Thus, we argue strongly against a general expansion of master's degree programs. Rather, we recommend targeted Master's programs specifically designed to support the development of a technically trained workforce in Wisconsin and the nation. We believe it is also important that the development of such programs reflect a long-term perspective rather than capricious near-term market demands.

There are several specific issues arising with this proposal that merit serious consideration:

*Structure*. Revitalization of the master's program requires a dedicated administrative entity and infrastructure. Perhaps an entity separate from the Graduate School would serve the needs of the program best. Adequate financial support for master's programs would need to come from university-wide resources. Since the targeted master's degrees envisioned here are cross-disciplinary and cross-college, development of appropriate admissions criteria and degree requirements will be challenging. As an example, students might enter the Master's of Science and Education program from either an education or science/engineering bachelor's program, but these students should graduate from the program with similar capabilities and knowledge. It will require a diverse faculty, perhaps including adjunct faculty members with work experience outside of higher education, to ensure that these objectives are achieved. Programs will need to be evaluated to ensure that they are meeting the needs for which they were designed.

*Nature of programs*. Programs should require a significant independent project/research component in addition to coursework. One of the UW–Madison's strengths is the depth and breadth of its research enterprise. To distinguish our programs from master's degree programs offered at other schools we must ensure that students are able to participate in independent work.

*Faculty staffing*. One consequence of requiring independent work, however, is that master's degree candidates require close one-on-one mentoring by faculty. This is expensive in terms of staff time. Given that these master's programs are fulfilling the teaching mission of the University, it follows that faculty who are actively engaged in supervising master's degree projects would be recognized as contributing to their teaching duties as they would were they teaching in the classroom. These programs may thus require revamping of existing graduate courses, development of new courses, and re-allocation of faculty teaching efforts.

*Funding*. It should not be expected that master's degree students in these targeted professional programs will be funded as research assistants. It is likely that these students must support themselves and pay tuition, perhaps with private sector sponsorship. Students should be eligible for TA assignments; this may be of particular interest in departments such as chemistry, physics, or mathematics with large service courses, where there are often insufficient numbers of doctoral students to serve as TAs.

**Physical Sciences Divisional Committee.** The substantial scope of the changes that we have outlined to position our campus to continue to provide leadership in the physical sciences and engineering causes us to recommend consideration of changing the Physical Sciences Divisional Committee structure. We admire the Biological Sciences Division's decision to trifurcate into separate committees concerned with curriculum, tenure decisions, and strategic planning. We believe that some comparable structure – perhaps bifurcation into one committee for tenure considerations and one for planning, curriculum and courses – may benefit the Physical Sciences Division by providing an opportunity for exploring these ideas in greater depth and by a widened cross-section of the Division's constituency.

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