Opportunities and Challenges for Interdisciplinary Research and Education

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ABSTRACT Interdisciplinary research and education (IDRE) holds center stage in current academic discussions. Despite the widespread agreement on the promises of IDRE, barriers for effective IDRE implementation remain significant. This study explored the opportunities and challenges of IDRE in integrated soil and water sciences at the Pennsylvania State University through a faculty survey and an educational project. The study revealed that: (1) co-advising graduate student is a common practice as a means of IDRE, and the overall positive aspects out-weigh the negative aspects; (2) joint faculty appointments receive mixed reactions, and are viewed by some as advantageous for the university but difficult for the faculty; (3) people issues are absolutely a critical aspect of successful IDRE; however, IDRE could also be accomplished by small groups or individuals; (4) synergistic approaches have not yet been commonly implemented, because IDRE collaborations often consist of faculty continuing piece-meal contributions independent of one another; (5) a new/renewed interdisciplinary undergraduate program in integrated soil and water sciences remains questionable as a viable solution to the declining undergraduate enrollment; (6) a potential new and broader graduate program appears to be promising, with a possible target on the emerging Critical Zone science (an interdisciplinary science that advocates the holistic studies of the Earth's near-surface environments, which extend from the top of vegetations to the bottom of aquifers); and (7) reward system needs to be enhanced to truly facilitate IDRE, and should be considered as a focus from both administration and practicality points of view. It is hoped, through such a study, that more true synergies can be realized through enhanced IDRE in academic environments.

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It is well recognized that the progress of science depends increasingly on an advanced understanding of the interrelationships among different disciplines and their components. An interdisciplinary approach is a proven vehicle for addressing complex issues of scientific and societal importance (NRC, 2001; Lin et al., 2006). Therefore, interdisciplinary research and education (IDRE) is now at the forefront of academic research and education. According to the National Research Council (NRC, 2004), *interdisciplinary research* is defined as:

> a mode of research by teams or individuals that integrates information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialized knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or area of research practice.

The study reported in this article has adapted this definition to address the opportunities and challenges in effective IDRE across disciplines within the Pennsylvania State University (hereafter referred to Penn State) and in other universities, with a focus on integrated soil and water sciences.

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Impact Statement

Valuable insights and tangible tips for effective interdisciplinary research and education are obtained through this study that are beneficial to faculty interested in developing stimulating and synergistic collaborations and to students desiring a better preparedness for an interdisciplinary future. The outcomes of this study can enhance the benefits and avoid pitfalls of interdisciplinary research and education, leading to more true synergies in academic environments.

Scientific milestones in history have directly or indirectly benefited from IDRE. A remarkable example is the discovery of DNA structure by James Watson and Francis Crick in 1953. An ex-physicist and a former ornithology student—along with some unwitting help from a competitor—cracked the secret of life. This synergy between a physicist and a molecular biologist won them the Nobel Prize in Physiology or Medicine in 1962 (The Nobel Foundation, http://www.nobel.se/; verified 1 May 2008).

Contemporary science has distinct characteristics of interdiciplinarity. *Big Science* (a term used to imply "bigness" in scientific research, which may include budget, staff, equipment, and/or organization) is increasingly called for by funding agencies such as the National Science Foundation (NSF) and numerous scientific consortia such as the Consor-

Abbreviations: IBIGP, Integrated Biosciences Inter-College Graduate Program; IDRE, interdisciplinary research and education; NSF, National Science Foundation; USDA, U.S. Department of Agriculture.

tium of Universities for the Advancement of Hydrologic Sciences, and the Weathering System Science Consortium (Lin, 2005). With emerging community-based *Big Science* comes a greater demand for IDRE. For example, the NASA's ongoing Mars Exploration Rover mission has demonstrated fruitful discoveries resulting from IDRE (Squyres et al., 2004a, 2004b), as well as a super example of scientific teamwork that has involved literally more than 4,000 people (Squyres, 2005). Research is increasingly done in teams across nearly all fields, suggesting the process of knowledge creation has fundamentally changed (Wuchty et al., 2007).

In the environmental arena where problems are generally complex and highly dynamic, no individual has all the necessary expertise to address such challenges effectively, hence requiring IDRE. Besides the necessity and synergy of taking on IDRE to address complex environmental issues of societal importance, the joy of friendships and collaborations is also part of the benefits of IDRE. By working together, many people believe that we can achieve more professionally while enjoying more personal and social satisfactions.

