Encouraging Multi-disciplinary Education and Inter-disciplinary Research

Chris T. Hendrickson[1]

Abstract

Multi-disciplinary education and inter-disciplinary research are often sought, but significant barriers exist. Impediments to such activities include unfamiliar jargon, dissemination of results to different audiences, increases in teaching loads, loss of overhead and research volumes, curricular restrictions, prejudice and time constraints. I suggest approaches to overcome these impediments. Indicators of inter-disciplinary activity include the variety of publication outlets, co-authors and enrolled students.

Introduction

Multi-disciplinary education and inter-disciplinary research are frequently touted as goals, but just as frequently flouted as a practice. In this paper, I will discuss some of the rationale for multi-disciplinary education and inter-disciplinary research, discuss ways to encourage this behavior, and provide some possible measures of inter-disciplinary activity. I write as someone who has both taught in multidisciplinary courses and participated in inter-disciplinary research.

The Accreditation Board of Engineering and Technology (ABET) provides explicit encouragement for inter-disciplinary education. The Engineering Criteria 2001-2002 requires undergraduate programs to insure that prospective engineers have "an ability to function on multi-disciplinary teams" [ABET 01]. In practice, this requirement often leads to project assignments in which students take on different roles such as designer or contractor.

This past year, a colleague and I served as advisors to a small multi-disciplinary team investigating the possibility of using pressure sensors embedded in asphalt to replace the common (and often broken) loop detectors for vehicles [Blair, Lim and Miyakawa 01]. The project involved modeling of pavement stresses due to vehicles, sensor

[1] Duquesne Light Professor of Engineering and Head, Department of Civil and Environmental Engineering, Carnegie Mellon University, Pittsburgh, PA 15213, phone 412-268-2941, cth@cmu.edu

selection and circuitry, laboratory experiments, design of a new system and cost estimation. It was a true multi-disciplinary challenge for the students involved. The project required close co-operation among civil and electrical engineering students, including writing a joint final project report. This is the type of experience that insures students will have the skills to work on a multi-disciplinary team. By the way, the project suggested that pressure sensors could be more cost-effective than loop detectors, but we will need some more work to check on the durability of the pressure sensor.

Civil engineers are well aware of the prevalence of such multi-disciplinary teams in professional practice. For example, project teams for buildings often include architects, structural engineers, mechanical engineers, and construction specialists, plus supplemental professionals such as lawyers or marketing specialists. Successful professional practice requires such team collaboration.

Inter-disciplinary research can also have significant benefits. Technology and new methods can be rapidly transferred from discipline to discipline. The boundaries between disciplines have research opportunities that are difficult to exploit in traditional research practice. Indeed, all the existing disciplines can be traced back to pioneering inter-disciplinary research. Inter-disciplinary research can also expand the boundaries of existing disciplines. For example, civil engineers can be significant contributors to micro-electrical mechanical systems or nano-technology research.

Most importantly, interdisciplinary work tends to be problem focused. Universities tend to get polarized and have faculty working on narrow problems or on engineering science that is not problem focused. Engineers in practice work on problems without regard to disciplinary boundaries. Interdisciplinary work can teach students to solve real, important problems, and this is good training for professional practice.

Interdisciplinary work does carry the danger of producing interdisciplinary dilettantes who never learn any subject in depth. Even undergraduates need to learn some area in depth, though not necessarily an entire discipline. Educational and research programs need to maintain a balance of breadth and depth in their portfolio of work.

Overcoming Barriers to Inter-Disciplinary Education and Research

Inter-disciplinary education and research are not easy, especially with the departmental structure of most universities. These barriers can be administrative, cultural or inherent in any multi-disciplinary undertaking. Below, I discuss some important problems and some amelioration approaches.

1. They don't speak my language.

All academic and professional disciplines tend to develop their own language or jargon that can be incomprehensible to outsiders. A specialized jargon provides greater speed in communication and a means to summarize common findings and methods. For example, all economists know about a "Pareto optimum," but outsiders may need an explanation. All transportation engineers know the characteristics of a "user equilibrium." Undertaking inter-disciplinary work requires translation from such jargon or spending the time to learn a new language.

