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Linking science and business:

Examples of educational innovation

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LINKING SCIENCE AND BUSINESS: EXAMPLES OF EDUCATIONAL INNOVATION

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Abstract

Since 1997, 30 universities in the U.S. as well as the University of Leiden in The Netherlands have launched educational programs to meet the burgeoning need of high-tech business, industry, and the public sector for a cadre of science- and mathematics-trained professionals, who will serve as liaisons, consultants, and managers in research-intensive employment. In the U.S., Master's-level degrees (called Professional Science Master's) are being offered in such areas as biotechnology, financial and industrial mathematics, environmental risk management, computational chemistry, nanotechnology, the physics of modeling, applied optics, and geographical information systems and its applications. The programs also include short courses in business basics, intellectual property issues, communication skills, marketing, and finance. In The Netherlands, Leiden University developed an entirely new 40-hour certificate in "Cases from Business Life" for bachelors students and a "Science-Based Business" Master's (SBB) at the graduate level. Both programs are for science/math students only. Other recent programs at Leiden, such as "Life Science and Technology" and "Sustainable Molecular Science and Technology" aim at specific multispecialisms as well.

In this paper, Frans Birrer of Leiden and Sheila Tobias, outreach coordinator for the Science Master's initiative in the U.S., present a descriptive overview of these programs: their philosophy against the background of the "knowledge society", their curriculum, their pedagogy, their funding, the participation of business in these ventures, the types of jobs aimed for, and a number of challenges.

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A new era

During the past century a revolution has taken place in the way we deal with change. Change has become a strategic asset. No longer is change something that merely happens to us, we welcome it, we try to plan it (with mixed success), and we compete with each other in how fast we can innovate and adapt. Science and technology are the central, though not the only, motor for this change and innovation.

More than anywhere else these pressures (and opportunities) are felt in business, where innovation is essential for staying in the race. The increased rate of change has necessitated a thorough reshaping of the structure of business organizations and jobs. Hierarchical structures, with little or no connections between vertical lines other than through the top, could not react fast enough to a dynamic environment. Various parts of the organization and clusters of specialists had to be brought into intensive communication and interaction with each other.

Science has not only played a crucial role in all this, being the major source of industrial innovation, it has itself become the subject of change as well. Its importance to industry has given rise to motives and rationales different from the traditional one that one pursues ‘knowledge for its own sake’. Applied research generates consequences and implications at an ever increasing speed. And even academic science has entered into a process of continuous transformation, discarding and recombining old branches and disciplines, and inventing completely new ones, introducing new research techniques, expanding our knowledge and our capabilities.

As higher education becomes an expected pre-employment training ground for an ever growing part of the population, the expansion of university education has been accompanied by a major expansion of academic research as well.

New professional requirements

The developments sketched out above have dramatically changed the requirements for employees, in business as well as elsewhere. Industrial economies have witnessed large scale dismissals of the blue collar worker in favour of the knowledge worker, having an ever higher level of expertise. Given the anticipated growth in the knowledge-intensive sectors of the economy in Europe, Asia, and the U.S., demand for technical talent is projected to increase disproportionately; in the U.S., according to the Council on

Competitiveness, by 51% between 1998 and 2008, roughly four times higher than average job growth in that same period.[3] The argument is familiar: A strong pool of science and engineering talent enables a nation to shift more of its economic activity into higher technology and more productive activities that support higher wages. Further, the availability of technical talent attracts additional high-value investment from domestic and even multinational companies.

Given the speed of change, clearly the knowledge worker must be willing and able to adopt new knowledge, and new fields of knowledge But this is not the only kind of flexibility that is required. Behind these developments is the more profound question: what is the nature of the “technical talent” needed? Do innovation and higher productivity depend mainly on raw discovery coextensive with the quality and numbers of specialized scientists and engineers? More and more, these specialists must at least have some feeling for the broader context that innovation depends on, for the application and adaptation of discovery and for the provision of resources, i.e. effective management of all three. If not the actual knowledge and skills to engage in these activities oneself, at the very least these “flexible experts” must have the capacity to reach beyond their own domain of expertise, to communicate and work with experts from in other fields. Employers do value science students for their analytic and above all problem-solving skills, but complain that, as a rule, they lack communication, negotiation, and consensus building skills and are ignorant of (indeed indifferent to) the financial and legal/regulatory parameters within which business entities have to operate.[4]