Interdisciplinary research and education efforts at Penn State and other universities have reached nearly every sector of academic life—from senior faculty to undergraduates, across academic disciplines, and at multiple campus locations. At present, Penn State's IDRE efforts comprise six major units in the areas of energy and the environment, life sciences, materials, computational sciences, social sciences, and arts and humanities. Interdisciplinary degree programs abound, including eight intercollege graduate programs (i.e., ecology, environmental pollution control, integrative biosciences, genetics, plant physiology, materials, operation research, and computational sciences) and many innovative undergraduate programs. Interdisciplinary undergraduate education is a longstanding practice at Penn State, as evidenced by (1) the science, technology, and society undergraduate program in the College of Engineering first offered almost 40 years ago; (2) the environmental resources management major in the College of Agricultural Sciences first offered nearly 30 years ago; and (3) the earth system science in the College of Earth and Mineral Sciences formed in 1986. Innovation and growth of IDRE at Penn State are continuous, as exemplified by the new bachelor of science degree in security and risk analysis in the College of Information Sciences and Technology (a new college founded on the principle of interdisciplinary education), and the forensic science major housed in the Eberly College of Science (which has become a nationally recognized field of study).

Despite the widespread agreement on the promising outlook on IDRE, barriers for effective implementation of IDRE and achieving its expected outcomes remain significant. The challenges stem from a variety of human factors, including human diversity, personnel issues, and unequal contributions and rewards for collaborators. At the institutional level, barriers to effective IDRE include insufficient incentives and rewards for faculty and students to conduct IDRE, a lack of compelling and cohesive scientific frameworks for IDRE, and the lack of strong leadership capable of producing the synergistic integration of multiple disciplines.

In the area of soil and water sciences at Penn State, we have experienced both benefits and challenges related to IDRE. For instance, a group of 14 faculty members in six departments at Penn State came together in 2005 and received a grant from the USDA National Needs Fellowship to train future professional and scientific workforce in integrated soil and water sciences. This grant was matched by Penn State that allowed the recruitment of six Ph.D. students in selected target areas of study. While an opportunity such as this is encouraging, special efforts are needed to reach a truly integrated approach and to foster a crucial and unusual synergy between the disciplines of six participating departments across three colleges involved in this project. Considerable efforts are needed to maintain adequate interactions among the faculty and students in this program, to develop truly cross-cutting research questions, and to prepare students for successful careers in agricultural and environmental sciences that are increasingly in need of interdisciplinary leaders and innovative problem solvers.

The objective of this study is to identify barriers, as well as opportunities, for more effective IDRE across academic communities at Penn State and other universities. Specifically, insights and strategies for enhanced IDRE in integrated soil and water sciences are sought via a faculty survey and the USDA National Needs Fellowship project. While the focus of this study is on soil and water sciences, the general principles and guidelines developed are applicable to other disciplines, and provide tangible values to faculty and students conducting IDRE. In addition, this study also touches the issues of undergraduate enrollment, and how a new broader and integrated degree program may be more attractive for educating the next generation of agricultural and environmental scientists.

Materials and Methods

An email survey was conducted to collect data from selected Penn State faculty members who have been involved in IDRE in areas related to soil and water sciences. To make such a survey simple and effective, a set of eight short questions were carefully formulated to gauge the current practices and core issues related to IDRE in academia (Table 1). This survey was sent to 60 selected faculty members at Penn State from nine departments in three colleges involved in soil and/or water sciences. Many of these selected faculty members have also been involved in one or more of the interdisciplinary graduate or undergraduate programs mentioned above.

A short message was provided with the survey, explaining the purpose of this survey and requesting a simple reply to the email by filling out the blanks in the survey questionnaire (Table 1). In addition, a couple of short notes were included, which gave the definition of interdisciplinary research as defined by the National Research Council (NRC, 2004) and a news flash about the Penn State Faculty Senate's recommendation for enhanced IDRE.

Among the 60 faculty members surveyed, 27 (45%) responded. One respondent did not complete the answers, and thus was excluded from the subsequent analysis. The distribution of the 27 respondents covered all the major collaborators of soil and water sciences at Penn State, including soils (10 respondents), crops (4), geosciences (4), civil and environmental engineering (3), forest hydrology (2),

Table 1. Survey questionnaire on interdisciplinary research and education in integrated soil and water sciences at the Pennsylvania State University (PSU).

1. How many graduate students have you co-advised with another faculty member at PSU?

   no. of graduate students already co-advised: _____

   no. of graduate students you may plan to co-advise: _____

2. Was co-advising a good experience to you, especially in comparison to the classical single-advisorship (e.g., co-advising graduate students as an "integrating glue" or "essential link" between faculty members)?

   Yes _____; Benefit: _____

   No _____; Reason: _____

3. Do you agree that a joint appointment of faculty members is a useful means of enhancing the engagement of cross-disciplinary interactions and attracting students interested in interdisciplinary research and education?

   Yes _____; Benefit: _____

   No _____; Reason: _____

4. Do you agree that finding a "right match" (people issues) is a critical aspect to a successful collaborative interdisciplinary research and education?

   Yes _____; Reason: _____

   No _____; Reason: _____

5. Do you agree that "synergy" (1 + 1 > 2) has obvious mutual benefits but not yet commonly implemented?

   Yes _____; Reason: _____

   No _____; Reason: _____

6. Do you think a new (or renewed) interdisciplinary undergraduate major (say, integrated soil and water sciences, or some other ones) can boost undergraduate enrollments?

