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Multidisciplinarity – the grand challenge and the future of academia

"In nature things overlap"

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Abstract

The most profound discoveries in science and technology are occurring at the intersection of disciplines. As science is progressing, the problems it addresses grow in complexity. This makes it increasingly more difficult to understand real world connections and to find solutions with a single discipline. In order to meet such a challenge many individuals pursue multiple degrees or undertake additional training to become multidisciplinary. But what does it take to become multidisciplinary and what can be gained? Judging by numerous conferences, modern research centres and innovative academic programmes around the world, multidisciplinary landscape is the place to be. Why is the shift to multidiscipline education happening now? What is the main force that drives the change? Is it the overlapping nature of science itself? The paper tries to address some of these issues.

Categories and subject descriptors: K [Computing milieux]; K.1 Computer Industry, K.3 [Computers and Education], K.4 Computers and Society, J [Computer Applications]; J.7 [Computers and other systems]

Keywords: cooperative research, multidisciplinarity, interdisciplinarity, cross-disciplinarity, transdisiciplinarity, education, innovation, curriculum

1. Introduction

The digital revolution has profoundly transformed the way research is done. New research directions emerged, posing scientific and technical challenge that increasingly cross the traditional academic boundaries. A growing number of scientific disciplines, from cognitive science to atmospheric modelling and genomics depend largely on advances in computer technology. Fastest computers, largest disks and most capable sequencing machines are being applied to its ends.

Recent developments in genetics and molecular biology, and the impetus of the genome projects made interaction between scientists more crucial than ever. Vast amount of information accumulated in computer databases worldwide is waiting idle for interpretation. In a large part processing of this information is a role of researchers in new disciplines, such as bioinformatics, which hold a promise to interpret the enormity of gene and protein data.

The changes to research compel major changes in education. The need for multidisciplinary education has become evident in various sectors of employment.

In the new reality universities are expected to broaden their missions and play a larger role in research enterprise both nationally and internationally. This requires graduates who have more diverse background and the combined expertise in more than one discipline, like e.g. biology and computer science, the disciplines that have not historically shared a common attraction. The rewards are great, so that are challenges.

2. The Hottest Buzzwords in today's scientific world

If there is a magic word that needs to appear in every mission statement, scientific article, research proposal or position paper these days, then the word is in the list:

Mutlidisciplinarity/Crossdisciplinarity/Interdisciplinarity/Transdisciplinarity

Figure 1: An Interlocking nature of science [6]. The top piece of the puzzle, is it Computing?

To begin, what is a difference between all these terms? Although commonly they are used interchangeably, we recognize their distinct character (there is by no means a single perspective or vision on the issue).

A goal of *disciplinary (DI)* science is a deep understanding of a single problem. It may involve many scientists but they use methods of a single discipline within well defined specializations. Figure 2 illustrates a disciplinary approach.

A *Mutlidisciplinary (MD)* research is a study of a topic not in one discipline but in several disciplines at the same time. The multidisciplinarity overflows disciplinary boundaries, while its goal remains limited to the framework of disciplinary research. Multidisciplinary approach (Figure 3) brings a broader view and a deeper understanding of the topic, like adding colours to a black/white picture.

An *Interdisciplinary (ID)* approach (Figure 4) attempts to go further by trying to derive a novel insight through the melding of concepts, methods and theoretical frameworks coming from different disciplines. Interdisciplinarity is often characterized in terms of the adage “The sum is greater then the parts” [5].

Crossdisciplinarity (CD) (Figure 5) describes any method, project and research activity that examines a subject outside the scope of its own discipline, without cooperation or integration from other relevant disciplines. In crossdisciplinarity topics are studied using foreign methodologies of unrelated disciplines. Crossdisciplinarity is useful in context when one discipline requires independent expertise from another discipline in order to progress.

Multidisciplinarity is different from crossdisciplinarity in this, that more then one outside discipline examines a specific topic.