2. Where will we publish the results?

Disciplines have their own journals, with varying levels of readership and prestige. There are far too many journals for anyone to read, so professionals concentrate on journals in their own specialization. But this focus creates difficulties for inter-disciplinary research. If I undertake inter-disciplinary research with an economist, I may end up publishing my research results in the economics literature rather than the civil engineering literature. Quite possibly, my civil engineering colleagues will never read such papers, and my research reputation will be thereby diminished. This is particularly a problem for academics relying upon outside letters of reference for promotion from members of a particular discipline. Fortunately, web sites and digital search engines make literature much more accessible now than in the past. There may also be problems in finding appropriate reviewers for inter-disciplinary research, but this is a problem that good editors are able to solve.

3. Won't multi-disciplinary increase the teaching load?

A first reaction for any course with an inter-disciplinary component is to have two instructors, thereby doubling the teaching load (measured in faculty time per credit). By extension, a multi-disciplinary course would have multiple instructors, although this rarely happens. Not involving an expert in each discipline runs the risks of having knowledgeable students hoodwinking a specialist instructor or not covering concepts outside of a single specialist's purview adequately. The practice of guest lectures and project review teams can help here.

4. What about my overhead and research volume?

Academic departments often receive a portion of indirect or overhead research charges as a means of financing department expenses. All academic departments are happy with greater research volumes. Indeed, research expenditure per faculty member is one measure used to rate the quality of engineering colleges [USNEWS 01]. As a result, administrators are loathe to permit inter-disciplinary work to re-direct research budgets to other departments. This problem has an easy solution, but one seemingly beyond the capabilities of many university accounting systems. Budgets should be allocated to different units so that research expenditures can be tracked within each unit.

5. We don't have room in the curriculum for multi-disciplinary work.

There is no end to the number of desirable topics in a civil engineering program. Moreover, new topics continually appear. For example, many argue that modern biology should be required for all engineers. It is difficult to agree on priorities among the possible topics. Given the importance in professional practice of multi-disciplinary projects, making room in the curriculum seems to be important. For example, more civil engineers will work on multi-disciplinary teams than will design a roadway pavement or a hydraulic structure.

6. Inter-disciplinary research just isn't very good.

Academic disciplines evolve with considerable effort from a large number of professionals. As a result, the disciplines become increasingly sophisticated and problems are examined repeatedly. In contrast, inter-disciplinary problems have received less attention and are often treated with less sophistication. A good metaphor for the research enterprise is an elastic sheet that is pushed up to greater sophistication by the support of disciplinary research. The areas below disciplines tend to sag below these high points. Assessing inter-disciplinary research requires a correction for the maturity of the research endeavor.

7. I don't have time for inter-disciplinary research.

Inter-disciplinary research has activation costs associated with learning new jargon and reviewing a new literature. Many researchers don't want to pay such a price. That is fine, as it means there are more opportunities for researchers willing to commit to inter-disciplinary endeavors.

Measures of Multi-disciplinary and Inter-disciplinary Activities

Interdisciplinary work is frequently cited as a goal, but not actually pursued in practice. In this section, I will suggest some measures of the extent of actual inter-disciplinary work. These can be useful for research proposal reviewers or advisory committees.

1. Co-authors: Have potential collaborators written joint papers?
2. Diversity of journals: A researcher pursuing inter-disciplinary work will usually publish in a variety of journals, often spanning several professional societies.
3. Course enrollments: How many non-majors enroll in the various courses offered by a department? For example, are construction courses in civil engineering attracting architects or mechanical engineers?

Conclusions

Inter-disciplinary education and research have significant advantages but also some substantial barriers. The administrative and cultural barriers to interdisciplinary can be removed or substantially ameliorated with proper attention.

Acknowledgements

This material is based upon work supported by the National Science Foundation under Grant No. 9700568. Thanks to my colleague Lester Lave for helpful comments.