   Yes _____; Reason: _____

   No _____; Reason: _____

7. Do you think an integrated graduate program in soil and water sciences (e.g., similar to PSU's Integrative Biosciences) is an appealing idea and may be worth of further exploration?

   Yes _____; Reason: _____

   No _____; Reason: _____

8. Any other suggestions on how to enhance interdisciplinary research and education at PSU in general (making it a truly positive and rewarding experience)?

   _____

   _____

agricultural engineering (2), horticulture (1), and agricultural economics (1). All 14 faculty members involved in the USDA National Needs Fellowship project were included in this survey; among them 11 (78.6%) responded, representing 40.7% of the total survey respondents.

It should be noted that some bias might exist in the sampling of this survey, as those selected and then responded to the survey appear to be more active in IDRE. On the other hand, such a possible bias may actually represent better current opportunities and barriers in IDRE in the areas of soil and water sciences at Penn State, which would match better the intended objective of this study.

The collected survey data were grouped into three career levels—junior, mid-career, and senior status (n = 9, 12, and 5, respectively), and the means of these three career levels were statistically compared using Chi-square test through NPAR1WAY procedure (Wilcoxon significance test option) in SAS (SAS Institute, Cary, NC). For the Survey Questions 2 to 7, the discrete answers (i.e., yes, no, or unsure) were converted to numeric values through artificial number assignments; however, the significance test results remained unchanged regardless of how the numbers were assigned. The written comments provided by the survey respondents were summarized and interpreted. The interpretations were linked to the experience of the USDA National Needs Fellowship project. All survey responses have been kept confidential throughout the survey process as well as in the subsequent analysis reported in this article.

Results and Discussion

The survey results provided valuable insights about IDRE at Penn State and other universities. It is interesting to note that the answers provided by the three career levels did not show statistically significant differences for the Survey Questions 2 to 7 (p = 0.308, 0.603, 0.123, 0.354, 0.588, and 0.354, respectively) (Fig. 1). This may reflect the common view of current practices and core issues related to IDRE in academia regardless of career levels. The number of graduate students co-advised by the three career-level faculty, however, did show a statistically significant difference (p = 0.007) (Fig. 2). Consequently, no further differentiation among the three career levels was attempted in the following discussions, with the exception of co-advising. Based on this survey results, plus the literature and the author's personal experience, some recommendations are made at the end of each section discussed in the following.

Co-Advising Graduate Students

Co-advising a graduate student across disciplines is considered an "essential link" between faculty members interested in IDRE. It is clear that co-advising is already a common practice at Penn State, and more seem to be happening (particularly from the beginning and mid-career faculty members; Fig. 2). The number of students "to be co-advised" among the three career-level faculty is less statistically significant (p = 0.099) than the number of students already co-advised by them (p = 0.007). This may, in part, be due to the uncertainty involved in future plans of co-advising. Further examination of the number of co-advised students among the three career-level faculty sheds additional light on the variability and conditions for effective co-advising. Five senior faculty members who

