Innovative Industrial Ecology Education Can Guide Us to Sustainable Paths

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Abstract

Many activities labeled "industrial ecology" are as ancient as human society (e.g. reusing materials, using waste from one process to fuel another). The idea, however, that industrial ecology is the "science of sustainability" has gained prominence only in recent decades. Within this landscape, industrial ecology is becoming more formalized – there is a journal, an international society and increasing numbers of educational efforts dedicated to the topic. While industrial ecology has become a fairly common reference in various types of literature, its inclusive nature makes it difficult to define – much like the concept it strives to support – sustainability. Hence, while there is general agreement among practitioners that education dedicated to industrial ecology is important, there is not agreement on the specific direction this should take. The metaphor —applying ecological principles to industrial systems — is *de facto* interdisciplinary. This creates philosophical and administrative conflict when designing courses and programs. There are several approaches evolving that employ the industrial ecology concept, but each has quite distinct foci. A simplified delineation of these approaches might include: 1) Focus on developing innovative technology/models; 2) Focus on quantifying processes and identifying "best" technologies and/or best uses for technology/models; 3) Focus on societal factors (economic, behavioral, paradigmatic) to find alternative ways to do things using existing technologies. The ideal approach is likely some combination of these three. However, in designing a formal curriculum, it is not feasible (nor necessarily desirable) to cover all three in depth. For industry leaders (and policy-makers) understanding the values and limitations in each is important. If industrial ecology is to promote sustainability, then decisions about how it is taught will greatly influence efforts to define and reach sustainability. Understanding the tradeoffs and opportunities inherent in the diverse directions that industrial ecology education is moving is important if we wish to continue to identify and clarify pathways to sustainability.

1 Introduction

Contemporary literature, both academic and popular, provides a plethora of articles about sustainability and its importance to the future of life on planet Earth. There are numerous organizations, public and private, dedicated to promoting sustainability and/or the idea of sustainable development. There are also numerous publications criticizing the sustainability concept as ill defined and not situated appropriately to affect real change. As Tarlock (2001) has noted, sustainable development and the more specific Environmentally Sustainable Development (ESD), are appealing ideas (who would oppose a clean environment?) without the institutional support to realize their potential. Contention surrounds the very language used because many believe that "sustainable development" is oxymoronic. While debate continues about what qualifies as sustainable and what a sustainable approach to development might be, there is little doubt that the terminology surrounding sustainability has entered the mainstream and environmentally sustainable development has become a catch phrase for attempts to prevent further travel down what are perceived to be unsustainable paths.

Within the ongoing discussions about sustainability, is another ESD – Education for Sustainable Development which has contributed research efforts and program ideas for teaching students at all levels about sustainability. Of course, this ESD is also fraught with debate as to what to teach, to whom, and to what purpose. Yet, there is a strong, perhaps even intuitive, sense that education is the single most promising vehicle for eventually reaching the basic sustainability goal set out by the Brundtland Commission of meeting our needs without jeopardizing future generations' ability to meet theirs. This perhaps reflects a commonality between sustainability and education. Both are advanced through trail and error and trial and success approaches. There is no obvious or precise mechanism to guarantee success in either.[1] Into this flow of ideas we also have ecological principles merging with industrial practices. Industrial ecology (IE) is becoming a noticeable presence in education in the United States and throughout the world, largely because it is perceived to be an applied effort that can provide direction for environmentally sustainable development.

The connections between IE and sustainable development are obvious. The philosophy driving IE applications, such as reusing materials, designing resource efficient products and processes, using waste from one process to fuel another, is not new. In fact, many waste eliminating ideas have direct counterparts in pre-industrial practices. In post-industrial society, however, we are facing the need to consider the ramifications from decades of development that disregarded ecosystem impacts and natural resource limitations. Rejuvenating old ideas and developing new methods are inherent in IE, explicitly and implicitly. The tools and practices within any industrial ecology rubric are geared to help societies develop without increasing environmental damage. The contemporary concept of IE in the United States traces its beginnings to an article in a 1989 special issue of Scientific

[1] Thank you to a reviewer for providing this insight.