Most particularly in the U.S. there is also some concern about “technological illiteracy” on the part of managers, a virtual “cultural divide” between those holding R&D positions and those commonly found in finance, marketing and management. Their companies would be more competitive, suggests Alan G. Merten, former dean of the Johnson School of Management at Cornell, now President of George Mason University in Northern Virginia, if they could find professionals having two or more (one technical, one nontechnical) specific areas of expertise.[5] It is noteworthy that it is the scientists who are calling for breadth. Merten is a mathematician by training. Neal Lane, former director of the U.S. National Science Foundation is a physicist. He writes: “Why has a society so

[3] Council on Competitiveness : Imperatives for innovation., 2001, Washington DC (Second National Innovation Summit, San Diego, April 5-6, 2001), p. 34.

[4] Sheila Tobias, Daryl E. Chubin, Kevin Aylesworth : Rethinking science as a career. Perceptions and realities in the physical sciences, 1995, Research Corporation, Tucson

[5] Alan G. Merten, “Managerial Science Gap Threatens U.S. Competitiveness: Survey,” News Release, 1995

broadly based in science and technology managed to define so narrowly the role and responsibilities of scientists and engineers?"[6] Business executives agree as well. Writes Lois Dipel, former VP Global Services at IBM: ",,,there is a great and constantly growing need in industry to produce students who are technically savvy and have a high degree of knowledge in the applied sciences, as well as a comprehension of the fundamentals of business and professionalism. Industry needs employees, who not only understand the technical nature of their project, but the business and legal aspects as well, and are able to communicate their mission to broad audiences."

Science and engineering graduates' supply

There is a general concern in the US and in several North European countries about the number of enrolments in science and engineering. Indeed, the number of Science and Engineering degrees given over the past 20 years in U.S. universities has been flat or declining in every science or engineering discipline with the exception of the life sciences; engineering by 45 percent between 1985 and 1995, mathematics by 32 percent and the physical sciences by 8 percent in that same period. Today only 5.4 percent of all 24 year-olds in the U.S. have science or engineering first degrees, compared with 7.2 percent in Japan, 8.9 percent in Korea, and 9.4 percent in the UK.[7]

In the Netherlands the decline of the number of students in science and engineering can be explained to a considerable degree from a demographic decline of the number of eighteen year olds of about 40% during the past 15 years. Industry has difficulty in finding specialists in some specific technical branches, and is worried about the size of the pool from which it can draw the most talented. Also, there are relatively few opportunities to get a university research position, whereas the many big companies considerably reduced their research laboratories at the same time,

This means that there are at least two major reasons for broadening the range of what is offered in science/technology studies. First, there is a need for science/engineering students with broader training. Second, it is important for those students who have talent for and take an interest in the study of science or mathematics to finish their science study even if they turn out not to have the talent or the wish for a research career. There are also some additional reasons.

[6] Neal Lane, U.S Congressional Testimony, 1995

[7] Council on Competitiveness, op. cit., pp. 35-37.

Investigations suggest, at least for the Netherlands, that one of the main reasons why potential students with talent for science and engineering decide for non-science programs, in the social sciences or in the humanities (most notably law, economics, and business sciences) is that they perceive the former as leading to very narrow job prospects, whereas the latter are more “open ended”.[8] This perception is not entirely correct (science and engineering students in the Netherlands are valued for their analytic and problem solving skills by employers for a much broader variety of jobs, such as consultancy), but the perception still persists. Broadening the science and engineering curriculum would make the wider job perspective more explicit, and thus could attract more students, and extend the “talent pool”.[9]

One more reason could be adduced for broadening the curriculum, one that is of a slightly more general kind. Science and technology have a profound impact on society. If graduates who will become experts in these areas are to live up to their responsibilities, their training cannot be confined to merely technical issues in one narrow field. Universities have the task to see to it that they deliver people who are capable of functioning at the level that can be expected of an academic, not merely with respect to their own discipline, but with respect to the much wider organisational and societal context in which they will practice their profession.