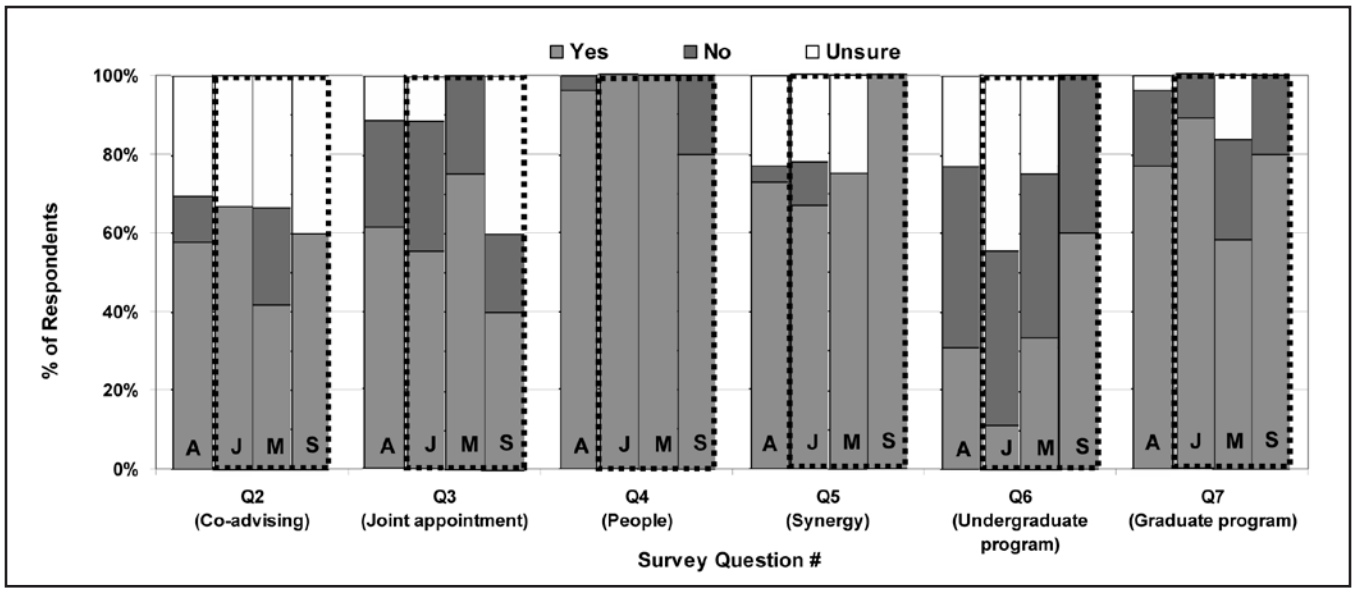

Fig. 1. Distribution of the percentages of respondents (A = all respondents) to the Survey Questions 2 to 7 (n = 26). Response percentages within each of the three career levels (J = junior, M = mid-career, and S = senior, with n = 9, 12, and 5, respectively) are also shown. The response means of the three career levels were not statistically different for the six questions.

responded to this survey had an average of five to six co-advised students, but are not planning to co-advise more, probably because of their proximity to retirement (Fig. 2). For the nine junior faculty members who responded to this survey, three are new to Penn State and thus have not yet experienced with co-advising; however, they are interested in exploring this mode of interdisciplinary collaboration by having one co-advised graduate student already planned (Fig. 2). The other six junior faculty members have already co-advised one to three graduate students. Except for one who already has three co-advised students and does not plan to have more in the foreseeable future (because of funding limitation), the other five junior faculty members all plan to have one or two more co-advised students. For

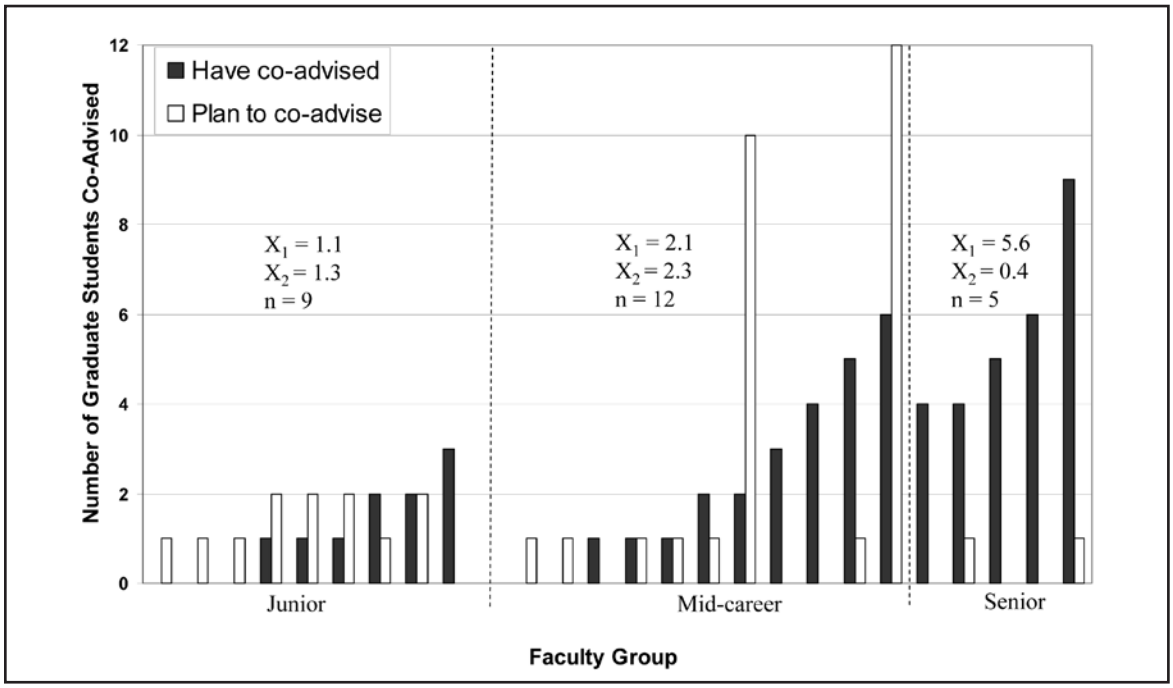

Fig. 2. Number of graduate students that have been co-advised or to be co-advised by three career levels of faculty at Penn State. The mean difference was statistically significant for the number of students already co-advised (X_1, p = 0.007), but not significant enough for the number of students to be co-advised (X_2, p = 0.099).

the 12 mid-career faculty members who responded to this survey, their co-advising interest and experience ranged widely. At one end of the spectrum, one faculty member does not seem to have interest or opportunity to co-advise any student, and another three do not plan to co-advise more at the movement. At the other end of the spectrum, two mid-career faculty members are "in love" with co-advising and plan to have 10 to 12 more students to be co-advised with other faculty members (Fig. 2).

