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# Secondary School-University Interface: Science and Engineering

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During the last decades a rapid increase in science-based technological improvements has provided mankind with a wealth of new opportunities for safer and more prosperous lives. Unfortunately, many of these opportunities have not benefited populations in developing countries, primarily because of a shortage of highly skilled manpower with the ability to take advantage of new and efficient research-based technologies. Also, many industrialised countries are now at risk. The recruitment of young talents for careers in science-based fields has declined for many years in these countries and some large countries are today heavily dependent on the importation of scientific and technological manpower. This paper provides a discussion of problems encountered and solutions attempted in connection with the recruitment of secondary school-leavers into science-based careers. This transition is often extremely difficult; as a result, shortages of students, which the universities consider qualified, and high dropout rates are common in university engineering and science programmes in many countries. These issues are illustrated by examples from two small and therefore possibly more innovative countries: Botswana, a developing country, and Denmark, an industrialised country. In Botswana a major effort was made to improve the science and math skills of high school-leavers before they entered the regular university science-based programmes. For a number of reasons, this activity was abolished, although it was successful in several ways. The university funding system in Denmark, a taximeter system in which state support is strongly dependent on student numbers, creates an unstable situation for subjects (lately engineering and science) with declining student populations. The situation has led to a series of (unco-ordinated) actions, but so far with limited success. Finally, the paper lists a number of conclusions and recommendations based on this discussion.

## THE INCREASING NEED FOR TECHNOLOGICAL INSIGHT IN DEVELOPING AND DEVELOPED COUNTRIES

A rapid increase in scientific knowledge and its application for technology development has changed the lives of most people on Earth. New, science-based technologies have created numerous opportunities for increased production, efficient environmental practices, fast global communication, better health and longer lives, and have improved access to information. Insight in, and ability to use, science and technology efficiently have become the keys to economic wealth, both among nations and within individual countries.

The important appearance of new, educated middle classes in many developing countries is to a large extent due to individual's ability to use technology efficiently for economic gain. Internationally, the educational standards of a country's workforce determines its potential for economic success, much more than the factors that earlier were very important, such as the natural resources of the country.

In recent years, science and technology (S&T) based opportunities have benefited industrialised countries most effectively, while many Third World countries have been unable to take sufficient advantage of such opportunities. The most common reason that these countries must still be labelled as developing is that they have been unable to develop or sustain a workforce that can take advantage of today's numerous technological opportunities.

The increased importance of scientific and technological knowledge accounts for much of the difference in the pace of economic development among countries. Countries and cultures that traditionally have valued scientific and technological knowledge highly, and, therefore, have been able to create the needed workforce, have made fast economic progress, while other countries and cultures that have not been able to establish and maintain an efficient technological labour force have remained behind economically. Also, research and research training are becoming increasingly important. Today, many technology changes are research-based; they take place much more frequently and it is usually of the utmost importance to keep track with this development. A workforce is now required that includes manpower with research training in the relevant science and technology fields and that is able to continuously evaluate and modify new technologies for local uses.

In other words, most citizens must be able to apply both science and science-based technologies in order for a country to be competitive [1]. In addition, some part of the workforce must know how to create new technological and scientific knowledge. While some rich countries rely to a large extent on importing science and technology talent and trained labour, this strategy is not feasible for developing countries. These countries therefore need to provide:

- efficient science and technology education *for the citizen* at the primary and secondary levels;
- a strong motivation for a sufficient number of young people to enter science and technology-based careers at different levels;
- a satisfactory preparation at the secondary level for science and technology studies, combined with first year curricula at the tertiary level which are in tune with this preparation;
- attractive and efficient undergraduate study opportunities in engineering and science at an internationally competitive quality level; and
- sufficient postgraduate science and engineering educational opportunities designed so that they do not lead to excessive brain drain.

Only a few developing countries are able to satisfy all these demands despite the fact that many are well aware of the obvious opportunities for national economic development through a buildup of a qualified S&T labour force. It is remarkable that the wave of *science for all* or *science for the citizen*, which has been increasingly dominant in industrialised countries during the last decade, has had relatively less impact in many developing countries. Instead, many of these countries have tried to emphasise S&T in higher education but have fallen short because of economic problems, lacking incentives and sometimes also traditions, insufficient infrastructure, and brain drain. Frequently, Third World countries have underestimated the complexity of the tasks involved, both in basic education, in higher education, and in the industry that should convert educational investments into economic development.

For example, the World's fourth most populous country, Indonesia, has tried hard to create medium and high technology industries [2]. In spite of a few isolated successes the country has not yet succeeded on a larger scale, partly because of a lack of co-ordination within the important sequence that includes secondary education, undergraduate programmes, graduate training, university-industry co-operation, industrial research and research training, and high-technology industrial applications. It might even be proper to include primary education as the first link in the sequence. There is evidence from several countries that weak or lacking science and technology education at the primary level has a negative effect on the motivation of students, especially girls, for later careers in science and technology fields such as engineering.