Finally, there is a *Transdisciplinary (TD)* research (Figure 6). As the prefix Trans indicates, it is a principle of scientific research and intradisciplinary practice describing the application of scientific problems that transcend the boundaries of conventional academic disciplines. Its goal is the understanding of the present world of which one of the imperatives is the unity of the knowledge [3]. Scientists from different disciplines learn from each other and develop a similar set of skills, while disciplinary strengths dominate. Transdisciplinary approach is said to dissolve boundaries between disciplines.

A symbolic pictorial representation of different *disciplinary approaches to research is shown below (the difference is really in a size of interface and dynamics).

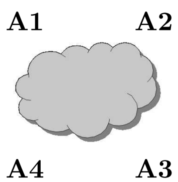

Figure 2: (DI)

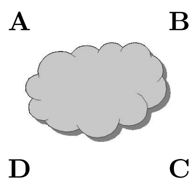

Figure 3: (MD)

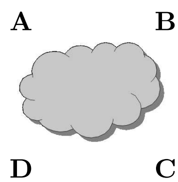

Figure 4: (ID)

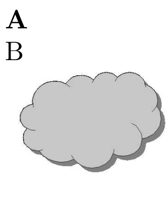

Figure 5: (CD)

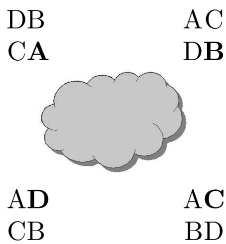

Figure 6: (TD)

3. Why Multidisciplinarity?

The question brings us to the anecdote about three scientists, physicist, biologist and mathematician, who are sitting in a street café watching people going in and coming out of a house on the opposite side of the street. First they see two people going into the house. Time passes ... . After a while, they notice three people coming out.

The physicist says:	"The measurement was not accurate".
The biologist says:	"They have reproduced".
The mathematician says:	"If exactly one person enters the house now, then it will be empty again".

Harmony between disciplines and knowledge is a challenge in disciplinary big bang and relentless specialization. This "team" cannot address the problem at hand.

So, what to do when researchers are thwarted by the confines of their own discipline's conceptual and methodological armoury? Take a multidiscipline approach? If so, which one?

In the context of new disciplines that emerged from existing ones through a marriage, such as *bioinformatics, bioengineering, biochemistry, nanotechnology, or medical robotics,* the term interdisciplinarity is more often used, while *ethnography, natural environment, energy or health* are better understood through a process of transdisciplinary modelling.

Interdisciplinarity is a good thing, as it is hoped to bring a novel understanding of the problem domain by integration of epistemologies from different disciplines. However, it is very difficult to achieve and often remains an elusive goal. There are also valid concerns about assessment of interdisciplinary work and challenges associated with interdisciplinary integration. According to Bannon, it is a mistake to assume that it is even possible to develop interdisciplinary theory, per se; attempts to build such a hybrid frameworks are destined to fail [2].

In practice many interdisciplinary enterprises work actually at the multidisciplinary level, where a group of researchers from different disciplines cooperate by working on the same problem towards a common goal, but they continue to do so using theories, tools and methods from their own discipline. Whilst such pluralism can provide an impetus to advance knowledge, it does so through *cumulative* process, which may occasionally result in an impasse or misinterpretation. By mixing together different terms, topologies and methods in one big melting pot, the outcome is all too often confusing rather then insightful [5].

4. What does it take to become multidisciplinary and what can be gained?

In the age of multidisciplinarity, students must be more agile and willing to take unusual assignments both over course of their education and in professional careers. It is widely believed that a higher level of competence in mathematics and computer/ computational science is necessary as foundations for multidisciplinary studies in science.

In addition to the areas of main major, students increasingly need to understand aspects of business, law, management and international issues. Those who have aspirations to work with genomics need a breadth of knowledge and skills, as well as unprecedented level of talents for cooperative work. So the niche is at the scientific boundaries. And, an advanced degree will bring the monetary rewards.