In terms of the experience with co-advising (especially in comparison to the classical single advisorship), the survey results revealed a mixed feeling: 57.7% positive, 11.5% negative, and 30.8% unsure (answering both *yes* and *no*) or not yet experienced (Fig. 1). From the written comments provided by the survey participants (explaining the reasons for their experience), it was apparent that the overall positive aspects out-weighed the negative aspects, particularly if appropriate cautions were exercised in formulating and implementing co-advising arrangement. Co-advising a student is a very real commitment on the part of the faculty to an IDRE activity and it provides tangible accomplishments. The common positive aspects of co-advising include:

- Benefits to faculty: Learning from another faculty member and even the student involved; conducting exciting science, which often leads to new discoveries at disciplinary interfaces; accelerating research by a broader knowledge base and a larger set of research tools; fostering collaborative grant proposals; pushing faculty's own thinking by being more actively involved; helping the exchange of teaching and mentoring ideas and styles.
- Benefits to students: Accommodating student's needs for expertise beyond an individual faculty member, and fostering student's own creative ideas; enriching student's experience and opportunities to collaborate in the future; providing additional resources and easier access to research equipment; plus additional support in job hunting.
- Other benefits: Facilitating faculty to recruit quality students by having access to a larger pool of candidates and gaining more inputs from another faculty member.

The voiced negative aspects of co-advising a graduate student are also multi-faced, including:

- Pitfalls to faculty: Conflict with co-advisor; more work to do; generally coming down to a single advisor making decisions.
- Pitfalls to students: Getting mixed messages from two advisors that could make it difficult to proceed with a focused research and balanced coursework; if the student is not diligent, the faculty members may lose accountability for the student by assuming that the other advisor has a greater contact or responsibility, leading to a drifted program and delayed progress; both advisors and student have a more complex set of relationships to negotiate and communicate.
- Other pitfalls: The accounting practices at the university and the formal policy of the graduate school discourage co-advising.

The last pitfall listed above is an issue important to administration's re-thinking. Fortunately, co-advising, particularly that relates to inter-department or inter-college graduate programs, is becoming more recognized and counted for in promotion and tenure considerations in some departments at Penn State. This trend has facilitated the existing practice of co-advising at Penn State, which will likely further promote IDRE (Fig. 2). Most of other pitfalls listed above are related to people and communication issues, as the success of co-advising arrangement depends on the persons involved and requires extra effort by all parties to maintain clear communications and willingness to reach a common goal or compromise that are agreeable to all. This does require explicit cooperation among faculty members and the students involved. Successful advising calls for (1) a clear vision or direction for the student, and concurrence between co-advisors; (2) a good personal match between the co-advisors and the student, allowing them to work well with each other; and (3) a good and regular communications among all parties involved.

Joint Appointment of Faculty Members

Joint appointment can be a way to enhance cross-disciplinary interactions for faculty and to attract students interested in IDRE. The survey results, however, were a mix, with 61.5% positive, 26.9% negative, and 11.5% unsure or not yet experienced (Fig. 1). Some faculty view the university as already offering sufficient opportunities for IDRE, and thus joint appointments do not seem to add much. Instead, the reward structure for faculty is more important as a focus. Positive comments for joint appointments, nevertheless, include:

- Benefits to faculty: Better exposure to a broader cross-disciplinary information and points of view of faculty and students in other programs; access to a larger pool of student candidates; creating a link between disciplines; increasing flexibility of research topics and funding sources; formalizing the relationships and expectations, rather than leaving them to chance, and increasing the awareness of research collaboration opportunities.
- Benefits to students: Established infrastructure that facilitates interdisciplinary scholarship; working freely between departments.

The pitfalls for joint faculty appointments are clearly centered on an additional complicated administrative burden for evaluation and tenure decision that could make it difficult for the appointee. Thus, some faculty members believe that it is not worth the gain, and a few even fear that it is indeed a detriment toward promotion and tenure. In addition, some faculty will voluntarily associate with individuals of different departments through self-organizing, and thus joint appointment may be viewed too much as a "forced" approach that cannot guarantee effective cross-disciplinary interactions. Hence, joint appointments are viewed by some as probably good for the university but rarely easy for the faculty.

It has been suggested that multi-departmental (or college) research institutes are what encourage interdisciplinary collaboration the most, which allow faculty to work together with some financial incentives while still keeping one primary academic home. An alternative is clusters of appointments, with several faculty members being hired at

the same time in different departments in the same general area. This is in line with joint funding for more discipline-oriented faculty. Well crafted cluster hires may be a good model for enhancing IDRE in targeted areas, which have been implemented in several universities.

