CHAPTER

Declining Demand among Students for Science and Engineering?

Georg Winckler and Martin Fieder

Leading industrial as well as developing countries have identified research and innovation as the driving forces for future economic development. As a consequence, policies aim at increasing not only research budgets, but also the number and quality of scientists and engineers. In this context the education of scientists and engineers is of increasing importance.

In 2000 the E.U. announced the Lisbon goal: to become the world's leading knowledge driven economy. A major step towards this goal is "the 3% objective" (3% of the GPD for research and development) in 2010. Related to this objective is the need for about 700,000 additional scientists in the public and in the private sector in the E.U. by 2010, about 50% of them at Ph.D. level. This number is derived from a comparison of the number of researchers per 1,000 members of the workforce between Europe and other parts of the world. In the E.U.-15 this number is 5.7, and 3.5 for the ten new member states. In Japan there are 9.1 researchers per 1,000 members of the workforce, and 8.1 in the U.S.

To achieve the objective of a leading knowledge economy, the role of European universities has to be strengthened. In the past, universities were perceived merely as sums of individual researchers or research groups, as conglomerations of individual departments or just as accumulations of study programmes. The Lisbon goal, however, implies that European universities emerge as strong institutions which are the main actors in creating and transmitting knowledge (Winckler, 2004).

GENERAL ENROLMENT — AND GRADUATION RATES

In several European countries (Austria, Finland, France, Germany, the Netherlands, Spain, U.K.) overall enrolment rates in post secondary education have risen generally, but differ significantly from country to country. The lowest rates have Austria and France with about 30% of an age-group enrolled in post secondary education; the highest enrolment rate has Finland with 77% (Germany: 35%; the Netherlands: 53%; Spain: 50%; the U.K.: 47% [OECD, 2004]; the data for Austria and Germany also include the sector of vocational training). These numbers indicate clearly that there are substantial differences between European countries, and between the U.S. and Europe. The low participation rates in higher education in Austria are particularly surprising because, until 2001, no tuition fees were charged and restrictions on access to higher education were introduced only recently — July 2005 — in a few fields, e.g., medicine.

Concerning overall participation rates in tertiary education, Europe is clearly lacking and is behind the U.S. (52% net entry rate in the U.S.) The low participation numbers in higher education in Europe may be explained by a high investment in vocational training at the upper secondary level. This is especially the case for Germany and Austria. If countries invest too much in vocational education instead of in higher education, they may run the risk of losing innovative power: vocational education enables workers to operate established technologies very productively, whereas general education enables workers to develop and adapt new technologies more easily (Krueger, 2004).

Increasing participation rates of the age-group in higher education might be a way to attract more students for fields of science and engineering. This seems to be a promising policy, especially in countries with low participation rates. Generally enhancing the accessibility of higher education — that is, the ability of people from all social and economic backgrounds to enter higher education — remains an important issue for future policy making. The "massification" of higher education should not be perceived negatively, since massification might be the very foundation of the modern knowledge economy (Usher & Cervenan, 2005).

ENROLMENT RATES IN THE SCIENCES AND ENGINEERING

The overall percentage of graduations in the sciences and engineering differ among OECD countries; graduation rates vary also with respect to the fields of study (OECD, 2004): in Korea, Germany, Finland, France, the U.K., Austria, Spain, Italy, Australia, the U.S. and Poland, from 14.9% in engineering and manufacturing to 1% in mathematics and statistics. Korea, Germany and

Finland are leading the pack. In contrast, the U.S. has a relatively low percentage of graduations in science and engineering (Table 1). One reason for the differences might be the existence of polytechnics in a particular country and the size of this sector.

Table 1: Percentages of graduations in the sciences and engineering of OECD countries (OECD, 2004). Vocational education in Germany and Austria are partially included.