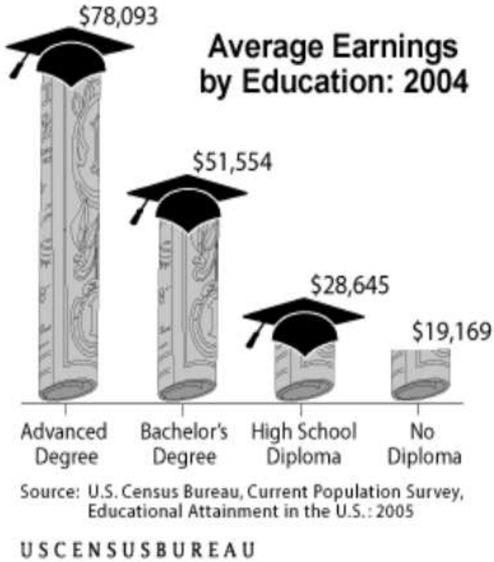

Figure 7: How the job market dictates salaries

Consequently more and more scientific research institutions look for graduates whose multidisciplinary thinking is a second nature. They strongly recommend that undergraduate background will be multidisciplinary, since an approach that spans multiple disciplines is needed to better understand real world problems.

The importance of multidisciplinary studies for addressing complex problems, like the climate change, creates great opportunities for many research interactions. Multidisciplinary research brings together people with different backgrounds. They can benefit from a more diverse set of solutions, but a need to work hand in hand is fundamental. Multidisciplinary work embraces the goal of advanced understanding of the problem in ways that would have not been possible through single disciplines. As such it has a lot to offer in term of opportunities and excitement. So, let all flowers bloom.

5. Who are the big players?

An example of large- scale multidisciplinary and multinational efforts is the Green Chemistry Grand Challenge project, a collaboration of researchers from Europe and U.S. that include several universities working on methods of extraction of chemicals from waste biomass.

The project involves a variety of expertise from Agronomics through Biology, Forestry, Chemistry, to Social and Environmental studies, and intensive computing on top of that.

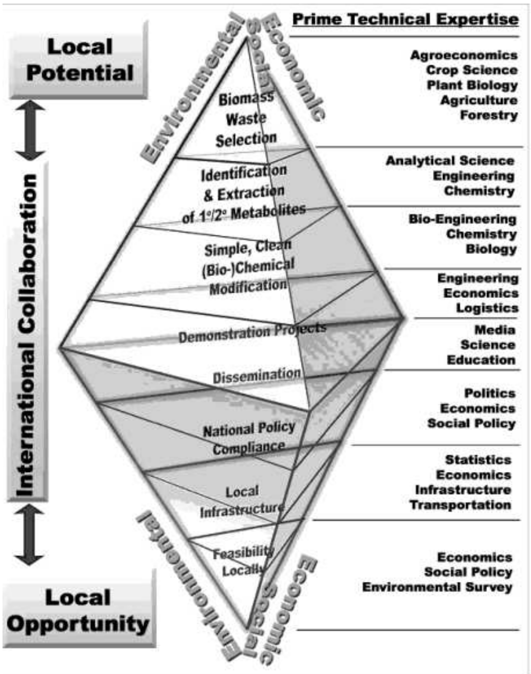

Figure 8: Many facets of the Green Chemistry Grand Challenge [9]

In the new research world international cooperation is intensifying. The growing research capabilities of the nations provide new opportunities for collaboration, especially in astronomy, oceanography and high-energy physics. A continuous call for intensive international research on such problems like global climate change, ocean depletion or acid rain resulted in founding many centres of excellence for specific research.

On the frontiers Bio* is a big player. Bioinformatics, Bioengineering, Biophysical Chemistry, Biomedicine. Nonotechnology is another big player; nano makes big things smaller; there is almost no discipline, which is not attracted by making things at the nano level.

More disciplines then ever have sophisticated computational needs and a bigger appetite for computer resources. Computing is a part of almost every scientific project these days. New generations of computers make massively parallel processing possible on a large scale. In order to fulfil the needs national laboratories are establishing powerful computing centres with super-crunchers installed. This marks a new era in high performance computing.