References

ABET, Accrediation Board for Engineering and Technology, www.abet.org, (accessed May 25, 2001).

Blair, Heather, Liam Lim and Laura Miyakawa, "Utilizing MEMS Pressure Sensors to Replace Inductive Loops at Traffic Light Intersections," Course 39-500 Project Report, Carnegie Mellon University, 2001.

US NEWS, http://www.usnews.com/usnews/edu/eduhome.htm (accessed May 25, 2001).

The Future of Civil Engineering Research: Targets and Needs

George F. List, Ph.D., P.E., F.ASCE[1]

Abstract

This paper focuses on the future of civil engineering research for the next 20-50 years. It has a North American focus, but world trends provide a backdrop against which the expectations are developed. A conclusion is reached that the needs have never been greater nor the challenges more significant in advancing the technology by which the life-supporting infrastructure of civilization is created.

Introduction

Since civilization began, we have been perfecting the life-supporting infrastructure upon which we depend today. It's easy to understand why the public might think civil engineering research is passé. Compared with many other areas such as electronics and biomedical engineering, research in civil engineering has been underway forever. Consider the fact that in 50 short years, we've progressed from vacuum tubes to large-scale integrated circuits. By many orders of magnitude, we've reduced the space and energy required to carry out extremely large-scale calculations. In contrast, the water supply system for New York City isn't that different from the one that supported first century Rome. And Rome's highways look similar to those that exist today. We're still using wheeled vehicles, steered by humans to traverse a travel way made of compacted stone. Nominally, this is a testimony to high quality engineering that civil systems, once put in place, have life expectancies in the hundreds of years. They last a long time, certainly a lot longer than electronic devices, or even the repairs we affect to refurbish and rehabilitate the human body. But we still need civil engineering research. The future demands it.

Severe Demand Pull

Research is needed because the demands on civil engineering systems are increasing at what seems like a double-digit pace. As world population grows, and the demands for life-supporting infrastructure become both larger and more complex, there's more,

[1] Rensselaer Polytechnic Institute, Troy, NY USA

not less need for research so we can provide a better, safer, more energy-efficient and more world-friendly set of life-supporting systems.

Consider population growth, the world's number-one dynamic and civil engineering's most difficult challenge. The United Nations (2001) estimates the world's population will grow from 6.1 billion in 2000 to 9.3 billion in 2050. This is an increase of 50% in only 50 years! Six countries, all of which need major infrastructure, will account for more than half of this growth: India, 21%; China, 12%; Pakistan, 5%; Nigeria, 4%; Bangladesh, 4%, and Indonesia, 3%. Moreover, while the population in the world's developed regions (where the infrastructure is) will remain relatively constant at 1.2 billion, the population in the less developed regions (where infrastructure is needed) will rise from 4.9 to 8.2 billion. In addition, 48 countries classified as least developed (where there's almost no infrastructure) will triple their population from 658 million to 1.8 billion. Unfortunately, among the more developed regions, 39 countries are expected to have population decreases. The Russian Federation, including Georgia and the Ukraine, is expected to have its population decline 28-40%. Italy and Hungary will experience a 25% drop and Japan and Germany will each lose 14%.

And then there's the issue of where this population growth will be rural or urban. The United Nations (1999) expects virtually all of the population growth between 2000-2030 to be urban. Almost none will be rural. While there are 2.9 billion inhabitants in urban areas today, that number will rise to 4.9 billion in 2030. That is: the world's urban population will grow at twice the rate expected for the world as a whole (1.8%/year versus 1%/year) and in 38 years, it will double. Moreover, most of this increase will occur in less developed regions, where the urban population will more than double from 1.9 billion in 2000 to 3.9 billion in 2030. In contrast, the more developed regions will see an increase from 0.9 billion in 2000 to 1 billion in 2030. Bernstein (2001) asserts that while in 1990 approximately two-thirds of the civil investments were occurring in developing countries, by 2020 two-thirds will be in developing countries!