A few countries have managed to establish an efficient string like the above and have therefore been successful in their attempts for fast technology-based economic development. Outstanding examples are South Korea and Taiwan. However, most developing countries have not yet managed to perform this task; if they had, they would no longer be developing countries. Unfortunately, for most developing countries it is becoming increasingly difficult to follow the East Asian examples from the 1970s and 1980s. This is primarily because of the even faster rate of technological change today and the increasing global competition in most technology product fields, which today includes competition from very large countries such as China.

It must not be overlooked that good teaching of science and technology at the primary and secondary levels provides significant contributions beyond those directly related to economic development. Environmental insight is one important example: environmentally proper behaviour in a population requires an understanding of the relevant scientific concepts. If the primary and secondary schools do not provide such understanding, the population is less likely to behave in an environmentally correct manner.

Another important example is political decisions of a science-based nature (eg dealing with energy, environment, health, etc) in both developing and industrialised countries. Such decisions can only be made optimally on the basis of a sufficient scientific insight among politicians as well as voters.

Unfortunately, the educational systems in many countries are unable to satisfy such demands, nor are they all able to provide sufficient incentives for careers in engineering and related fields. However, even when incentives exist, they may not be sufficient. In many countries the nature and demands in most S&T fields at the university level, combined with insufficient quality of the upper secondary level teaching in mathematics and science, result in large, first-year dropout rates among university students in science, engineering and many other science-based fields.

## MOTIVATION FOR SCIENCE AND ENGINEERING STUDIES: DENMARK AND BOTSWANA

Some industrialised countries have seen a drastic drop in the enrolment in engineering programmes during the 1990s. This is, to a limited extent, a result of technology driven demographic realities: the introduction of simple, efficient birth control methods (*the pill*) in the early 1970s had a significant effect on birth rates, especially in some European countries. Therefore, in recent years, the number of 18 to 24 year olds has started to decline quickly in these countries. In Denmark, for example, this decline will eventually reduce the group of prospective university students by more than 25%, from about 75,000 in 1990 to well below 55,000 in the first years after the turn of the century [3].

However, in Denmark and several other highly developed countries these demographic changes can only account for a small part of the decline during the early 1990s in the recruitment of young people for studies in hard sciences and engineering. Between 1988 and 1995 the number of applicants for engineering education programmes fell by 40% in Denmark, 35% in Switzerland, 10% in the Netherlands, Norway, and the German region closest to Denmark [4]. In the UK the number has dropped rapidly since 1993. On the other hand, enrolment in engineering programmes increased by around 50% in South Korea and by 35% in Sweden between 1988 and 1995 (from a low level however).

Part of the reason for the declining interest in science and engineering observed in many countries is the competition from other studies, which seem to appeal more to today's students. Denmark has generous unemployment benefits that reduce the fear of unemployment, and has fairly uniform salaries among different academic fields. This may contribute to the popularity of the arts at Danish universities. In recent years the humanities have been able to attract large numbers of Danish students in spite of less encouraging job prospects in most of these subjects. Table 1 shows the development in enrolment at Danish universities in humanities, science and engineering. Tak-

Table 1: New enrolment in Danish Universities (1990-96).

| | Humanities | Science | Engineering |
|---|---|---|---|
| 1990 | 2800 | 2800 | 5000 |
| 1993 | 3600 | 2800 | 4100 |
| 1996 | 5500 | 2100 | 3100 |

Source: (Danish Ministry of Education, 1997).

ing into account the considerable (although recently declining) dropout rates that still exist in Danish science and engineering programmes, it is expected that the total annual production of engineers in Denmark will drop from over 3000 in 1991 to well below 2000 around the turn of the century [5].

Furthermore, the enrolment in science programmes at Danish universities has shifted from a reasonable balance between the *hard* (chemistry, physics) and *soft* sciences (biology) to a distinct preference for the latter. While, for example, university chemists can replace chemical engineers in wide areas in the workplace, providing such replacement is likely to be much more difficult for those trained in soft sciences.

Chemical engineering is an interesting field from another perspective. After the enrolment of women students in chemical engineering reached over 50% of the total by about 1990, this percentage dropped below 25% of the total by the mid 1990s [3][5]. A similar, sudden decline in the participation by women has recently been observed in other higher education programmes also, both within the hard sciences and in pharmacy. The explanation for this is not clear.

Some see both the shift away from engineering and the shift from hard towards soft sciences partly as a result of the differences in the workloads involved in different study programmes. Surveys among Danish university students indicate that studies in engineering and hard sciences are much more time-demanding than studies in humanities (requiring up to twice the number of weekly work hours), while the workload in the studies of soft sciences is in-between these two extremes. The complaints among Danish students target less the workload itself, but more the fact that a high workload in the studies reduces their possibilities for holding income earning jobs besides the studies. The generous public grant scheme in Denmark, which provides all students with substantial grants and low interest loans, as well as the freedom for all tuition fees in Danish universities, has apparently not changed this.