American bearing the cover title, "Managing Planet Earth." This publication was one of many in the late 1980s and early 1990s focused on planetary environmental and social concerns, reflecting reaction to multiple events around the world. Within a relatively short time the world witnessed the ozone hole, worldwide contamination emanating from the hot and cold wars, the Exxon Valdez oil spill, numerous negative reports concerning biodiversity, global warming, and poverty. In the US, Time Magazine did not select a "Man of the Year" in 1988, but instead highlighted Earth as "Planet of the Year." This emphasis on Earth and its inhabitants followed the trail that the Brundtland Commission blazed in 1987 with its call to appreciate Our Common Future. From within this fomentation sustainability arose as a potential product, process, and paradigm to address the rather negative news about planet Earth's condition. There also came calls for industry to change common practices. Hence, in 1989 we find two researchers from industry proposing that we might use ecosystems as a metaphor for designing industrial operations to enable us continue traditional development, but with fewer negative impacts (Frosch and Gallopoulos 1989).

In the ensuing decade IE began maturing and is currently being professionalized. There now exist the Journal of Industrial Ecology and the International Society for Industrial Ecology (ISIE). There have also been a solid number of books published about IE. As IE has grown, it has engendered debate about what it does or should encompass and whether it represents the beginnings of a paradigm shift or is simply refurbishing the status quo. There is evidence that like the term "sustainability," the phrase "industrial ecology" is becoming a buzzword within higher education with diverse definitions and applications. Internet searches reveal myriad references to industrial ecology as a general concept, as a course title, as a research focus, as an assigned reading topic and as a conference session topic. A cynical person might view this as "green wash" – attempts to garner students, funding, and recognition by invoking popular ideas but without actually generating any substantive change in the educational content or process. A more optimistic interpretation is that the prevalence of the phrase "industrial ecology" within higher education implies a growing recognition of the interconnections between technology and the environment, between industry-driven lifestyles and ecological principles, and between education and environmentally sustainable development. It also may reflect a concerted effort to seek answers to the negative ramifications of many of these relationships. Industrial ecology has been called the science of sustainability[2] and this paper focuses on IE and its evolving role in creating a roadmap to guide individuals and organizations toward a more sustainable existence. I argue that the lack of consensus about what IE is or should be grants it power to become a force for change and that its growing prevalence in higher edu-

[2] Industrial ecology is not alone in making this claim. The Columbia University Earth Institute states that the programs at the Biosphere 2 Center teach the "science of sustainability." The Bija Vidyapeeth Education for Earth Citizenship program says that its students have the opportunity to practice the "art and science of sustainability." Neither of these programs focuses on IE. Like the general idea of sustainability, the "science of sustainability" remains a fluid concept.

cation has the potential to either promote this force or stifle it. The research reported here focused on identifying education programs that invoke the IE moniker and analyzing the potential impact these programs may have on actually moving society toward sustainability.

2 Method

To identify IE programs in higher education, I requested information from faculty and researchers at universities in the US and throughout the world. These individuals are ISIE members or attended the inaugural ISIE meeting in 2001 in the Netherlands. Additionally, in 2002 I conducted an Internet search of the schools listed on the University of Texas, Austin's Web Central, which provides links to regionally-accredited US universities. For every university web page with an internal search engine, I entered the phrase "industrial ecology." For schools without an internal search engine, I looked at academic programs and searched for the words "industrial ecology" within course listings and program descriptions in business, engineering, environmental studies/science and other programs. Many of these searches uncovered syllabi that focused entirely on IE, or featured IE as part of a course. While these individual representations are relevant and reflect IE's growing popularity, this project focused on more expansive efforts and only includes programs where students can earn a degree with an IE-relevant focus or can conduct IE-related research as part of an institute or research center. A spreadsheet summarizing information about the various programs as is available through the ISIE web site: http://www.yale.edu/is4ie

This is by no means an exhaustive report on all programs that might have IE-relevant degrees and/or research. There are likely many universities offering programs that fit within the IE paradigm that were not uncovered in this search because they do not use the specific phrase "industrial ecology." For example, there are numerous "green chemistry" programs available, but this search did not reveal them if they do not self-describe as being "industrial ecology." Additionally, programs are continuously being created and modified to reflect changing knowledge bases and societal desires. While not exhaustive, this project reviewed more than 1000 universities and therefore does provide solid data about where and how IE is evolving within higher education.