People Issues

People issues are absolutely a critical aspect of successful IDRE, as shown in this survey results that are independent of faculty's career levels (Fig. 1). Only one senior faculty member believes that finding the right problem and providing administrative and financial support is a necessary first step for successful collaborative IDRE, and then finding the right people match. The remaining 25 respondents (96.2%) agreed that most professional collaborations do not work well because personalities get in the way. Once the right mix of personalities are identified, the interaction is productive and both parties seek to continue the relationship. This is consistent with the report of *Nature* Editorial (2003). Interestingly, many literatures, including an impressive and comprehensive report by the National Research Council on *Facilitating Interdisciplinary Research* (NRC, 2004), covered little personality issues in their discussions. From this survey, many interesting comments shed light on perhaps the most important but challenging issue in achieving successful IDRE, as summarized below:

- People are the most important attribute in collaboration. In any collaboration (whether it is interdisciplinary or in the same field) personality issues are probably more critical than scientific issues. The major hindrances often boil down to relationships.
- Part of scientific inquiry is a creative effort that involves many facets of one's personality. Collaborative research is most successful when personalities and scientific approaches mesh. If personalities or research/education conflict, the collaborative arrangement is not healthy for anyone.
- People chemistry and area of expertise coupled with a similar expectation of a graduate student are critical to a successful three-way faculty–faculty–student interaction in a co-advising setting.
- It is difficult to collaborate if potential collaborators lack the people skills to develop fruitful relationships. Often these skills are not considered adequately in hiring process. Recruiting faculty that have the personality and research interests that make it possible to work collaboratively is essential.
- Approaches of IDRE require faculty to put more efforts into understanding each others' language and interest. This works much better when two parties get along on a personal level. Many espouse the benefits of interdisciplinary work; however, few are willing to actually do the work required.
- Working styles, existing tools, and experience combined shape the quality of collaborations. Different approaches to developing and designing research experiments can be a source of conflicts and frustrations. Because of multiple views and approaches, some collaborators may feel their interests and needs are not respected, appreciated, or adequately considered.
- There are issues of flexibility, trust, confidence, and respect at play when sharing ideas. Some people are just not good at sharing ideas with other people or different disciplines.

An experienced faculty member who participated in this survey said it well: "Collaboration is generally 'self-organizing.' To make IDRE successful, people need to have a common vision and also personalities that enable effective interactions and collaborations." It is abundantly clear that collegial atmosphere, mutual respect, and mutual benefit are essential to synergistic IDRE.

Noteworthy is that, while IDRE has obvious emphasis on interactions and people issues, it does not have to be done by large teams. It could be accomplished by small groups of people or simply individuals, which could avoid or minimize people problems. Research is a creative process that sometimes is best done on an individual basis. In fact, some scientists believe that the most innovative ideas come from a very small number of scientists at rare moments, whereas planning of large-scale projects requires the consensus of many scientists (Hao and Gong, 2006). It is also commonly believed that many of the most significant conceptual breakthroughs in science come at the hands of individual investigators or small groups of researchers, rather than through structured large collaboration (NRC, 2001). Too much emphasis on large IDRE at the expenses of individual creativity may, over time, stifle creativity (NRC, 2001). A real key here is how to link individual creative efforts into an overall interdisciplinary framework. "Faculty who can do this while keeping some of their own basic research going are real gems," noted by a senior faculty member who participated in this survey.

Synergy

The Question 5 in this survey addresses an issue that has significant impacts on how we view and conduct IDRE. While most people recognize that "synergy" (interpreted here as $1 + 1 > 2$) has obvious mutual benefits, 73.1% of the survey correspondents agreed that synergistic approaches have not yet been commonly implemented, with another 23.1% unsure and 3.8% disagreed (Fig. 1). A few survey participants indicated that the meaning of the Question 5 in the survey was not clear enough, leading to their unsured or splitted answers.

Synergy in interdisciplinary projects is the goal and has been so for decades. This is the reason for forming many research institutes on Penn State campus and elsewhere. For example, social scientists who study people's behavior may be critical to explain why "technically sound" soil and water best management practices are not adopted by certain groups of people. A key to synergistic research is to have an overriding model, conceptual at least and quantitative at best, linking the parts to make the whole more meaningful. This is where persons who can model systems need to be hired to pull the disparate parts together in a research. Often, however, IDRE gets the sum of the parts and it does not represent true breakthrough. Each part may be good, but with limited gain from the collaboration. Much of current collaboration consists of faculty working independent of one another. Other reasons why synergistic efforts are hard to implement include the following, which are based on the comments received from the survey:

- It is hard to find colleagues to work well with. Many people are not willing to take the time to go talk to other scientists in other fields.
- Sometimes collaborations are synergistic. Other times, "collaborators" are only in it for selfish reasons and not the goals of the project.
- The university reward system discourages IDRE participation. Infrastructural support is not there to reward all parties adequately. Often one party benefits more than another.
- Interdisciplinary research and education can be very time consuming and publishing IDRE can be a problem (such as first author issue).
- Most practitioners value synergy as a necessity for further advances in many fields of sciences. Implementation, however, would depend largely on external factors, such as funding, ease of communication, and personality.
- It is hard to make IDRE happen by a top-down approach. Attempted collaboration without synergy can be disastrous.