Viewed another way, in 1950, only one city in the world, New York, exceeded 10 million people. In 1975 that number had increased to 5 (Tokyo, New York, Shanghai, Mexico City and São Paulo) and the largest, Tokyo, had outdistanced New York's 1950 population of 12.3 million by reaching 19.8 million. Today there are 19 cities in the world over 10 million and most are in developing countries. The top city, which is still Tokyo, has 26.4 million inhabitants. By 2015, the number of cities over 10 million will rise to 23; five will be over 20 million; almost all of them will be in developing nations; and New York will have dropped to 8^{th} on the list. Bernstein (2001) asserts that about 80 of the world's 100 largest cities will be in developing countries!

The second crisis is water. A report from the United Nations (1997a) suggests that a third of the world's population already suffers from "moderate to high stress" due to over-demand from and pollution of water supplies and two thirds will suffer "moderate to severe water stress" in 30 years if current trends continue. Either civil engineers have to solve this problem or someone else will. It is a crisis of huge proportions. The report states "the situation not only imperils human health and development on a vast scale, but also the aquatic and terrestrial ecosystems on which much of the earth's life depends." The report says that by 2025, the needs of an additional 5 billion people will have to be met if the world's population is to have access to safe drinking water and sanitary systems. With the world's population presently at 6.1 billion, that means creating new water and sanitary systems for the present world's entire population!

The third crisis is food. Civil engineers don't often think of agricultural infrastructure as being part of their "responsibility," but perhaps that perspective needs to change. The United Nations report makes it clear that there is a growing interdependency between the expansion of agricultural production and the provision of potable water. In fact, the report asserts that global food supplies may be put in jeopardy if the water problem isn't resolved, leading to economic stagnation, and the possibility of "local and regional water crises with global implications." The report urges us to deal with the water crisis in tandem with global food security.

The fourth crisis is sustainability. Sustainability has seen considerable civil engineering attention. The United Nations (1997b) asserts that while catastrophe is not imminent, "pursuit of business as usual is most unlikely to result in sustainable development in the near future." The report highlights the close linkages between economic growth, human development, and good management of the world's natural resources. The report states that the outlook for sustainable development is not encouraging. It says the gains that are being made are offset by the growing scarcity of fresh water, loss of forests and productive agricultural land, and increases in the number of desperately impoverished people.

So in summary the major question is this: how can civil engineering research be directed so that these challenges do not become major world crises. How can we provide the infrastructure needed to avoid worldwide strife? And more importantly, how can civil engineering research be directed so that these crises are averted. How can we make it possible for the world to accommodate an additional four billion people in the next 50 years, most of whom will be in very large urban areas. It is unlikely that yesterday's technologies will suffice for these challenges. We've never seen infrastructure challenges this great.

Major Research Emphases

So where should civil engineering research be focused? The answer may depend upon whether one's focus is on North America or the world. For North America, the emphasis needs to be on finding new ways to make our existing investments more reliable, longer-lived, less susceptible to natural phenomena, and more cost-effective, especially for incremental new construction and rehabilitation. But for the world, research should be focused on finding cost-effective ways to make massive investments in context-sensitive, safe, sturdy, and cost-effective civil engineering systems. New ways are needed to build everything from housing stock and water supply systems to transport systems.

This juxtaposition leads to an important observation about our own leadership position in civil engineering research. If our focus is too domestic, the world will pass us by. To focus on the world might mean our own infrastructure will slip. We must find ways to commingle the efforts, and diversify our support, as in a mix of NSF, etc. and research organizations abroad.

We must also interweave our efforts with the research that's receiving national support. Areas like biotechnology and information technology are where the "action will be." The others are microelectronics, nanotechnology, tether-free communications systems, virtual-reality based engineering, and engineering for the service economy. We need to mine these national initiatives so they produce significant spillover benefits and technology transfer for civil engineering.