OECD Countries	Engineering, manufacturing, construction % of total Graduations 2002	Life sciences % of total Graduations 2002	Physical sciences % of total Graduations 2002	Mathematics and statistics % of total Graduations 2002	Computing % of total Graduations 2002	**Total**
Korea	27.4	2.1	3.5	1.9	3.5	**38.4**
Germany	17.6	3.4	5.0	1.7	3.3	**30.9**
Finland	21.6	1.4	2.0	0.6	3.4	**29.0**
France	12.5	5.8	4.9	2.5	3.0	**28.7**
U.K	10.1	6.2	4.8	1.4	5.7	**28.1**
Austria	18.0	3.6	3.0	0.7	2.7	**28.0**
Spain	14.3	2.5	3.1	1.2	3.2	**24.3**
Italy	15.2	3.3	1.6	2.0	0.7	**22.8**
Australia	7.7	3.3	2.3	0.5	7.9	**21.6**
U.S.	6.3	3.7	1.4	0.9	3.4	**15.73**
Poland	7.3	0.7	1.2	0.6	1.0	**10.8**
Average	**14.9**	**3.4**	**3.0**	**1.3**	**3.4**	**25.3**

Enrolment rates in science and engineering seem to be cyclical (Bhattacharjee, 2004). Despite a recent modest increase of the enrolment rates in the U.S., the 1993 peak has not been reached since.

INCREASE IN NUMBER OF RESEARCHERS AND THE EVOLUTION OF RESEARCH TEAMS

If Europe wants to increase the number of graduations in order to raise the total number of researchers, care has to be taken to ensure that the rise in number of researchers is in line with the "absorbing" capacity of the overall research system. Growth that is too fast may lead to inefficiencies in the use of resources. The absorbing performance of a research system is especially determined by the formation and composition of research teams: the size of research teams should be large enough to enable specialization and the division of labour (Katzenbach & Smith, 1993); it may spur creativity, but may also promote conflicts and miscommunications (Larson *et al.*, 1996). Due to these reasons, the evolution of research teams takes time and depends on parameters like team size, fraction of newcomers and the tendency of incumbents to repeat previous collaborations (Guimerà *et al.*, 2005).

CURRICULUM DEVELOPMENT

Universities play a major role in educating future scientists. Therefore, it is of great importance to make the curricula in science, medicine and technology more attractive to students and to increase thereby the number of graduates in these fields. Traditionally the courses offered in science and technology are too much weighted towards the "knowledge domain" (Barnett, 2004). What is needed is that learning is based on the discovery of new knowledge to inspire a passion for discovery.

The attractiveness of curricula will be increased by focusing on making students familiar with the range of methods (including mathematical and statistical tools) currently used in physics, chemistry, molecular biology or other fields. Sufficient methodological competence is one of the most important prerequisites for working as a scientist. Acquiring methodological skills will usually take a long (and sometimes difficult) time. In addition, science and engineering students acquire the substance of knowledge mostly during "field work", guided by experienced scientists. This kind of "knowledge transfer" is highly relevant for the training of future scientists. The design of science curricula should take into account the fact that guidance in research by experienced scientists is necessary.

Due to these reasons, especially in Europe, a new understanding of the "design" of science and technology curricula should emerge. The Bologna Process provides a unique chance to do so. Despite excellent general scientific education of students, early participation of students in research projects should be offered. Project management and other transferable skills should also be part of the curricula from the very beginning (Gago, 2004).

Interdisciplinary education is of special importance for the sciences, as often problems in the sciences can only be solved by intensified collaboration among disciplines (National Academy of Sciences, 2005). Concerning undergraduate and graduate interdisciplinary education, the academy gives some recommendations:

- Interdisciplinary work should be regular in order to strengthen experimental knowledge;
- For undergraduates to gain deeper interdisciplinary insights, they need to work with faculty members who offer expertise both in their

home discipline and in working together with scientists or scholars from other disciplines;

- Most important for a student is to take a broad range of courses and develop a solid background at least in one discipline. To instigate a broader horizon of students, universities should not offer curricula which are so packed with obligatory examinations that it is nearly impossible for students to take any courses outside their primary field.

WOMEN STUDYING SCIENCE

Overall the proportion of female students enrolled in higher education has been increasing since the 1970s (currently 50 to 60%). Despite this high overall enrolment, it is important to increase the number of women studying sciences and engineering if more scientists and engineers are needed in the future. Yet women opt less frequently for a science curriculum, especially one in the "hard sciences" and engineering when mathematics is an important prerequisite. As mathematics is less important in the life sciences, a high percentage of women have opted for the life sciences (e.g., out of all students enrolled in engineering, only 20% are women, in the "hard sciences" 40% are women, yet in the life sciences the figure is 65%; [Ayalon, 2003]). The reasons might be manifold and may include social influences as well as other more contested factors. Differences between the sexes in mathematical problem-solving remain ambiguous (Walsh, 1999; Green, 1999). As this theme is usually discussed ideologically and emotionally (see, for example, the discussion about the remarks made by Lawrence Summer, president of Harvard University [Dillon, 2005]), for the sake and the importance of the issue, an honest and less ideological discussion needs to take place.