Another reason for the decline in recruitment for engineering and science, even more disturbing than the relative popularity of the humanities, is lack of appreciation for science and technology in Danish society. This is illustrated by data in the OECD report *Education at a Glance* (1995), which presents the results of national surveys of the importance given by the populations to various academic disciplines in secondary schools. The populations in Denmark, Finland, the Netherlands and the UK found, in general, academic subjects at the secondary level less important than populations in other countries. Only between 50% and 60% in these countries had a positive response, compared with over 70% in, for example, Austria, Portugal and the US.

The low appreciation of secondary school science and technology in Denmark may be related to traditionally low standards in the training of science teachers for lower secondary schools (however, since common sense eventually prevailed in Denmark, these standards have recently been considerably improved). In contrast the preparation of upper secondary school science teachers in Denmark takes place at a high level, with a Master's degree in the subject matter as a minimum requirement. It is therefore also understandable that a recent comprehensive international survey of mathematics and science learning (TIMSS) placed Danish upper secondary school students at the top, and Danish lower secondary school students below average, in their age group. Another reason for the poor appreciation of school science and technology in Denmark may be a very poor coverage of S&T in Danish media. This may possibly be related to the uniquely low emphasis given to science, technology and even the environment in the well-established programmes for training of journalists in Denmark.

The results for the importance given to different academic disciplines show that Danes, among all OECD countries, have found secondary school mathematics and science less relevant. These subjects were rated important by only 36% and 46%, respectively, of the population; the corresponding numbers for Sweden were 91% and 65%, and for the US 96% and 85%. This may help explain the strong decline in recruitment for engineering in Denmark during the 1990s, as well as the increase observed in Sweden.

In this connection it is important to realise that a decline in student numbers within a specific higher education field in Denmark has secondary effects that are likely to lead to a quality decline in the field. The reason is that Denmark applies a *taximeter* system in higher education; state support for each field depends on the number of students who pass their examinations in the field. Although the taximeter system is highly praised by some economists, the resulting financial dependence of university departments on fast changes in student preferences can be very unfortunate. Academic environments, especially in the laboratory sciences, cannot be scaled up and down during short time spans without severe quality effects.

In spite of considerable political debate on the issues the reaction of the Danish Government to the recruitment problems has been surprisingly meek. The government refers to some, mostly minor, initiatives and reforms that it hopes over time will correct the situation, for example:

- A strengthening of science subjects in the teacher training colleges for primary and lower secondary school teachers.
- The introduction of hands-on science education in Danish primary schools in the early 1990s.
- Substantial government grants for *quality development* in science and engineering university programmes. These grants have, to some extent, offset the decline in government support for the subjects due to the lower enrolment (the taximeter system).
- An evaluation of the status of school physics and other initiatives within physics education in upper secondary schools; the drop in student interest for high school physics is by some seen as the major problem.
- A country-wide *science festival* in the fall of 1998, with participation of educational institutions, public libraries, industries, etc.

It is difficult to imagine that these initiatives can produce fast changes. The reforms that are most likely to have a lasting effect - the strengthening of primary school science and the related teacher training - are not likely to produce significant results for years to come. This is hardly surprising however. The lack of strong and concrete actions in Denmark reflects common government attitudes to long term problems for which the government can not be held directly accountable.

Some countries that are still able to fill their engineering programmes have nevertheless also seen some problems. For example, in spite of the high importance given to secondary school mathematics and science by the US population, the standards in US secondary schools within these subjects are still very low, according to several international surveys. Nor have secondary schools in the US been able to motivate a large part of the best and brightest young talents for science-based careers. Many engineering students at US universities must today be recruited from abroad, especially at the graduate level. This is not an ideal situation for the country since there is an unknown and possibly high probability that many of these will not remain in the US after graduation, or that they will return to their home country at a later time in their careers. Even if they do not return, the situation is far from ideal. Many of these students represent an important part of the talent mass in their home country, frequently a developing country, and their talent is often badly needed at home.

It is a major concern among some in the US and other industrialised countries that there has not only been a quantitative shift away from studies in engineering and hard sciences among young citizens, but there has also been a quality shift. Science and engineering programmes in the US today receive a much smaller fraction of the group of most talented and gifted students than they did in the 1960s, following the Sputnik-inspired science and technology wave. Today's *science for all wave* and even an earlier *environmental education wave* in many countries have not been able to change this situation, except possibly in the biological sciences, where environmental concerns among the young have helped increase recruitment, at least in those communities where such concerns are strong.