New Programs in the US – “Science-(and Mathematics) Plus”

During the past eight years, a movement to *professionalize* the master’s degree in the sciences and mathematics has taken hold in the U.S. in fields such as industrial mathematics, applied and industrial physics, computational chemistry, environmental science, and biotechnology. The master’s degree, according to certain science-based industries in the U.S. had been the “missing degree” in business, largely because, in the sciences, the U.S. master’s had traditionally been considered a “failed Ph.D.” To remedy

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[8] Uulkje de Jong, Marko van Leeuwen, Jaap Roeleveld, Marloes Zijl : Deelname aan hoger onderwijs. Toegankelijkheid in beweging. Kiezen voor hoger onderwijs 1995-2000, 2001, Ministry of Education, Zoetermeer
J. Warps : Kiezen voor bèta in het wetenschappelijk onderwijs. Een onderzoek naar de keuze voor zachte- en harde bètaopleidingen door vwo-WO doorstromers, 2001, IOWO/Axis, Nijmegen/Delft

[9] Frans A.J. Birrer & Sheila Tobias: Addressing the beta image problem in the university curriculum: the Leiden workshop "Cases from private enterprise", in Jens Hojgaard Jensen, Mogens Niss, Tine Wedege (eds.): Justification and enrolment problems in education involving mathematics or physics, 1998, Roskilde University Press, Roskilde, pp. 183-193

its reputation and to provide business with a needed graduate-educated population of *science- (or mathematics)-trained professionals*[10], a number of research universities and at master's granting institutions as well (supported either locally or by the Alfred P. Sloan Foundation) have launched practice-oriented (as against research-oriented) professional science master's degree (PSM) programs in the sciences and mathematics. In addition, supported by a $50 million grant from the Keck Foundation, there is since 1997, one new self-contained graduate institution, Keck Graduate Institute in California, entirely given over to producing a master's in biological science (MBS) for the biotechnology industry. [Both sets of programs are described on the web at www.sciencemasters.com and www.kgi.edu]

The new "science master's" programs are distinctive in that they are two years in duration, in many cases interdisciplinary, and combine "core" courses and science electives at the graduate level with a set of "plus" or "professional" components. These are intended to expose PSM students to topics in business, law, finance, and project management. In all programs, business and industry affiliates are involved both in providing advice and direction and in placing students in required internships. As of late Spring 2003, there are approximately 75 PSM degree programs at 40 institutions of higher learning. Only 700 students have enrolled so far, since in the vastly decentralized U.S. system, programs each need to design their own curricula and pursue their own state-level "accreditation". However, of the 70 first graduates who were on the job market in 2002, 59 had gotten jobs with promising career ladders at average salaries of $50,000 within four months of graduation.[11]

So far, 33 percent of the PSM enrollees are female, 14 percent new Americans (immigrants), and 8 percent indigenous "historically underrepresented minorities" – a ratio that the U.S. programs are determined to increase. The reason for the especial appeal to women students of science and mathematics, it is believed, has to do with the length of the degree program (two years), the portability of the degree (multiple job targets), and the flexibility of the non-research career.[12]

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[10] Sheila Tobias & Frans Birrer: The science-trained professional. A new breed for the new century, Industry & Higher Education 12 (1998) pp. 213-216

[11] Cassandra Simmons, "New Career Paths for Science-Trained Professionals: A Progress Report on the Alfred P. Sloan Foundation's Professional Science Master's Degree Program" (2003), The Conference Board, New York, Document E-0002-03. Available under Studies/Reports on www.sciencemasters.com

[12] Interviews by Sheila Tobias with selected women students in the programs.

Many business- and industry-oriented students enrolled in these programs say that before finding them, they had considered designing their own degree. They persevered in trying to find departments where they could get a (terminal) master's degree without being treated like second-class citizens. They thought they would then enroll for an MBA. But most of the business people advising the PSM's in the U.S. say that an MBA is not essential for the business expertise science professionals need. The PSM is designed to provide the right mix of science and business, especially for startup companies that rely on motivated, well-rounded individuals capable of continuous development of their skills in a rapidly changing environment.