3 Results

Table 1 provides a consolidated view of where programs that use the phrase "industrial ecology" in describing themselves appeared in higher education as of late 2002. This project identified 69 different universities with 87 different programs and centers. The disciplinary focus for degree-granting programs was determined based on both the name of the department and the degree(s) awarded. For research

centers, the types of disciplines featured and the kinds of research being conducted determined which disciplinary focus was appropriate. Therefore, the Engineering/Technical focus includes all types of engineering, as well as architecture and construction programs. The Environment group includes environmental science/studies and natural science departments. Business/Economics and Policy/Planning are self-explanatory. The Multi- /Interdisciplinary groups featured some combination of the previous disciplines and the Other category represents individual programs in public health, human ecology, environmental history, and one degree program called industrial ecology. While this program is technically based, it is the only one completely self-referenced as IE and hence it seemed more appropriate to put it with Other than with the Engineering/Technical group. Many universities offer IE-related research opportunities to students through institutes or research centers. These are distinguished from degree-granting programs in Table 1.

Table 1. Educational Programs Featuring Industrial Ecology

Disciplinary Focus	Total	Degree Programs	Centers
Engineering/Technical	26	21	5
Environmental	12	12	0
Business/Economics	13	13	0
Policy/Planning	5	4	1
Multi-/interdisciplinary	24	14	10
Other	7	7	0
TOTAL	87	71	16

In addition to the disciplinary distinctions, the education efforts that include industrial ecology as a focal point can be grouped into three broad emphases: 1) designing innovative technologies and processes; 2) quantifying processes and identifying "best" technologies and/or best uses for technology and/or models; 3) assessing societal factors (economic, behavioral, paradigmatic) and the relationships between human aspects and technological applications.

The educational programs in the first emphasis area include basic pollution prevention concepts often found in engineering and chemistry departments as well as some design for environment programs and other more advanced IE applications featured in engineering, architecture and other disciplines. Because so many of the programs highlighting IE are technically based, it is not surprising that many of them emphasize creating new technology that is more energy efficient and less polluting. As the contemporary IE concept emanated from within industry, it is also fits that IE is comfortable in the technical realm and comfortable with a focus on new technology.

The second area with significant IE-relevant research and education is in employing models and activities to identify "best" practices or best technologies for a particular issue. Researchers in this area try to quantify current processes, such as resource use, which can then highlight ways to reduce resource use. Both technically orientated and social science departments feature these types of activities.

Rapidly expanding efforts in life-cycle assessment and material flow analysis fit within this grouping, as do many eco-park and industrial symbiosis projects. Several multidisciplinary programs fit in this category as well.

The third type of education related to industrial ecology and sustainability encompasses social factors. Educators and researchers in some social sciences and a few in the humanities have also recognized IE as a powerful tool for moving toward sustainability. Economics are obviously a key human factor and economic ideas have been a consistent presence as IE has evolved. In recent years, some business schools have added courses and concentrations to provide students with information about the connections between industry and environmental and societal impacts. Additionally, a few policy and planning programs have included IE principles in their curricula to connect decisions about development and other human activity with environmental impacts. The search for IE education programs found efforts in diverse departments as well as in multidisciplinary programs intended to combine technical knowledge with social science and sometimes humanities disciplines. This includes several science and technology studies programs, which explicitly emphasize the connections among science and technology and society.