The negative quality trend in the recruitment may have been most pronounced in some Western European countries, where engineering and science today receive a strongly reduced share of the best and brightest high school graduates. In Denmark, for example, the competition to enter the academic engineering programmes (leading directly to a Master's degree) was so hard in the 1950s and 1960s that only the best 5 to 10% of the upper secondary school graduates (an already highly selected group at the time) were allowed to enter. The corresponding engineering programmes today have plenty of empty spaces. It remains to be seen what effect the (on the average) lower academic talent will have on industrial development.

While many Central Asian and Eastern European countries have experienced a similar development in the recruitment for engineering and science, the interest for science-based fields, as well as the recruitment for engineering studies, are both still strong in many Third World countries. Sometimes this is primarily a result of the huge demand for higher education of any kind; in other cases engineering and science education, which provide the best opportunities for employment in the private sector, are specifically in demand by young people. But, as we shall see, such specific demands do not necessarily come by themselves. An interesting example is found in Botswana, one of very few countries in sub-Saharan Africa that has performed well in economic terms during the last decade. What did Botswana do right? Part of the answer may be found in the dedication to science education at all levels and the long-term planning in this context that has been demonstrated by the Ministry of Education in the country.

Table 2 shows the number and percentage of upper secondary school students in Botswana who have chosen courses at the highest level available to most, English O-level in combined and specific science subjects (A-level courses are not offered in secondary schools in Botswana except for one or two private schools). Examinations are carried out by a British agency (Cambridge Overseas School Certificate Examination), which probably ensures general quality rather than relevance in Botswana and which, to a large extent, leaves control of the courses outside the country [6]. It may be added that the number of upper secondary school students taking 0-level mathematics also increased strongly during the period and reached 100% in 1991. It should also be mentioned that a structural change in the education system of Botswana in 1986 created more academic and independent senior secondary schools in charge of the last three years of high school. This corresponds to the structure that has been relatively successful in many European countries.

Table 2: Number and % of upper secondary students in Botswana enrolled in O-level science courses [6].

| | Combined science | Physics | Chemistry |
|---|---|---|---|
| 1981 | 195 (13%) | 67 (5%) | 78 (5%) |
| 1986 | 422 (19%) | 489 (23%) | 494 (23%) |
| 1991 | 3000 (49%) | 1267 (21%) | 1377 (23%) |

The growing number of upper secondary school students in Botswana enrolled in separate science courses reflects an increase in the interest for taking these subjects and an increase in the availability of such courses. The numbers in Table 2 also illustrate the fast growth in upper secondary school enrolment in Botswana. Compared with many industrialised countries, the present situation in Botswana provides an excellent background for expansion of science-based fields, including engineering, at the tertiary level institutions in the country. In Danish upper secondary schools, for example, the enrolment in the most advanced science and mathematics courses dropped from around 5000 in the mid 1980s to about half that today.

The increase in interest for the more demanding, independent science courses did not come by itself. In connection with the fast growth in upper secondary school enrolment during the 1980s, the Ministry of

Education in Botswana required that career counselling be provided in all upper secondary schools. The purpose was that all students should know which career opportunities they would have (and, maybe even more importantly, which they would not have) by making specific course choices during their upper secondary years [6]. The goal was that one third of the students should take the independent science courses; the actual number doing so is still only 20-25% in chemistry and physics (see Table 2). The Ministry also stressed that schools should encourage those students who do not take separate science courses to at least take the combined science course. The intention was to increase the number of career opportunities available to them after graduation from high school.

It is striking that the career counselling at the upper secondary level in Botswana emphasises the sciences, while in Denmark, which also has compulsory career counselling in upper secondary schools, the opposite is likely to happen. The reason is that most counsellors in Denmark are upper secondary school teachers with research degrees at the Master's level in foreign languages and other non-science subjects. At the most recent count, 428 upper secondary school counsellors in Denmark had degrees in Danish, English and history, compared with 36 with degrees in physics or chemistry [3]. It seems highly unlikely that counsellors without any scientific background will be efficient in the promotion of career choices in the science-based fields. In spite of warnings about the risks caused by the unbalanced background of the secondary school counsellors, some of which were given before the recent decline in student intake in science and engineering, little was done to correct the problem [5].

The question is now what the consequences of this situation will be for Denmark. The successful, expanding Danish high technology industry, which is the engine of recent Danish economic successes, is not likely to slow down much because of the insufficient domestic supply of engineers and scientists, a shortage which already now is clearly felt in industry. In some cases research activities have been moved abroad (eg to China), but more commonly industries have found the needed labour force in other European countries, eg chemists and chemical engineers from Germany, which for several years had an oversupply of graduates in these fields. Because of the demographic development in the region and similar motivational problems among secondary school graduates in Germany and other neighbouring countries, these sources are drying up fast. It seems likely that recruitment in the future increasingly will have to take place in developing countries, following the pattern now seen in North America. This way the outcome of poor Danish counselling and lack of efficient measures to ensure recruitment for science-based fields may eventually include brain drain from developing countries in Eastern Europe, Africa and Asia.