6. Trends in Universities' Enrollments (US)

Novel approaches and multidiscipline academic programmes attract a large slice of high school graduates. A shift of students' interest to new bio* programs is widely observed. The growing interest in biomedical engineering is clearly visible on the chart. Source of data [8]

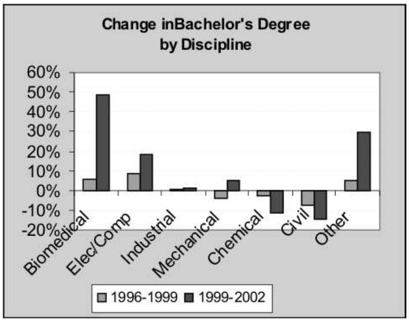

Figure 9

Graduate enrollment trends – Source of Data [8]

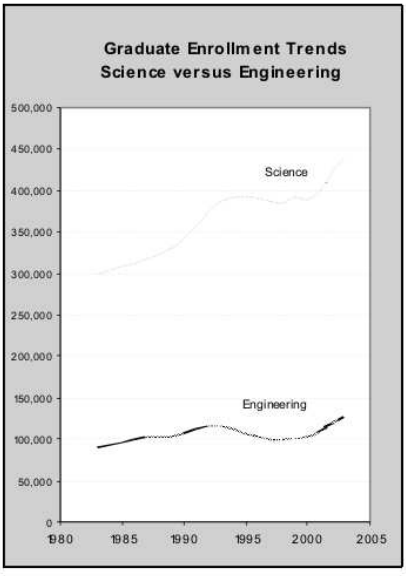

Figure 10

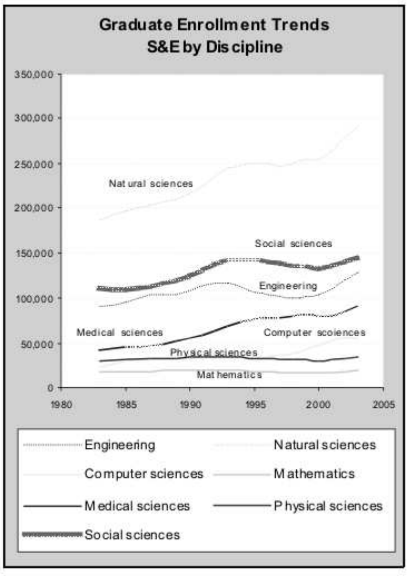

Figure 11

Note: In source of data [8] the category *Science* includes two subcategories, *Natural Sciences* and *Social Sciences* (i.e. sum of the top two lines on Figure 11 results in the top line on Figure 10). S&E denotes Science and Engineering.

Trends in doctorates awarded in US – source of data [8]

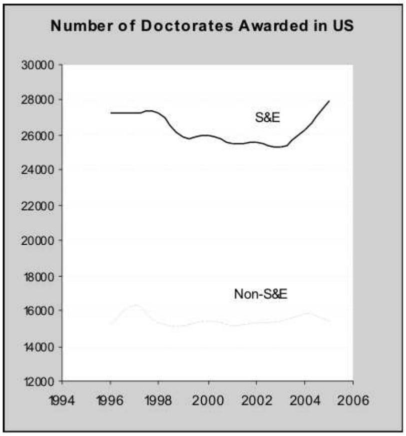

Figure 12

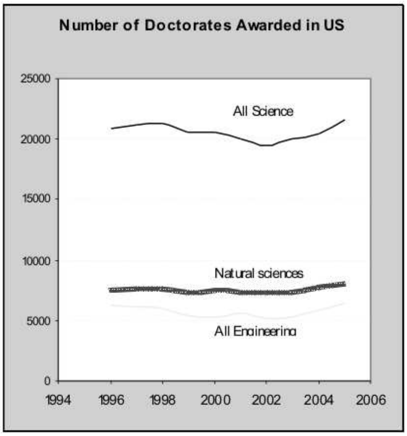

Figure 13

Number of doctorates awarded in US in 2005 hit all-time high.
On the left: Science and Engineering (S&E) versus Non-Science and Engineering (Non-S&E).
On the right: Science versus Engineering (with the natural sciences share in the middle).

