Interdisciplinary Activities in Mathematics and Science in the United States

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Abstract: This paper outlines the need for interdisciplinary efforts in mathematics and science at university level in the US. It summarizes the different types of activities currently taking place. They are spread along a spectrum from minimal coordination to complete integration; each having different advantages and disadvantages. Examples of each type or activity are briefly described.

Kurzreferat: *Interdisziplinäre Aktivitäten in Mathematik und den Naturwissenschaften in den USA.* In dieser Arbeit wird die Notwendigkeit für interdisziplinäre Bemühungen in Mathematik und in den Naturwissenschaften an Hochschulen umrissen. Die verschiedenen Typen der derzeitigen Aktivitäten werden aufgezählt. Es gibt ein weites Spektrum der Zusammenarbeit von minimaler Kooperation bis hin zu vollständiger Integration; jeder Typ hat unterschiedliche Vor- und Nachteile. Bespiele für jeden Typ werden kurz beschrieben.

ZDM-Classification: B10, M10

1. Background

In US universities, undergraduate students generally take courses from many academic departments. For example, a student whose major field is biology will generally take calculus from the mathematics department, chemistry from the chemistry department, and physics from the physics department. Since US students seldom decide their major field until they have been at the university for a year or more, most introductory math and science courses enroll students from a range of departments and many who are undecided about their field of concentration. The courses taken in other departments have to be approved by the major field, but the content is seldom closely supervised by the major field. This system is very flexible for students and faculty – a student can change major fields and still count some or all of the courses already taken, and faculty can teach the same course to large numbers of students. However, there is an important loss under this arrangement. The loss is the coherence of a student's program: the intellectual connections between the subject matter in courses in different departments. The effect is noticeable: students view their subjects as utterly separate, and often do not see how the mathematics they have learned applies in physics, and are surprised to see that the chemistry they have learned applies in biology.

2. Recent interdisciplinary activities

In the last ten years, there has been a significant effort in the US, supported by the National Science Foundation, to increase the links between mathematics and other fields. These links range from separate but coordinated courses, taught with input from two or more departments, to fully interdisciplinary programs taught by an interdisciplinary team of faculty. There has also been an increase in the number of interdisciplinary programs that students can enroll in, such as environmental studies or biomedical engineering.

Even limited efforts at coordination are beneficial for students and sometimes eye-opening for faculty. For example, a mathematics topic can look quite different when used in another field – partially explaining why students have such difficulty in using what they have learned in a different course. As an example, the definition of a line integral in a mathematics course depends on the parameterization of the curve, while the definition used in a physics course emphasizes the geometric and physical interpretation and does not mention parameterization. A student may well not recognize that these are equivalent. Another example is provided by constrained optimization using Lagrange multipliers: mathematicians often argue geometrically and go directly to conditions on the partial derivatives, while economists work from economic interpretations and the Lagrangian function.

In this paper I describe the types of interdisciplinary activity currently taking place in the US. Each type of activity has its advantages and disadvantages, but all start to break down the compartmentalization of fields.

3. One faculty member teaching one course with applications from other fields

The easiest type of interdisciplinary work occurs when the faculty teaching a course gets input on topics, examples, and approaches to the material from one or more other fields. This could be mathematics with applications, or chemistry in the context of environmental and life sciences, or the physics of aviation.

Many of the new curricula in mathematics and chemistry are of this type. The calculus materials from Duke University are applications-driven, as are those written by the consortium based at Harvard, with which I am involved. Iowa State and the University of Illinois wrote materials which are oriented toward a particular field (engineering and life sciences, respectively). The chemistry consortium at Berkeley is producing material showing the role of chemistry in everyday life, and others have designed a physics course centered around the idea of flight.

The advantages of these courses are that they are easy to schedule – no coordination of faculty or student schedules is needed. The syllabus, still being entirely in the hands of one department, is as flexible as before. Teaching these courses is some extra work for the faculty, but not a huge amount. The faculty member has to become familiar with the use of his or her field in one or more other areas, but there is no ongoing coordination during the semester.

It might seem rather small-minded to list as one of the advantages the fact that these courses don't take ongoing coordination. However, the practical success of these endeavors often does depend on such practical issues. When the semester is underway, the faculty are often busy enough that courses that often require ongoing coordination are hard to maintain once the initial group of faculty has moved on to other activities.

The disadvantage of this type of course is that it doesn't fully break down the compartmentalization between different fields. These courses are sometimes more educational for the faculty (who learn about where their material is used) than for the students (who may see the applications as extra work added on, or as contrived).

However, the efforts at designing and teaching courses with applications are worthwhile. They are much more interesting for many students. In addition they dignify the subject matter by the “conspiracy theory” of teaching: the students are impressed by the fact that the faculty have taken the trouble (“conspired”) to find out and agree upon what should be taught. The effect is that the students take the material in both courses more seriously.

4. Two faculty members teaching two coordinated courses

These courses require the cooperation of two (or more) departments and often of the registrar. A group of students is enrolled in two (or more) courses and take them simultaneously. The syllabi of the courses are coordinated, and the order and presentation of the topics are designed to complement one another.