## THE GAP BETWEEN SECONDARY SCHOOL OUTCOMES AND UNIVERSITY EXPECTATIONS

A common problem in many countries is the gap that frequently exists between the real outcomes of secondary school education and the expectations that many universities have about these outcomes. This problem is particularly serious for university programmes in engineering, hard sciences and some related fields. In many other subjects the demands to secondary school learning may also be high, but the relationship with specific school subjects is less obvious.

The problem is usually viewed quite differently by universities and by secondary schools. The former are frequently convinced that the latter do a poor job, while the latter often feel that the former are unrealistic in their expectations. The reason for this, and the underlying cause for the widespread poor co-ordination between upper secondary and higher education, is that often neither party takes any significant responsibility for this educational transition. The difficulties are made worse by the fact that the management of secondary schools and the management of higher education in most ministries of education are performed by very different units, which by tradition do not co-operate much.

In practice the problem is only felt at the universities, which, based on a conviction that they are not responsible for the poor preparation, are often tempted to react in a less responsible way. The two following strategies are commonly applied, although neither of them is likely to provide positive results:

- The universities proceed with their programmes with little regard for the students' problems.
- The universities lower their academic demands during the first year, in the hope that students will catch up later.

Neither of these strategies is satisfactory. A common result of the former is extensive repetition and high dropout rates in engineering and science programmes. As a predictable consequence of their negative experiences, many of the unlucky students who leave their studies this way will have developed hostile feelings towards the subjects, instead of their earlier, positive interest in S&T.

The foundation for the second strategy, a hope that the students will catch up later, is frequently not realistic. If the students after a soft start find the demands in their later studies too hard for them to handle, this may lead to extensive repetition or late dropout, thereby being even more costly for them. Institutions may choose to lower the standards and demands for the whole study programme in an attempt to prevent this, but this will result in a qualitatively poorer final product. Fortunately, as we shall see, there are more constructive ways to deal with the gap between secondary and tertiary institutions.

University administrators, eg engineering or science deans, are at times very outspoken when they blame secondary schools for the situation. This rarely improves the situation. University officials frequently forget the immense influence the higher education sector has on upper secondary schools through the way they train the teachers for these schools. There is little doubt that poor preparation of teachers during their studies is one among several causes for unsatisfactory outcomes of secondary school education.

What are the more sensible ways of dealing with the problem? There are at least two simple strategies that might work:

- An open and frank discussion based on an understanding of common responsibility between universities and secondary schools about interface problems. Examples include curriculum problems; possibly followed by a number of concrete, co-operative activities, such as new in-service teacher training programmes for existing teachers; improved teacher pre-service training; access to university laboratories for upper secondary school students and teachers.
- Introduction of special courses with the purpose of bridging the gap between the outcomes of secondary school teaching and the university requirement in the subjects of specific interest, usually mathematics and science.

The first constructive option is not used nearly to the extent possible. It is striking that countries often deal with upper secondary schools and universities as two completely separate entities in spite of their obvious interdependence. A study of the present challenges for engineering education in the US was recently carried out by organisations representing primarily higher education, research and applications (ie industry), but not secondary school teachers [7]. In the report from the study it is stressed that:

> *the main responsibility for improving mathematics and science preparedness of students lies with the elementary and secondary schools.*

The report is optimistic about the potential importance of ongoing activities to improve the preparation of students for engineering studies. The report suggests improving grades 6-12 curriculum work in mathematics and science, the development of national science education standards, teacher training initiatives by the US National Science Foundation that bring together science and engineering faculty with education faculty, and increased federal spending on pre-college mathematics and science, etc [8]. However, the optimism expressed in the report with regard to these secondary school initiatives may in part be a result of an unwillingness of the academic/industry group to deal directly with the problems in secondary schools. The report encourages a breakdown of the traditional barriers between secondary school students and teachers and university faculty, but the concrete proposals given to reach this goal are not very specific (*visit each other*, and *let college students mentor high school students*, etc). Although such initiatives exist in the US, the report admits that they presently are *uncommon*.

Nor does the Danish report have any specific suggestions in this area, although it also deals in some detail with the poor motivation and, to a lesser extent however, insufficient preparedness for studies in engineering and science provided by Danish upper secondary schools [3]. In some countries, professional organisations for specific fields have made a special effort to include secondary, sometimes even primary, school teachers. One example is the American Chemical Society, which in recent years has increased its involvement in primary and secondary education considerably. In principle the professional organisations may have excellent opportunities for bringing the two parties together; such co-operation may sometimes provide added benefits of particular value in developing countries, where it is often difficult for professional societies to reach a critical mass of members.