Of course, the three categories I have created to describe the types of efforts currently available in higher education are artificial constructs. The lines between the categories are fuzzy. Developing innovative technologies flows into quantifying processes, which merges with social factors. Design for environment courses and programs, for example, can legitimately highlight one, two or all three emphasis areas. Employing the three categories defined here is instructive, however, because they highlight that programmatic emphases can play a significant role in how IE is perceived both within and outside academia and influence where IE is likely to appear on campus. My research suggests that many programs offering degrees related to IE are being molded to fit within an existing departmental paradigm. Therefore, depending on the university and the department where a design for environment specialty arises (to continue that example) the courses and research opportunities may have very different foci. Like sustainability, the phrase "industrial ecology" is being applied to diverse activities and knowledge. There are researchers and practitioners from within each of the three categories who claim that their emphasis area is equivalent to industrial ecology. At one university, the civil engineering department may include industrial ecology as a key tenet of their program and emphasize creating energy efficient technology while another university features IE in the business department and emphasizes "green accounting" techniques. (This could also happen within a single university). The courses taught and research conducted are quite different for these two departments, yet both claim to be providing students with experience related to industrial ecology. In general, because IE is being overlain onto existing, discipline-based education, there is the potential for individuals within any given program to not recognize that IE currently operates within multiple paradigms and is not limited to the scope within their discipline. This potentially has far-reaching implications for the route that IE may take in the quest for sustainability. If, for example, people with decision-making authority (likely social science or humanities types)

equate IE as simply a twist on "clean technology" it may not receive the attention it deserves in determining funding and/or actual implementation. This potential situation is (or should be) of interest to IE practitioners, as this paper discusses.

The three approaches identified here, if combined, should encompass the mix of ideas that may allow IE to help lead human society toward a more sustainable existence. When examined more closely, however, gaps appear and questions arise as to whether IE is a force for change or is contributing to maintaining status quo. For the social scientist or humanities person examining the existing educational offerings, one gap becomes immediately apparent. While there is tremendous diversity in the disciplines represented in IE education, the focus continues to grant primacy to science and engineering approaches. There is still a strong emphasis on developing new technology and refining existing technology by quantifying various parameters. There is significantly less attention being paid to the human aspects of an industrial society and the role that human-based disciplines might play in contributing to the broad concept of industrial ecology and developing its role in sustainability. Further, human factors that are emphasized, such as traditional economic theory, have been implicated as deeply as technology in contributing to our current unsustainability (Ruckelshaus 1989; Foster 2001).

4 Discussion

For decades researchers and pontificators have suggested that our increasing technological capability will not provide what is required to reach a sustainability goal. At the outset of the modern environmental movement, White's (1967) seminal article on The Historical Roots of Our Ecological Crisis called not for new technology, but for new philosophy, for new attitudes about the relationship between man and nature. Tibbs (1999) thoroughly discusses the conundrum that technology poses by noting that it provides "greater ability to solve existing environmental problems, but also the potential to make them much worse if future technology is used without social and ecological discipline" (71). Tibbs notes that changes in beliefs, values and behavior are necessary to fully harness the power of technology that is necessary for a sustainable future. Turning concepts (IE or sustainability) into actions does not hinge on technology or on a more environmentally aware business community, but on rethinking entire systems that perpetuate the status quo. More than a decade ago, William Ruckelshaus (1989) in the same publication that evinced the contemporary ideas about "industrial ecosystems" noted that moving toward sustainability would require societal-level modifications at scales equivalent to the agricultural and industrial revolutions. He called for government policy (informed by science and with access to innovative technology) to lead the charge toward this new revolution. He wrote, "in creating the consciousness of advanced sustainability, we shall have to redefine our concepts of political and economic feasibility. These concepts are, after all, simply human constructs; they were different in the past, and they will surely change in the future" (174).

Although they are important, developing new technologies or promoting less damaging corporate practices are not revolutionary forces. Being sustainable will require most human societies to revise their ideas about and feelings toward the planet and natural resources. This is an all-encompassing endeavor that includes redefining politics and economics, but reaches even further. And this is perhaps the most powerful reason that education is the most promising vehicle to carry us to a sustainability revolution. Good education provides the opportunity to challenge existing paradigms, to encourage people to see issues from a novel perspective. Just as IE actually embraces pre-industrial ideas, so too considering pre-industrial education may be appropriate for IE and for sustainability. As Foster (2001) has noted, history, philosophy and literature, the tenets of liberal arts education, may actually offer better fuel for our attempts to educate as a way to reach sustainability. Including these disciplines when we talk about industrial ecology may enable IE to become a truly revolutionary tool. As an example, philosophy is embedded in IE as researchers debate the appropriate metaphors and analogies to use in framing IE (Isenmann 2002; Ehrenfeld 2003). Because IE is not clearly defined, it offers an incredible opportunity for educators and practitioners to develop unique and innovative approaches to thinking about industrial society and incorporating new ideas into disciplines with long histories and entrenched paradigms. The power that IE may bring into education and into broader social-cultural venues is to enable all disciplines, from within their unique perspectives, to think about "industry" as a symbol for contemporary global society and its relation with ecology. IE can encourage all disciplines to question: how did industry come to be in its present state? How did my discipline contribute to this process/development? How can my discipline contribute energy toward effective change? Conversations with my engineering friends reveal that these questions are typically not welcome within the technical academic realm. These, however, are precisely the types of broad, far-reaching questions that humanities academics are encouraged to explore.