7. Academia in Transition

The role of universities in modern society described by Einstein sounds amazingly accurate:

> *"We are here to counsel with each other. We must build spiritual and scientific bridges linking the nations of the world."*
>
> *(Albert Einstein, 1947)*

The policy of promoting specialized training in technical fields that was encouraging students to know more and more about less and less is being gradually replaced by a growing awareness that perhaps it would be better to know less about more and more. Industry is no longer making a clear distinction in what it expects from engineers and scientists, but it generally expects the scientists to be more practical and engineers to be more curious about the nature of things. The caps, gowns and diplomas may look the same but the groves of academe have changed radically over the past decade.

We witness changing paradigm within existing academic units, as academic departments are hiring more faculty with strong computational inclinations and supplementing lonely researchers by multidisciplinary teams.

Increased reliance on computers and instruments has resulted in revision and/or elimination of laboratories. Some educators even question the need of "wet laboratory courses" for high school students, non-majors and pre-med students.

8. Emerging Multidisciplinary Programs

Large number of academic institution world wide offers programmes at the interface between disciplines through revisions of curricula and cross or joint appointments of faculty. The new programs spring up like mushrooms. When you look through the list (to mention just a few) you may think "mix-and-match" disciplines to make your own.

: Applied Science
: Biomedicine
: Bioinformatics
: Biotechnology
: Biochemistry and Biophysics
: Computational Molecular Biology
: Computational Science
: Computational Physics and Oceanography
: Computational Genetics
: Computational Geophysics
: Cognitive Science
: Ecological Economics
: Electronic Media and Communication
: Environmental Science and Engineering
: Science and Genomics

9. Impact on Computer Science Departments

Simplistic analysis of recent developments in science brings us to conclusion that science is increasingly about collection, organization and transformation of information. If we view Computer Science as "a systematic study of algorithmic processes that describe transformation of information", then computing underpins science in a far more fundamental way.

What drives advances in science is actually the computer industry; the science is only a passive beneficiary of the relentless innovations in computing. It is no accident that the most vibrant areas in computing today are those tightly coupled to scientific problems, such as sensor networks, data integration and grid computing.

As researches attempt to study the collective behaviour of larger systems in biology, climate or seismology, the goal is to develop computer simulation systems as tools for studying system-level behaviour, and computer scientists have a lot to say there.

Since both data processing and simulation systems demand hardware, software, algorithms and theory, successful science collaboration must include computer scientists as key members. In turn, Computer Science departments will need to train and reward individuals whose focus is on computing innovations required for science, what may be called applied computing [10].

A broad range of skills is required from software engineering team members, as they seek to produce relevant software solutions that are timely and of high quality. Communication between the academic and industry community though is ever existing difficulty.

Digital methodologies not just digital technologies are the hallmark of tomorrow's research.

10. Conclusions

The ability of universities to broaden their mission and play a larger role in research enterprise will be critical. Many new scientific and technical jobs will require more flexible, across-disciplinary relationships both with and among universities, industries and governments.

Multidisciplinarity is an important theme of looking into academic curricula to broader science education at all levels and to engage young people into S&E from early age in order to produce graduates whose multidisciplinary thinking is a second nature.

Many academic programmes have shifted to multi/interdisciplinary in the recent decade. Some traditional disciplines, such as molecular biology or microelectronics are merging with other fields, or being redefined.

If the trends identified in *Indicators 2006* continue undeterred, three things may happen:

- The number of jobs that S&E require will grow
- The number of US citizen prepared for these jobs will level
- The availability of people from other countries will decline

As a result critical problem of the S&E labour force in US will surface.

Widespread changes underway in the research and development landscape have impact on how universities fund, conduct and disseminate research efforts. Educational innovations are being widely implemented but financial and safety concerns loom large universities. A central question that all must be concern themselves with is how to exploit the new technological capabilities in such way that they can be beneficial and useful to human kind.

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