However, a merger is not necessarily easy; in spite of substantial efforts by the American Chemical Society, it still has enrolled only a tiny fraction of American chemistry teachers as members.

The second of the constructive options, offering special courses that are able to bridge the gap between secondary and tertiary institutions, may be viewed as a pragmatic reaction to a situation that is not ideal. The selection system for entrance to tertiary studies varies between different countries; sometimes they also vary considerably even between different universities or study programmes in the same country [1]. It seems to be most common to base the selection on the result of a national examination as part of the conclusion of the secondary studies, but some countries have special national university entrance examinations.

Science and engineering programmes at Danish universities have agreed on specific minimum requirements with respect to the courses in mathematics, chemistry and physics, which prospective students must have passed during their upper secondary studies in order to be admitted (however, their grades in these subjects are not counted). In connection with the fast drop in enrolment during the 1990s, it has been tempting to reduce the requirements, but in most cases this has been avoided. Instead, an increasing emphasis has been placed on short, intensive courses in the science subjects; such courses are now accepted as a replacement for lacking courses in the upper secondary schools. The intensive courses often use university facilities. However, upper secondary school teachers with little connection to the host university often teach these courses. At times this may be a pedagogical advantage, but it may not help the students overcome the needed change in their study habits. The course activities in Denmark generally take place in the last summer month between high school graduation and the start of the fall semester in the universities.

Although the short courses generally have been considered very effective, it is not surprising that a recent increase in these course activities has led to considerable debate. Among the most commonly asked questions are:

- Do the students learn as effectively during a short, intensive course as they do when the course is spread out over a full year?
- Can the learning accomplished during the crash courses become long-lived (instead of following the rule, *what comes fast, goes fast*) if they are followed without delay by higher level university courses in the same subjects?
- Will the existence of such summer courses, providing students with a *second chance* in science-based subjects, make it even more tempting for them to avoid the demanding, high level science courses in the upper secondary schools?

So far there seems to be little agreement on the answers to these questions. Instead we shall turn to Botswana, where a more extensive *bridging course* in the sciences was established 20 years ago, and after some time reached high levels of both recognition and institutionalisation.

## BRIDGING SECONDARY SCHOOLS AND UNIVERSITIES IN BOTSWANA

As in several other parts of Southern Africa, the secondary schools in Botswana had severe difficulties in satisfying strict international standards at the graduation level, especially in mathematics and sciences. In 1976 this led the Free University of Amsterdam, as a result of a specific request from the University College Botswana, later the University of Botswana, to propose Dutch donor support. Later they also asked for European Union support for a programme of assistance in the build-up of a system of *bridging courses*. The intention was that these courses should bridge the gap between the international standards at the University of Botswana, which require a competence at the top end of the English 0-level from the first year students, and the strongly varying standards in the secondary schools in Botswana, which, as an additional complication, were expected to undergo a fast expansion in the near future.

The Pre-Entry Science Course (PESC) was started in 1977 in Botswana as a co-operation between the Free University of Amsterdam and the University of Botswana [9]. During the following years similar programmes were started in neighbouring countries, also in partnership with the Free University: in Swaziland in 1978 and in Lesotho in 1981. Teaching in Botswana started out with a considerable input from Dutch university teachers and Dutch student teaching assistants; also the financing was at first almost exclusively provided by foreign donors. During the 20 years the programme was implemented, the contribution of local teachers increased; also, BSc students at the University of Botswana have been extensively used in the courses.

Initially, and for the first few years, the duration of the programme was six months. In 1980 it was decided to expand it to seven months, running from early January to late July, thereby filling a gap between the end of the examinations in the upper secondary schools in December and the start of university studies in August. The increasing participation of young people in a one year long national community service scheme, which was made compulsory in 1985 for those who wanted to enter higher education institutions or the public service in Botswana, did give rise to several practical problems, but the management of the community service scheme has, over the years, shown a great deal of flexibility in order not to reduce the intake in the pre-entry science programme [6].

The PESC changed in 1982 from donor-funded projects to a fully-fledged department of the Faculty of Science at the University of Botswana. Even after this institutionalisation the programme continued to receive significant levels of donor support, but over the years the Government of Botswana increased its support to the point of providing the lion's share of the costs. From the start the main purpose of the courses was to increase the number and quality of students entering University of Botswana programmes which demand a good background in mathematics and science. Later, other higher education institutions also began to benefit from the programme, as described below. To reach the goal of PESC required much more than an upgrading of the subject matter knowledge of the students from their secondary school O-levels. It also required a change in their attitudes to the studies and an improvement in their feeling of personal responsibility towards the learning process.