Such views are not yet shared by science faculty overall in the U.S. Many remain wedded to training the next generation of scientists defined not by what they know but by what they do. Others train practice-oriented master's students only reluctantly because they are not going to work in their laboratories. Still others have legitimate fears that programs like the PSM will give students both too little science and too little business. But industry people say, for many of the positions for which there is high and growing demand, the PhD is not required and not preferred.

New programs in the Netherlands – developments at Leiden University

For a long time, the only courses at the general universities in the Netherlands[13] for science students that extensively referred to professional practice were those in *"Science and Society"*. Originated in the late sixties, these programs addressed the responsibilities of scientists and science trained professionals concerning the social consequences of science and technology in general, and the student's future responsibilities as a science expert in particular. Business aspects were discussed in such courses, mainly from the perspective of public interest. Leiden University had and has several of such programs at the departments of the various sciences.

In 1996, Frans Birrer and Sheila Tobias designed an entirely new kind of program at the Leiden science faculty: the workshop *"Cases from private enterprise"*. This is a one week (40 hours) program, with a core of a few (usually three) different cases, each filling most of one day. A case basically consists of a strategic management decision in a science based company, usually involving several dilemmas. Students work on these cases in small groups, and after they have worked out the case they present their findings

[13] The term 'general universities' is used here in contradistinction to 'technical universities' or polytechnics.

in the presence of someone from the company. The remaining two days are filled with interactive teaching blocks on topics such as finance, economics, management, and patent law, some of which return in the cases.

The main goal of the cases, as well as of the whole workshop, is to expose students to modes of analysis and reasoning that are different from their own, technical mode. In the workshop, they are confronted with precisely those kinds of problems they tend to feel insecure with: difficult trade offs where highly diverse qualitative aspects have to be weighted against each other under a lot of uncertainty. For this approach, cases were needed that did not require any advance knowledge of business science or any other non-technical subject. Since no such cases could be found in the literature, they were developed in Leiden, with generous help from various companies. During the past years, these and similar cases came to be employed elsewhere in the Netherlands as well.

The workshop makes students experience for themselves rather than simply being told what business is like. This is highly appreciated by the students (even those who conclude that they prefer to do research find the workshop valuable for making that choice). The workshop runs with about 20 students a time, from all disciplines in science (including mathematics). Extensive collaboration with students from other disciplines was actually another aspect that that most students did not experience before the workshop, and it gives them some idea of what it is like to work in heterogeneous teams as is common in modern organisations.

A few years after the start of the workshop, the general universities signed an agreement with the Minister of Education, part of which implied that the science faculties would offer the possibility of doing a master's that combines science with business oriented courses. Given its experience with the workshop, it is not surprising that Leiden was very quick in realising this next step.

The program, much more extensive than the workshop just described, is called *'Science Based Business'* (SBB). With Harmen Jousma as program leader, and in collaboration with the Center for Business Sciences of Leiden University, a program was developed that was run for the first time in 2001. The full program comprises a 12 week course 'Introduction to business sciences', a 16 week internship, and a few weeks in between for taking special courses, usually on topics relevant to the internship. It is possible to do only the 12 week introduction course, but this does not lead to the Science Based Business certificate.

The introductory course has three main blocks: strategic marketing management, finance management, and project management, and some additional special topics (with professionals from the business world coming in to share their experience). As part of the project management part, students have to construct a project plan for a business organisation as a final assignment. At the moment, the introductory course is run two times a year, with about 20 students a time; about half of them choose the full SBB program, including the internship. Separately from SBB, a course *"Entrepreneurship in ICT and Life Sciences"* has been developed.

Two more bachelor's/master's programs in Leiden should be mentioned in this context, both started by the science faculty together with the science faculty of Delft University of Technology. Both reflect the need for the integration of different knowledge fields. One is *"Life Science and Technology"* at both the bachelor's and master's level, started in 1999. More recently, *"Sustainable Molecular Science and Technology"* started (in 2002, so far only at the bachelor's level). The latter in particular aims to educate science trained professionals for specific job niches, integrating natural science with social science and humanities around the theme of sustainability.