The E.U. is increasing efforts to raise the proportion of women researchers in the sciences: according to the working document "Women and Science: Excellence and Innovation — Gender Equality in Science", €5.7 million will be earmarked for women and science in 2005-2006, bringing the total in the Sixth Framework Programme to around €20 million. A series of gender monitoring studies, designed to monitor progress in gender equality and relevance awareness in the Sixth Framework Programme are currently being launched, as well as an expert group "Women in Science and Technology". The expert group involves the participation of many prominent representatives of European industry with the goal of developing an integrated approach to the cultural change involved within companies in this respect (EU — News from Science and Society in Europe, May 2005). If programmes are turned into action, the "family career conflict" faced especially by female scientists should be considered (Watkins *et al.*, 1998).

PUBLIC UNDERSTANDING OF SCIENCE

To make a curriculum in science and technology more attractive, public awareness of the importance of science and technology has to be raised among school children. Among other initiatives the establishment of "children's universities" contributes to a high visibility of research from school childhood onwards. The number of universities engaging in such activities has sharply increased, e.g., the University of Vienna has organized a "Children's University" every year since 2003, with more than 2,000 children attending in the summer of 2005.

The example of U.S. high schools dedicated to science demonstrates that an intensified science and technology education leads to trained graduates who have an excellent foundation for further studies. These schools offer opportunities especially for women (Kendall, 2005). Universities and research organisations should provide opportunities to prominent scientists to communicate complex scientific subjects to the public (Schiermeier, 2005).

THE DEMOGRAPHIC DEVELOPMENT

In many western industrial societies, the current demographic trends hamper the evolution of innovative knowledge societies. There are two possible reasons: (1) It is well known that, especially in the hard sciences, many discoveries and innovations are done by scientists in their early years (Zuckermann, 1979); (2) A society with a majority of older people may not be driven as strongly towards future goals and visions as is the case in societies with a majority of young people. Among other points, these two reasons might explain the recent success of fast-growing economies, such as China and India.

A SCIENTIST'S CAREER

Most scientists are less interested in earning high salaries, but rather are ethically or emotionally attached to their work. Hence, it is important to specify the role, responsibilities and entitlements of scientists as well as of employers accordingly. The nature of the relationship between scientists and employers or funders should be conducive to successful scientific performance, for example by granting freedom of research. In March 2005, the E.U. Commission launched a European Charter for Researchers and a Code of Conduct for the Recruitment of Researchers (*Journal of the European Commission*, 2005) in order to contribute to the attractiveness and sustainability of a trans-European labour market for researchers.

GOALS AND VISIONS

The interest of young people in science and engineering will increase if goals and visions are challenging and attractive. It is up to the people responsible for the development of research to communicate empathy for research to the public. Focusing solely on the goal of increasing economic growth rates or merely stressing the importance of research for well-being might be too technocratic: broad visions for research strategies should be developed. As outlined by the Center of Cultural Studies & Analysis (2004) in the paper "American Perception of Space Exploration", the overall vision should include the following key features:

- Visions must reflect the larger culture in which they must operate;
- Visions are contextual. If the context changes, the meaning of the visions changes;
- Visions depend on the belief that the future should be better than the past;
- A cultural belief that everything can and should be improved;
- An ethic that celebrates and rewards inventors and innovation;
- Business interests that promote the vision of a "better" world in which their products play a key role;
- A driving external force or event that makes the vision the optimal and necessary choice.

CREATIVITY AS A DRIVING FORCE

The most important point may also be the most incomprehensible: creativity. We must try to attract the most creative and unconventional thinkers into our research systems. As Herbert Simon (Simon, 1983), winner of the Nobel Prize in Economics, explained creativity:

- The disposition to accept uncertain problem definitions and to structure them;
- To engage over a longer period of time with one problem;
- To acquire relevant and potentially relevant background knowledge.