In order to provide students with the necessary knowledge, courses were offered in biology, chemistry, informatics, mathematics and physics, as well as in language and study skills [10]. The science courses contained a very considerable amount of laboratory work. An equally important goal of the programme was to create more mature university students, especially by encouraging independence and critical thinking and avoiding the traditional rote learning encouraged by external examinations which still dominate many secondary schools in Africa (and elsewhere). The textbooks, which were issued to the students, were a mix of upper secondary and college level books.

At first, the small number of students enrolled helped secure an easy dialogue between university teachers and students in the programme. Later, a formal system of counselling was introduced, based on teaching faculty acting as tutors for groups of students (about 30 students each). Provision of career guidance remained one of the main tasks of the teachers involved in the counselling system.

The teachers in the PESC programme became increasingly interested in educational research. Many of them are now very active in the field and their work includes a wide range of subjects [11]. The educational research opportunities have provided important work incentives for the staff, as well as support for the teaching activities. The teaching staff in the programme also helped to promote science in society in general, in particular in co-operation with the upper secondary schools and their teachers.

It is interesting that even after the pre-entry programme became incorporated in the Faculty of Science of the University of Botswana in 1982, it remained very difficult to establish close contacts between the Faculty of Science and the teachers of the pre-entry programme. This was the case in spite of the fact that a number of surveys among the academics in the faculties of science and education at the University of Botswana revealed considerable satisfaction with the pre-entry activities [12].

The pre-entry course programme has over the years attracted an increasing number of applicants, well over 1000 per year during the last decade. Typically, around 25% of these applicants (in the early 1990s about 350) have been admitted to the pre-entry programme and over 80% of these complete the seven months programme. Some special effort has been made to attract female students, but the female participation remained low; it had only reached about 20% in the early 1990s. This is an indication of a considerable waste of talent [13].

The graduates of the pre-entry course would typically have direct access to a wide range of options for tertiary studies [12]. The most important and common was to continue into the first year of the BSc programme at the University of Botswana (the recommendation given to about 60% of the students enrolled in the pre-entry programme). After completing the first year of the BSc, students can work towards a BSc degree in the sciences, mathematics, or computer science, or a BEd degree in science and mathematics education at the University of Botswana; or they can enrol directly into various degree programmes at the polytechnic and agricultural institutions in Botswana. It must be noted that many of the most able students leave the country after completing part (usually two years) of their BSc studies in order to specialise in academic subjects that are not available at the higher education institutions in Botswana.

A group of less academically inclined pre-entry graduates (typically about 15% of the students enrolled in the programme) was given several alternative options to enrolment in the first year of the BSc programme. In particular they could choose between a number of less demanding diploma programmes at any of the above institutions. A small number of graduates from the PESC programme did not continue in any academic programme.

Did the Pre-Entry Science Course in Botswana do what it was supposed to do? Did it increase the number and quality of students in science-based fields in the country? The number of students qualified for the first year of the BSc programme at the University of Botswana has grown from about 70 in the late 1970s to over 300 in recent years. Although academics in the Faculty of Science at the University of Botswana have never been completely satisfied with the subject matter knowledge and abilities of the first year students, they seem to agree that the problems would have been much worse without the pre-entry programme. It is therefore tempting to answer *yes*.

How would the situation have looked today without the pre-entry course? In spite of several uncertainties, including the very fast growth of upper secondary enrolment during the lifetime of the programme, there is little doubt that the problems would have been much more severe [12]. This conclusion is based on staff and student surveys, correlation studies of student performance during the first year of the BSc programme and student choices after the pre-entry programme. Also, a number of additional surveys and evaluations, taking into consideration a wider range of aspects than the purely academic, indicate that the initiative has been worth the effort [14].

However, in spite of its considerable contribution towards increasing the number and quality of students entering science-based tertiary level programmes in Botswana, PESC was never considered a perfect solution. Irrespective of the widespread recognition of the accomplishments of the programme the University of Botswana decided to close it when the 1995 intake had graduated. What were the major complaints?

One common complaint was that the programme was required for all students who wanted to enter a science-based university programme, not just for the weakest, *borderline* students (which were the target for the otherwise similar bridging programmes in Lesotho and Swaziland). The universality was less of a problem during the early years, when the course was needed by almost all students; very few upper secondary school students obtained high grades in their 0-level courses. The fact that a small number of top students were given training they did not really need was also less noticed locally as long as the costs were covered by foreign donors [15].

Over the years the number of high school graduates with high grades in their 0-level courses increased considerably. Such students could choose university studies in social science, for example, and enter the programme without delay, while they would have to take seven months of *unnecessary* courses if they wanted a degree in a science-based field. As a result, PESC became to be seen as an obstacle rather than an opportunity. To make matters worse, there was no guaranteed entry in the science-based programmes after completion of PESC; this was determined by the grades obtained. In a few cases, students with good secondary school grades who had qualified for entry in non-science programmes failed in PESC and were therefore not allowed to enter higher education studies [15].