When each individual on the team works closely with others to make sure they anticipate and consider what the others are doing, the true nature of an interdisciplinary synergy is likely to emerge. Unlike universities, this kind of synergy is already built into some organizations such as the USDA–Agricultural Research Services units, which are organized around problem areas. Participants seek to hire new members that complement existing capabilities and build synergy under a well-articulated overarching research plan, often a longer-term one (5 years or longer).

Interdisciplinary Undergraduate Major

Some studies suggest that students, especially undergraduates, are strongly attracted to interdisciplinary courses or majors, especially those of societal relevance (NRC, 2004; Schneider et al., 2005). Other studies indicate that reputation is a key to attract students, not necessarily "structure" or some kind of formal major (NRC, 2004). Because undergraduate enrollments in many majors at Penn State, including environmental soil science and environmental resources management, have declined considerably in recent years, this survey also intended to look into possible solutions to this problem. Among the 26 faculty respondents, only 30.8% agreed that a new (or renewed) interdisciplinary undergraduate major (e.g., integrated soil and water sciences) can possibly boost undergraduate enrollments, with the majority (46.2%) saying no, and another 23.1% saying maybe or maybe not (Fig. 1).

The arguments that support a new (or renewed) interdisciplinary undergraduate major in integrated soil and water sciences include the following:

- Soil scientists fail to highlight the water part of what they do, and thus students seldom know this. Water science is what drew many to soils. Water is something the average person knows, it is more often discussed in the media, and it is the topic of public policy debates/arguments at both the local and national levels. To draw students, this is the aspect that should be better promoted.
- Water addresses the interests of more students and appeals to a broader pool of candidates. If configured appropriately and marketed aggressively, there could be a net gain in student interest and job opportunities.
- A university-wide focus on a water program would be attractive. Soil is part of the overall environmental and ecological systems. Water cycle cuts across many boundaries (atmospheric, soil, geologic, and biological), and thus has been recommended as a unifying theme for understanding complex environmental systems (National Science Foundation, 2005).

The arguments that question the need for a new (or renewed) interdisciplinary undergraduate major in integrated soil and water sciences include:

- Current programs at Penn State provide students with the ability to develop dual majors and to customize individual studies to address nearly every conceivable course of study. Marketing of the major is more of a bottleneck or limitation. A new major will not work if it just shuffles students around rather than a net gain in enrollment.
- There are already too many majors at Penn State. Students have difficulty understanding the differences and deciding what they want to major in beyond a broad topic in the first 2 years of college. Dilution can easily destroy success.
- It depends on whether the field is perceived by students as fresh and exciting. If the field is so new or so esoteric that students find it difficult to envision what they will study or do with such a degree, then the new major will struggle to attract students.
- Interdisciplinary majors are still not managed well enough from an administrative point of view. They will not be successful until the reward system is changed to reward faculty more for interdisciplinary activity than they are rewarded for disciplinary activity. With declining faculty numbers, the disciplinary departments would resist interdisciplinary competition for resources.

The survey comments provided some options that may be better than creating a new (or renewed) interdisciplinary major. One is to bring in students through the traditional departments, and then offer an interdisciplinary course or two toward the end of their degree. The other is to make the major broader than soil and water (such as "environmental science" or another inter-college major) that undergraduates understand. On the other hand, some faculty members indicated that they cannot compromise the established instruction for a broader major.

Integrated Graduate Program

Penn State's Integrated Biosciences Inter-College Graduate Program (IBIGP) is a nationally recognized model of excellence for IDRE (NRC, 2004). Therefore, an integrated graduate program similar to the IBIGP model might be appealing for soil and water sciences. The majority (76.9%) of the faculty respondents in this survey supported this idea, with 19.2% opposing and 3.8% unsure if this would work formally but perhaps informally (Fig. 1). Compared with the undergraduate major, this graduate-level integrated soil and water sciences program received a much more positive support across all three career levels of the surveyed faculty (Fig. 1). The benefits include the following:

- The field is of growing importance. Across Pennsylvania (and indeed, across the nation) water is a critical issue. Where there is a demand for knowledge, there would be a demand for an academic program. Many graduates interested in soils are actually interested in both soil and water. Such programs have been successful at other institutions.
- This graduate program would have to be broader in order to have a major impact (e.g., to include ecology and others, and have several tracks to cover natural resources, engineering, and policy or legal interests). It would have to open major funding sources to be of interest (such as NSF's complex systems and global environmental change programs).
- This kind of program would facilitate the development of students as "system-wide" scientists. The key is to articulate why the integration is an improvement. Getting a broader training in two fields is better for students in their job hunting.
- This is probably the only real way to get at complex questions. At the graduate level, this is the theme that would cover the right scope for a productive education.

The comments against a graduate program in integrated soil and water sciences include the following:

- This area could be addressed within existing disciplines using informal collaborations. A graduate program has considerable overhead associated with it and should only be considered if there is a sizeable and potentially long-term demand for the program.
- At the graduate level, a student already has plenty of opportunity to define an individual program. It is also important that a graduate student has an identifiable disciplinary focus. Most jobs are still defined in that way.
- It is more important to have a great soils program, one which is recognized as a great educational experience for students. This would include interdisciplinary research opportunities for students.