Much research on how to incorporate environmental sustainability into education concludes that the principles within sustainability must somehow be integrated into all subject areas at all grade levels (Haury 1998). Similarly, an ideal approach to IE education would encompass all three of the categories that I have identified. This, however, implies a Renaissance education with individuals becoming masters of multiple disciplines. Because our knowledge base is significantly broader and deeper than during the Renaissance and because of existing formal education structures, this is not currently realistic. There are ways, however, to get the revolutionary vehicle in gear using existing academic systems. We need to continue to develop disciplinary strength while finding a way for students to recognize and appreciate the information and ideas being generated in other disciplines.

The concept of holistic management provides one intriguing model for beginning to apply information from the diverse disciplines that currently have or are developing IE-focused programs (Savory 1999). Figures 1-3 reflect evolving approaches for addressing societal concerns and issues. We have long recognized that the model shown in Figure 1 is not appropriate. No single discipline can pos-

sibly address the "whole" of any issue. The shift to multi- and/or interdisciplinary education and applications as shown in Figure 2, reflected an attempt to address the ineffectiveness of the single discipline approach. But, because they rarely recognize or accept the "whole" as the driving force, multi- and/or interdisciplinary teams have also not been able to provide sustainable solutions to many persistent problems. What has the potential to be more successful is to ensure that students in all disciplines develop skills to allow them to see what a particular issue demands from a variety of perspectives and to recognize what their discipline and other disciplines can provide to effectively address the issue. As Figure 3 shows, allowing the "whole" to tap the most relevant information is likely to be a more effective (and perhaps efficient) way to reach some desired endpoint. Of course, because all disciplines have their own paradigms which guide pedagogy and practices, there will be incredible dissension as to what constitutes the "whole," what the desired endpoint is, as well as what the appropriate role is for any specific discipline.

To help address this, I propose that all students pursuing education related to IE and/or sustainability should receive formal training in communication and teamwork. This builds on recent movements toward more integrative approaches to policy research and utilizing collaborative processes in making policy decisions (Susskind et al. 2001; Claussen 2001). With improved skill in these areas, research and decision-making teams will more readily recognize the need to identify the "whole" of an issue and to then apply their individual specialties in a more productive fashion and to recognize when the traditional approach from any discipline may not be effective or appropriate. This model allows students and society to continue to benefit from specialized education, which has provided increased knowledge in all disciplines. Students should be encouraged to "go with their strengths" and to follow their passions. Within formal education, they need to be able to focus the majority of their time on the content within their discipline so that they become fluent in civil engineering, art, microbiology, literature, geology, business administration, psychology or whatever they choose to do. All disciplines, however, must also realize that a negative consequence of extremely specialized education is that it is very easy to lose perspective on just how narrow our educational experience becomes. The classic joke about engineers believing that a multidisciplinary team includes an electrical engineer, a civil engineer, a mechanical engineer, and a chemical engineer exemplifies this.

All specialists, including those with multi- or interdisciplinary "specialties," must recognize that their discipline alone does not have the potential to drive industrial ecology (or any other approach) all the way to sustainability. Additionally, all specialists must be open to the idea that the prevailing paradigms of their discipline may contribute to perpetuating non-sustainable activities and attitudes. Therefore, an educational model that provides students with opportunities to exchange ideas and to identify ways to apply very diverse, but very specific disciplinary training to sustainability concerns may be effective. Examining an issue from diverse perspectives and using tools from diverse disciplines to identify information and to analyze information creates a synergistic effect, which may provide the fuel necessary to propel a sustainability revolution. I am not suggesting that im-

proved communication and teamwork will magically provide the answers for achieving sustainability. Rather, it is a first and crucial step toward finding ways to shift our philosophy that is so closely linked to our ideas about technology and development and social order. These are key to generating the revolution that Ruckelshaus (1989) says is required.