To see where the leading indicators are today, we can start with the web page of the National Science Foundation (NSF, 2001a):

- dynamic systems, especially their behavior, modeling, sensing and auto-adaptive control;
- geotechnical systems and hazards mitigation, both of the natural environment on the built environment (e.g., earthquakes) and the obverse (e.g. contaminants, geo-environmental engineering);
- infrastructure-related information systems, including management information and hazard response systems;
- solid mechanics and materials engineering, including the deformation, fracture, fatigue, friction, wear and corrosion of all types of materials, as well as coatings and surface modifications for extreme service conditions; and
- structural systems and engineering, including the design, construction, repair, rehabilitation, durability, resilience, safety, upgrading and maintenance of structural systems and materials.

Moreover, there is the environmental program at NSF (2001b). Its emphasis is on innovations that reduce the adverse effects of solid, liquid, and gaseous discharges into the natural environment. It also focuses on innovative remediation techniques and technologies.

Clough (2000) provides insightful thoughts. He emphasizes research on water, transportation, land use, biotechnology, information technology, nanotechnology, materials in general, e-business, enterprise management, streamlined construction, and sustainability; a cogent list of significant challenges.

Bernstein (2001) also offers a perspective. He presents thoughts about where the design and construction industries will be in 20-50 years. It's a very useful backdrop against which to consider research directions:

- Infrastructure will be more decentralized and smaller with miniaturization of many technologies.
- Knowledge about advanced materials will be an essential competitive asset.
- Biotechnology will be a leading source of innovation in environmental engineering.
- The interaction of energy, information technology, and infrastructure may cause the biggest revolution in urban infrastructure design in several hundred years.
- Heavy use of information technology will be involved.

- Production on a global 24/7 basis will become the norm.
- There will be emphases on international practice and service (not just technical support).
- Civil engineers will become the "master builders" for many initiatives.
- Projects will a) make heavy use of prefabricated components and packaged systems, b) involve substantial interaction among multiple disciplines, c) be design-build-operate in nature, and d) have environmental concerns as an integral part of each project, not an afterthought.

The sense of civil engineering research presented here has significant overlap with these current perspectives. We think the emphases need to be on 1) water; 2) sustainability; 3) construction tools and techniques; 4) transportation; 5) telematics; 6) modeling, simulation, command and control; and 7) new materials. We consider each of these in some detail.

Water. The looming challenge is water. Postel (1999) claims that mankind is drawing enough water daily to fill 140,000 Olympic-size swimming pools. Places like Bangkok and Mexico City are sinking. The list of locations illustrates the universality of concern: the Gaza strip, Bhopal, Tripura (India), Nepal, western Jordan, Ocean City (NJ), southeast Asia, Mexico City, and the Northern Mariana Islands. No geographical area seems to be immune.

We should lead the world in this research (NSF, 2001c). Civilization will collapse without water. Even sustainability becomes irrelevant. The World Bank (2001) says that inadequate water supply and sanitation could pose the largest threats to human health in third-world countries. We need ways to replenish supplies quicker, with greater efficiency and less cost (e.g., Hellstrom, Jeppsson, and Karrman, 2000). Moreover, it seems that greater efficiency will bring higher waste concentrations, which will make the task of wastewater treatment even more challenging.

The leverage of more research couldn't be better. Clough (2000) says the US will spend $300 billion over the next 20 years to upgrade its water systems. Clough also says that polluted runoff from cities and farms is the leading source of water contamination in the U.S., causing 60 percent of the pollution problems. And about 40 percent of the United States' waterways are so contaminated people cannot fish or swim in them. This means holistic research is needed.

Higher Ground for Humanity (2001) says, the earth is 75 percent water but only 1% of that water is drinkable. And there's a tug-of-war between drinking water and agriculture. Clough (2000) points out that India, which now contains 1 billion people - a sixth of the world's population, has drilled some 8 million wells to triple its grain harvest during the past 50 years, and that has barely kept pace with population demand. And as a result, India is now depleting its underground water reserves twice as fast as they are being replenished. We need to be exploiting our technological know-how to help solve these problems.

So civil engineering research needs to be civilization-focused, not just narrowly related to the built infrastructure. If, as Postel (2000) asserts, agriculture accounts for 70 percent of the world's water usage, then efficient farming and irrigation methods should be a top priority, supported by civil engineering research, in