Reflection: the new knowledge society and the problems of quality control

The reasons for curriculum innovation that were described before are directly related to the growing literature on what is called the "knowledge society".[14] More in particular, some themes concerning the integration of science and practice, and accordingly of different knowledge fields, were brought up in two books by a group of authors including Michael Gibbons and Helga Nowotny.[15] In the first book, a main idea was that the borderlines of traditional disciplines, and the borderline between science and practice, were dissolving. The second book aimed amongst other things at an elaboration of how such heterogeneous processes could take place and be managed. Since these books have been so frequently quoted, and their topic so relevant to the issues discussed here, we will

[14] E.g., see Nico Stehr : Knowledge societies, 1994, Sage, London

[15] Michael Gibbons, Camille Limoges, Helga Nowotny, Simon Schwartzman, Peter Scott, Martin Trow : The new production of knowledge. The dynamics of science and research in contemporary societies, 1994, Sage, London
Helga Nowotny, Peter Scott, Michael Gibbons : Re-thinking science. Knowledge and the public in an age of uncertainty, 2001, Polity Press, Cambridge

use them as an occasion to provide a few comments that distinguish our own views, and then connect those to teaching practice.

In the second book, the authors acknowledged that where in the first book they had been using terms like 'hybrid quality control' they had not been very specific as to how exactly this was to be conceived. One of us had observed already before the appearance of the second book that there were some fundamental problems in this area; it turned out that they remained largely unsolved by the second book.

First, one cannot simply dissolve all disciplinary and other boundaries. Some compartmental boundaries and standardizations are necessary to maintain manageability, in particular to control the goal displacement and evasion strategies that will inevitably take over in a fragmented constellation.[16]

Second, different disciplines and different problem solving situations require different validation criteria and procedures. Integration is not simply a matter of combining already validated results, it means revalidation for every single piece according to the specific problem context.[17] It is precisely the sensitization of students to these different validation contexts and the problems they pose that should be at the core of curriculum design.

The problem of quality control extends to teaching. A nontrivial problem in launching new degrees at and across disciplinary boundaries may be quality control; harder to set and harder to enforce than within any one discipline or traditional profession. In the sciences and mathematics, competencies are well defined, specific, and taught in a sequential order of increasing difficulty. A physicist measures a student's achievement in terms of the level of problems a student is able to solve, and therewith declares the student "trained" or "not trained." In contrast, the curriculum at or across disciplinary boundaries and intended for students with various backgrounds, cannot be so ordered. New measures and new ways of furthering quality have to be developed by educators in conjunction with a multiplicity of stakeholders, including university administrators, future employers, funders, and potential student enrollees. One gross measure of the "success" of the programs launched so far in the U.S. is student enrolment (as of 2003,

[16] Frans A.J. Birrer: Combination, hybridisation and fusion of knowledge modes, in Gerd Bender (ed.): Neue Formen der Wissenserzeugung, 2001, Campus Verlag, Frankfurt am Main, pp. 57-68

[17] Frans A.J. Birrer: Combination, hybridisation and fusion of knowledge modes, op. cit.

700); another could be job placement (as of 2003, 100). But “quality” cannot be reduced to such measures alone.

The challenge of defining and implementing quality control at the post-secondary level foreshadows the larger issue of self-regulation within the new professions themselves. To the extent that the “new knowledge worker” is independent, flexible, works with a variety of clients, he or she leaves the sheltered environment of both the bounded discipline and the bounded profession. Medical doctors police their own members as regards malpractice; lawyers have the power to disbar. But these are long-standing professions with openly promulgated standards and procedures. How will science-trained professionals self-regulate where: they are working at the boundaries of more than one discipline, criteria are local and temporary, perhaps even employer-determined, and there is no well-defined cohort?

In the 70 or so Sloan Foundation and Keck Foundation-funded PSM programs in the U.S., the problem of program evaluation is partially solved by the loose enforcement of a “model”: Programs must be two years in duration; programs should if possible involve an internship; programs must have a board of business/industry affiliates before curricula are developed, advisers who both assist and critique the program content; programs must offer a set “professional” (“plus”) courses [described above], assistance with job-seeking (placement), and some kind of “branding” experience so that the student is defined by others and defines him or herself as a *Professional Science (or Mathematics) Master’s graduate* in the future.