Many environmental studies and environmental science programs attempt to provide multidisciplinary opportunities for students and the research presented here show that multi-disciplinary programs are the second most common place to find IE in higher education. However, there is ongoing debate about whether existing multidisciplinary curricula are effective (Luke 1996; Soule and Press 1998). Many environmental education programs use a simplistic and ineffective model suggesting that once the science is understood, students can simply apply social science knowledge and find a solution to a problem (McKeown-Ice and Dendinger 2000). There are severe institutional barriers to establishing truly cross-disciplinary efforts in most universities. Tenure requirements, accreditation concerns, grant giving, and power struggles within and among departments make it difficult to fully collaborate across campus. Even when there are opportunities, they are typically not truly integrative. Simply taking courses from various departments or taking courses taught by professors from different disciplines does not promote the kind of interaction that I suggest is necessary. Additionally, these programs are not necessarily appropriate for students who are truly passionate about being a chemist or an historian but who want to apply their skills to IE and hence to sustainability issues. There are programs available that understand this and have been organized to address it. The University of Michigan's Certificate Program in Industrial Ecology is one example. Students overlay the IE-relevant coursework as a complement to their traditional degrees in business, engineering, natural resources, environmental health sciences or public policy. The Norwegian University of Science and Technology applies a similar approach in their multidisciplinary program. Students from various departments (natural science, engineering, social science, humanities) specialize in industrial ecology from within their home department. These types of programs reduce the potential for students to see IE as somehow disciplinary specific as they have colleagues from various departments who are also learning about IE.

Additionally, there is evidence that some research efforts are taking a much more holistic approach. Emerging IE research is addressing the connections between resource use, technology and the human factors that will combine to determine what technology is acceptable and how resources are actually used. One effort that will contribute to better understanding the role that behavior plays in determining "best" practices is a project to identify practices that seem logical, but may not be advantageous in all circumstances. For example, it seems to be common sense that developing secondary markets for goods will lessen resource use and hence reduce environmental damage and promote sustainability. This is part of the mantra: reduce, reuse, recycle. Yet, recent research is revealing that for some products, having a strong secondary market actually encourages resource use as it increases demand for "new" products (Thomas 2002). The "common sense" idea is not necessarily a uniform truth. There are also research projects

emerging that couple models from social science concerning human motivation and behavior with IE-relevant tools such as life-cycle assessment and material flow analysis (Hofstetter 1998; Binder 2002). These prototype research efforts reflect a generous move toward helping IE become a more effective sustainability vehicle by better understanding people and their relationships with materials, resources, and technology. The researchers are moving well outside their disciplinary boundaries and are working with colleagues from diverse disciplines as an attempt to merge their expertise with other expertise. Encouraging students to engage in similar activities and thought processes as they pursue IE-relevant education seems prudent.

In searching for IE programs I found that many efforts are evolving within research centers or institutes. This is likely related to funding strategies as well as a result of the difficulties in implementing change in traditional departments, especially to introduce a subject that is not rigidly defined or part of any accreditation criteria. While they often suffer from lack of institutional support, centers and institutes can be an effective model for promoting IE and its role in sustainability within existing educational structures. Additionally, if a research center is successful, it can serve as a catalyst for developing new departments and degree programs. Allowing students and faculty from various disciplines (ideally from diverse schools throughout the campus) to conduct research together through an institute provides an excellent opportunity for the individuals to see an issue from diverse perspectives and to make connections among various disciplines. The approach proposed here to highlight communication and teamwork skills could be addressed within an institute as well as within a classroom setting. Such an education will prepare students for the challenges of conducting research and working with industry and/or the public once they graduate.