Creativity and innovation have been the driving force in the evolution of Homo sapiens from the beginning, with the invention of first tools, art and technology, up to now. More scientists and engineers should inspire more creativity and innovation in our world.

REFERENCES

Center for Cultural Studies & Analysis. (2004). *American Perception of Space Exploration*. Presentation 21 April, 2004, Washington D.C.; available online: *http://www.hq.nasa.gov/office/hqlibrary/documents/o55201537.pdf*

Ayalon, H. (2003). "Women and Men Go to University: Mathematical Background and Gender Differences in Choice of Field in Higher Education". *Sex Roles*, 48, pp. 277-290.

Barnett, R., Parry, G. & Coate, K. (2004). "Conceptualising Curriculum Change". *The RoutledgeFalmer Reader in Higher Education*, Ed. Tight, M., RoutledgeFalmer, London & New York, pp. 140-154.

Bhattacharjee, Y. (2004). "Weak Economy, Higher Stipends Send More to Graduate School". *Science* 305, pp. 173.

Dillon, S. (2005). "Harvard Chief Defends His Talk on Women". *The New York Times*, 18 Jan 2005, p. 16.

EU — News from Science and Society in Europe. (2005). Quarterly newsletter, Issue n° 2, May 2005.

Gago, J. M. (2004). "*Europe needs more Scientists*", Report to the EC conference: "Increasing Human Resources for Sciences and Technology in Europe", Brussels, 2 April 2004.

Green, B. A., De Backer, T. K., Rav-Indran, B. & Krows, J. (1999). "Goals, Values, and Beliefs as Predictors of Achievement and Effort in High School Mathematics Classes". *Sex Roles*, 40, pp. 421-458.

Guimerà, R., Uzzi, B., Spiro, J. & Nunes-Amaral, L. A. (2005). "Team Assembly Mechanisms Determine Collaboration Network Structure and Team Performance". *Science*, 308, pp. 697-702.

Journal of the European Commission. (2005). *Recommendation on the European Charter for Researchers and on a Code of Conduct for the Recruitment of Researchers*. European Commission, Brussels. (L75/67, 11 March, 2005).

Katzenbach, J. R. & Smith, D. K. (1999). *The Wisdom of Teams: Creating the High-Performance Organization*. HarperCollins, London.

Kendall, P. (2005). "Hothouse High". *Nature* 235, pp. 874-875.

Krueger, D. (2004). "US-Europe Growth Differences: The Role of Education". 32, *Volkswirtschaftliche Tagung der Oesterreichischen Nationalbank*, Vienna, pp. 37-49.

Larson, J. R., Christensen, C., Abbott, A. S. & Franz, T. M. (1996). "Diagnosing groups: charting the flow of information in medical decision-making teams". *Journal of Personality and Social Psychology*, 71, pp. 315-350.

National Academy of Sciences, (2005). *Facilitating Interdisciplinary Research*. National Academies Press, Washington D.C.

OECD (2004). *Education at a Glance 2004*. OECD, Paris.

Schiermeier, Q. (2005). "The philosopher of photons". *Nature*, 234, p. 1066.

Simon, H. A. (1983). "Discovery, invention, and developement: human creative thinking". Proceedings of the National Academy of Sciences of the United States of America, 80, pp. 4569–4571.

Usher, A. & Cervenan, A. (2005). *Global Higher Education Rankings. Affordability and Accessibility in Comparative Perspective*. The Educational Policy Institute, Washington D.C.

Walsh, M., Hickey, C. & Duffy, J. (1999). "Influence of Item Content and Stereotype Situation on Gender Differences in Mathematical Problem Solving". *Sex Roles*, 41, pp. 219–240.

Watkins, R. M., Herrin, M. & McDonald, L. R. (1998). "The juxtaposition of career and family: a dilemma for professional women". *AWL J. 1*, Winter; available online: http://www.advancingwomen.com/awl/winter98/awlv2_watkins5.html

Winckler, G. (2004). "The Contribution of Universities to a Knowledge-Based Economy". *32, Volkswirtschaftliche Tagung der Oesterreichischen National Bank*, Vienna, pp. 51-55.

Zuckermann, H. (1979). *Scientific Elite. Nobel Laureates in the United States*. MacMillan Publications, London.