A few alternatives were suggested from the faculty comments. One is a graduate minor that would work well if structured similarly to the computational science graduate minor at Penn State. The other is to develop more synergistic co-advising, with the background of students in improved mathematics and science to make this work. A third option is in line with the future outlook for modern soil science, hydrology, and geosciences, that is, to target the emerging science of the earth's Critical Zone (NRC, 2001; Lin et al., 2005; Wilding and Lin, 2006). The *Critical Zone* concept provides an appealing framework for integrated studies of soil, water, rock, air, and biotic resources in the earth's surface and near-surface environments. Interactions at these interfaces between the solid earth and its fluid envelope determine the availability of nearly every life-sustaining resource and provides the foundation for all human activities. Hence, the National Research Council has identified the integrated studies of the earth's Critical Zone as one of the most compelling research areas in the 21st century (NRC, 2001). Within the emerging Critical Zone science, water is at the forefront and the center stage. The NSF has been recommended by its Advisory Committee for Environmental Research and Education (AC-ERE) to focus on water as a unifying theme for research and education on complex environmental systems (National Science Foundation, 2005). Therefore, a new integrated graduate program under the umbrella of Critical Zone science and with a focus on water as a unifying theme appears promising. As water and soil are the two critical components of the Critical Zone (Lin et al., 2005), advancement in integrated soil and water sciences will benefit from such a broader and integrated graduate program.

Other Aspects to Enhance Interdisciplinary Research and Education

Many other suggestions on how to enhance IDRE at Penn State were provided in the comments from the Survey Question 8. These are summarized below into two categories—institutional and personal aspects:

Institutional Aspects

- Rewards (such as promotion and tenure, salary, and honors) have been clearly voiced in this survey as the most desirable means to encourage and facilitate IDRE. Currently, promotion and salary are usually judged on what an individual does, not on what a group does. At present, the reward and recognition system is to individually build a dynasty and one's own castle rather than being a collaborative participant. This issue was voiced as the biggest challenge at the National Institutes of Health's symposium on "Catalyzing Team Science" (National Institutes of Health Bioengineering Consortium, 2003).
- Administrative structures that promote and support IDRE are needed. The university administration currently is based on departments and addressing department needs and turf. This does not facilitate interdisciplinary programs. College-wide visions and priorities should be continuously worked on to supersede individual departmental priorities that sometimes limit effective interdisciplinary work.
- There is a need of deliberate accountability during annual reviews and promotion and tenure evaluations to a faculty member's home department and to interdisciplinary programs. Until this happens, faculty will be torn between the required duties of the department and the "volunteered" time to the inter-departmental programs.
- Administration needs to put more money into interdisciplinary environmental science, and to increase faculty participation in interdisciplinary initiatives and contracting. Encouraging greater interaction during proposal development stage is a practical means of improving IDRE. It is also more effective to allow the interactions to develop around a specific problem rather than defining an integrated department or major and then expecting members to interact in the predefined area. A faculty member in a discipline such as soil science can interact and contribute in many different interdisciplinary groups (e.g., soil and water, soil and archeology, soil and engineering, soil and agronomy, soil and geology).

Personal Aspects

- Initiative on the part of individuals is essential for interdisciplinary research. One should not wait for others to initiate the process of collaboration.

- Mentors need to share with younger faculty members the experience of successful collaboration.
- Interdisciplinary research and education will be personality driven, but having communal space where everyone can get together would facilitate.
- Colloquia are stimulating and engaging. It is good to set aside a day once or twice a year for students and faculty to meet, and present their work in a structured, yet informal, setting. Better collaborations germinate from such connections.

Summary and Conclusions

A survey of 60 selected faculty members at Penn State has yielded valuable insights regarding the practice and outlook of IDRE in integrating soil and water sciences. The survey information collected, supplemented by the experience from a project funded by the USDA National Need Fellowship program, allowed the examination of barriers and opportunities for IDRE across academic departments at Penn State and other universities. Among the seven aspects investigated in this study, the following three findings are of particular interest: (1) the existing reward system needs to be improved to provide better incentives and recognitions for faculty and students conducting IDRE; (2) improved people and communication skills are absolutely essential in successful IDRE, thus personality match and relevant training are important to facilitate IDRE; and (3) a potential new integrated graduate program that is broader than soil and water sciences appears to be promising, with a possible target on the emerging Critical Zone science that may unify many disciplines. The first two findings are consistent with the report of *Nature* Editorial (2003). This study also found that no significant difference existed among the three career levels (junior, mid-career, and senior faculty) in their answers to the survey questions, with the exception of the number of graduate students that they have co-advised (which showed an increasing trend with increasing career level). This study has gained tangible values including useful tips for more effective co-advising of graduate students, for junior faculty members to develop stimulating and synergistic collaborations, and for students to better prepare for an interdisciplinary future.

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