In fact, this approach can help meet employer expectations and redress deficiencies in current educational efforts that produce environmental managers. Thomas and Nicita (2003) found in their surveys of Australian employers that "the ability to work in a team" was the single most important attribute that they expected from environmental program graduates. Communication skills (written and oral) were also extremely important and ranked higher than research skills. Similarly, Benton and Cottle (2000) surveyed corporate and government organizations about their experiences in hiring students to work in environmental affairs and they found that among non-computer skills, 48% of respondents said that the students lacked "integrative skills." This was the most common response. Presentation/communication skills were noted by 43.4% of respondents and writing skills by 42.2%, the number two and three responses, respectively. Clearly, the programs in existence purporting to train people for careers in environmental fields are not adequately addressing these key themes.

This is not news in some technical fields. For example, professionals with the National Academy of Engineering note that a strictly technical education is no longer sufficient to prepare engineers for what they will face when they enter the workplace. Wulf and Fisher (2002) write that, "As the world becomes more complex, engineers must appreciate more than ever the human dimensions of technology, have a grasp of the panoply of global issues, be sensitive to cultural diversity,

and know how to communicate effectively" (36). McLellan (2000) agrees, "To be effective in the policy world, young scientists need to learn analytical and communications skills that are relevant to that world" (40). This is especially salient to the IE community. Attendees at the 2nd International Society for Industrial Ecology conference in June 2003 repeatedly emphasized that for IE to make a difference in promoting sustainability, it is time for its ideas to move from research labs to decision-makers' desks.

The model depicted in Figure 3 reflects one way to ensure that future employer surveys no longer identify teamwork, integration, and communication skills as deficient and helps to ensure that freshly minted IE specialists know how to integrate diverse information and to better communicate across disciplines. The expanding IE presence in curricula and in research institutes provides engineering and other technical programs an opening to address growing concerns that technical education needs to be revised to adapt to changing social and cultural dynamics. Additionally, it fits with broader societal demands for improved communication between technical experts and public that includes both technical information and the values and emotions related to various issues (Waddell 1995). Just as no single discipline can address an issue, it is no longer sufficient or appropriate to employ a one-way communication process whereby technical experts simply "inform" the public and/or decision-makers. To embark on a more stable ride toward sustainability, embracing a more complex approach to communication will be paramount – especially as cultural differences are increasingly important in designing sustainable programs and practices in non-industrialized nations. Therefore technically trained individuals need exposure to non-technical perspectives, including humanities-based perspectives, and need to be comfortable communicating with other disciplinary experts about all aspects of an issue. Of course, this works the other way as well. Students in humanities and social sciences do need a better understanding of technical issues if they are to contribute to a sustainable society. However, as the data here reveal, the majority of efforts related to IE are not in the humanities or social sciences and there is a strong possibility for this to create a roadblock to our efforts to reach sustainability.

Improving communication and expanding IE education to include a broader set of social science and humanities perspectives will likely increase the nebulous nature of IE. For many, the lack of a consistent and uniform definition for sustainability and for industrial ecology is troubling. I contend that the flux in these concepts is allowing diversity to flourish and encouraging researchers and practitioners to creatively apply their own perspectives and ideas. Because sustainability will require not doing things the same way we have always done them, this creativity can be a powerful force. IE cannot be a driving force for sustainability if it limits itself to one, or a few disciplinary tracks. In contemporary educational settings, creating a static definition may lead to confining IE to a particular place on campus. The evidence presented here suggests that this is already happening by default. As technical based programs expand, the perception that IE is strictly a technical program may preclude experts in other areas, especially the humanities, from exploring the potential for all disciplines that resides in the philosophy driving IE. Being the "science of sustainability" is a nice motto, but em-

phasizing science and technology based programs at the expense of other perspectives will not provide the quickest route to sustainability. In fact, attempts to insulate science and technology from other, less quantifiable, human factors will likely impede efforts toward sustainability. Perhaps the revolutionary power in IE and sustainability is in NOT unifying our ideas and approaches but continuing to remain open to new ways of thinking and being. The rapidly growing interest in IE is encouraging, but there is still much work to do to ensure that the educational processes that teach tomorrow's researchers and decision-makers how to "do" industrial ecology, are not promoting a very narrow and limited view of what it will take for IE to chauffeur us along the path of sustainability.

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