With respect to the Leiden programs, similar remarks can be made. For the bigger programs (Science Based Business, Sustainable Molecular Science and Technology), prior investigations were made as to what would be the 'market', in terms of students' as well as employers' interest. The final proof, however, will be in the careers of future graduates.

Challenges

A number of challenges remain. We will briefly describe a few of the major ones that we perceive.

Combination of different forms of expertise (validation contexts).
The interaction of different fields of expertise will be a core characteristic of the new knowledge society. We indicated earlier that the combination of different validation

contexts that is involved constitutes a far from trivial issue. In an age of increasing technical and social complexity, miscommunication between experts can have serious consequences. Though there already exists some literature on issues like multidisciplinary collaboration, much in this area still has to be explored. Can common patterns and common pitfalls be identified? What are the best ways to conduct multi-expertise collaboration? What individual competencies are required? And what is the best way to train students for these competencies? As described before, the quality control of such training programs will be an ongoing issue for improvement.

Doubts about "vocationalism" in graduate education.

Two types of considerations are to be distinguished here. On the one hand are more or less categorical objections to any attempt to make university education address future careers other than in research. We believe that such objections are simply misplaced. It is a matter of fact that many university graduates do not enter into a research career, and it is rightfully expected of university graduates that their high level of thinking is not confined to one narrow field of expertise. On the other hand is the uneasiness that business and industry (short-term, commercial) concerns might get to dominate university education (or even university research). Here the views that merely proclaim the breaking down of boundaries are reason to be cautious. Boundaries may be functional for management. Business and industry representatives can have input but not control over program design. It is in their interest too that their highest educated employees have also learned to see beyond the local and immediate pressures of the daily practice in an individual company, and to produce critical views where necessary.

Undervaluation and unfamiliarity.

Undervaluation (in the U.S.) and unfamiliarity (in Europe) with "master's education" in the sciences and mathematics in general and with practice-oriented higher education in particular. With the Bologna Agreement, the EU countries will shortly be aligned as regards the three-year bachelors, five-year master's. As for the U.S., apart from the sciences, master's education is the fastest growing segment of American higher education, with nearly 450,000 degrees granted annually. The requirement of an independent thesis for the master's degree in traditional university subjects was thought to be harder to break down. But while the 40 universities with PSM degree programs in the U.S. have had to petition their Boards of Trustees and/or state authorities to permit the non-thesis (professional) master's, no petition has so far been refused. There may also be some rigidity among hiring managers, who are used to hiring engineers and research workers, and are not as familiar with "flexible experts", not yet aware of how these new recruits will fit into traditional organizational structures, nor how the organization can make productive use of their skills. This is a problem that only time and the positioning of program graduates will solve.

Financing

Financing programs and financing students are linked in the U.S. where the professional master's, like other professional degree programs is on a pay-your-own-way basis. Several Federal agencies support scientific research, which includes generous support for the training of future researchers. When research is only an ancillary part of the program, however, science and mathematics students are rarely eligible for support. This problem is being addressed theoretically and pragmatically. The need for a supportive *infrastructure* for science populated by professionals who can interface with researchers is the central theoretical argument. Efforts to influence Federal and state legislators to press funding agencies to include master's students in their funding programs are the pragmatic aspects. Recently, the U.S.' "Council on Competitiveness" has agreed to promote the Professional Science (and Mathematics) Master's as part of its education campaign. At Leiden, the programs are basically financed from the government money for the university. As already mentioned, the Science Based Business program was in fact the implementation of a strong wish of the Ministry of Education regarding the broadening of science programs. For the start of some other programs, such as Sustainable Molecular Science and Technology, there was additional subsidy from the Ministry.

Perceived competition with recruitment for the Ph.D. degree.

This is of real concern in the U.S. where, in the past decade, fully half the Ph.D. students in the physical sciences, mathematics, and engineering have been foreign nationals, filling slots that would otherwise have gone empty because of a reduced level of interest on the part of U.S. students in these degree programs. Competition for U.S. nationals is fierce, and with the post-September 11 restrictions and delays in processing foreign student visas, may become fiercer still. Nevertheless, recruitment for PSM programs in the U.S. does not target Ph.D.-oriented students, but rather recent science and mathematics graduates, who might otherwise enroll for the MBA.