Examples of this kind of course pairing often involve one of the courses described previously. Harvard’s targeted math courses, which coordinate a special section of multivariable calculus and physics, or multivariable calculus and chemistry, are an example. The “Courses in Common” program at the University of Arizona is a program which coordinates two or three courses: for example, calculus, writing, and engineering design.

The advantages of this arrangement is that the syllabi can be done right from the students’ point of view. There is no longer any reason for students to see the math in the physics course first unless that is intended. In addition, each faculty member has clear responsibility for one course – his or her own. The students generally have a much better experience, though often as much for social reasons as intellectual. Since they now share two or more courses with the same group of peers, this group of students frequently becomes a real “learning community”. A sense of community is one of the most powerful forces in most students’ lives, and a community in which intellectual issues are regularly discussed can change the role of academic work in their lives. (The same effect is seen with the professional development workshops designed at Berkeley to help at-risk students succeed in mathematics courses.)

The disadvantages of such coordinated courses are that the syllabi are not flexible. If they are to stay coordinated, each faculty member must stay more or less on schedule. This can cause a problem either if the students in one course ask a lot of interesting questions, which the instructor would love to take time to answer, or if the students in one course are not understanding, requiring the instructor to spend time on more elementary material. Regular meetings between the faculty involved are essential in this system – and often hard to schedule. Notice, however, that the disadvantages of this structure – a rigid syllabus and the need for regular meetings – are exactly those of a large multi-section course following a common syllabus. Such multi-section courses are already common in US math departments, even though they don’t have the added advantage of helping faculty learn how things are done in a different discipline. Thus, the scheduling involved should not be regarded as an insuperable obstacle.

5. Two or more faculty members teaching one integrated course

The most ambitious courses are where groups of faculty have come together to write and teach a truly interdisciplinary course. There a team teaches the course, usually with more than one faculty member in the room at the same time. In some cases the dialogue between faculty in different fields is an integral part of the course.

The examples of such integrated courses are the new courses found in Stanford’s Science Core, and the integrated math/physics courses taught using the new calculus materials, for example at the Colorado School of Mines, Diabolo Valley College, Auburn University, and the University of Puget Sound. Some of the courses designed by the engineering coalitions are the same type, often involving more than two departments. For example, the integrated curriculum at Rose Hulman involves mathematics, physics, chemistry and engineering.

The advantage of these integrated courses is that the students see the faculty doing exactly what we have been exhorting them to do: talk to one another to see the interconnections between disciplines. The sense of the unity of science and of the role of mathematics as the life-blood of many fields is demonstrated more effectively by such courses than by any other method.

The main disadvantage of such courses is the time it takes to develop them, which can be enormous. Scheduling faculty in different departments to be free at the same time should not be as difficult as it is, but this can also be a significant drawback in keeping such courses going.

The other concern voiced by students and faculty in a course in which students receive one grade for work spanning several fields is that the pressure for grades is magnified. A student who fails now fails three courses out of four instead of perhaps one out of four. In the US, such pressure is considered undesirable, especially for first year university students.

6. Conclusions

Efforts of the type described here are vitally important to US universities today for two reasons. From the point of view of the students, they will not see their subjects as interrelated unless the faculty does and unless the faculty takes the trouble to present them that way. From the point of view of the outside world – in particular legislators and funding agencies – departments which are separate, and perhaps in feudal-style competition with each other, engender less respect and are vulnerable to selective cuts. The universities need to present, both to students and to the general public, a coherent, unified front where each discipline is seen to be an essential part of the whole academic enterprise. When the faculty members in a university recognise the essential worth of all the disciplines taught, not just their own, then the rest of society will appreciate what universities have to offer. Interdisciplinary courses are one powerful expression of this appreciation.

7. List of sample Web addresses

The following Web addresses contained, at the time of writing, material on interdisciplinary teaching. It is not intended to be exhaustive, but a sample of the kind of information that is available.

Mathematics with applications

Connected Curriculum Project (Duke University)
http://www.math.duke.edu/modules/
Calculus & Mathematica: BioCalc (University of Illinois)
http://www-cm.math.uiuc.edu
Middle Atlantic Consortium for Mathematics and Its Applications Throughout the Curriculum (University of Pennsylvania)
http://www.math.upenn.edu/∼ugrad/macmatc.html

Chemistry with applications

Modular CHEM Consortium (University of California at Berkeley)
http://www.cchem.berkeley.edu/Education/
ChemLinks (Beloit)
http://chemlinks.beloit.edu

Biology and related fields

BioQUEST (Beloit)
http://bioquest.org
Case Studies (University of Buffalo)
http://ublib.buffalo.edu/libraries/projects/cases/case.html

Integrated science, mathematics, and engineering

Science Core (Stanford University)
http://scicore.stanford.edu/
Foundation Coalition (Rose-Hulman, Arizona State, and other institutions)
http://fc.rose-hulman.edu/
http://www.eas.asu.edu/∼asufc
Elite Program (University of Arizona)
http://www.sie.arizona.edu/faculty/addenda/sen/sen.elite.htm
Undergraduate Computational Engineering and Sciences Project
http://www.krellinst.org/UCES/index

Learning communities

Washington Center
http://192.211.16.13/katlinks/washcntr/

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