When this dissatisfaction was combined with the increase in costs of the fast growing PESC programme to the government of Botswana, it became difficult to maintain the activities in an unchanged form. However, the programme was never considered a waste; there is little doubt that it played an important role throughout the two decades it existed. It provided useful experience. The University of Botswana is presently considering proposals to introduce specific entry courses for all faculties, including science, but this time the courses will be specifically targeting the *borderline students*, ie those with low secondary school grades [15].

Clearly, universal pre-entry programmes in countries like Botswana must be seen as less than perfect solutions. There is still insufficient active dialogue between the academics in the Science Faculty at the University of Botswana and the upper secondary schools; even the dialogue between the academics and the teachers in the institutionalised Pre-Entry Science Course was never as strong as it needed to be. Any new initiatives must ideally target two ultimate goals:

- To strengthen upper secondary education in the country so that it approaches the demands of the higher education science and technology faculties.
- To modernise university teaching so that it becomes better able to handle more diverse (including many less well prepared) student groups.

Pre-entry courses specifically targeting borderline students, like those that are now considered in Botswana, may often be a cost effective way to support progress towards the second of these goals; however, it is important that the first goal is never forgotten.

## CONCLUSIONS

In order to be competitive in today's markets, to ensure efficient solutions to science-based societal problems, and to help people to take advantage of scientific knowledge in their daily lives, nations must provide an increasing amount and quality of science and technology education to all citizens. And they must produce a sufficient number of scientists and engineers, trained at an up-to-date level in their respective fields. Some of them must be able to produce new knowledge in their field.

Quantitative problems with the recruitment for studies in engineering and other science-based fields may be solved through a strengthening of school science at all levels by mobilising the media, industry and others more efficiently in the promotion of career choices in science and engineering fields, and most of all, by providing sufficient, high quality counselling for students (and their parents) in upper secondary schools. Quality counselling may also help direct a larger share of the most gifted and talented secondary school students towards careers in engineering and science.

So-called quality problems among secondary school graduates are often primarily differences between the realities of learning in upper secondary schools and the expectations of university teachers and curricula. They are particularly pronounced for students enrolling in engineering and hard science programmes. The university teachers should not, as is often done, neglect these problems. This will increase dropout rates. They cannot be solved by simply lowering the university requirements during the first year either. This may result in lowered standards throughout the degree programme.

In the long term the interface (quality) problems must be solved, at least partially, through a strengthening of upper secondary school mathematics and science. In order for this strengthening to take place, universities must be much more involved and must engage actively in a dialogue and other kinds of interaction with upper secondary schools and their science faculties. However, the problem is not based in the secondary schools alone. In many cases it will also be necessary for universities to adopt new and more efficient learning (rather than teaching) strategies which work better for diverse groups of first year students. Improved recruitment of the best and brightest secondary school graduates for science-based fields will also help reduce the problem.

It is surprising that dialogue and co-operation between upper secondary schools and universities are almost nonexistent in many countries. Universities depend critically on the input of upper secondary school graduates, and upper secondary schools depend equally critically on the supply of new teachers from the universities. The latter issue, which has not been covered in any detail in this paper, has been discussed with special reference to science teachers in developing countries [16]. Ministries of Education, donors, and development banks may support a necessary and potentially highly constructive process by ensuring that the interface problems are dealt with in both secondary school and higher education projects. A possible strategy, which is likely to work well for the groups involved, is to always provide strong incentives for secondary school/university co-operation in relevant projects.

In the short term, urgent interface (quality) problems may have to be dealt with through the establishment of special courses in science and mathematics that can bridge the gap between the realities of learning in upper secondary schools and the expectations of university teachers and curricula. These courses should specifically target the weaker students (which in some cases may be a majority). The courses may be crash courses that take place over a few weeks between graduation from secondary schools and the start of university studies, usually a few months later. However, doubts have been expressed about the lasting value of science knowledge obtained in crash courses. Therefore, and also depending on the size of the gap, it may be preferable to spend more time on such courses, especially for weaker students, maybe adding up to a full year of study between the secondary school and the university. In the latter case an institutionalisation of the courses within a university seems to be advantageous.

As was seen in Botswana however, there may be risks involved in the requirement of an extensive preentry course activity. While adding a full year or even a semester of mathematics and science courses may make pedagogical sense, it makes degrees in science-based fields longer and less competitive when compared with degrees in other fields. This may further increase possible recruitment problems in engineering and other science-based fields.

It is also risky, although in a different way, to make supplementary programmes short, convenient, and easy. This may tempt students to avoid difficult, high level courses in mathematics and science in the upper secondary schools, with the belief that they can easily make up for it if their later choice of university studies makes this competence necessary. When, after graduation from their secondary school, they have to make the final decision on their field of study, a requirement of supplementary mathematics or science courses may seem less attractive, and they may decide to avoid science-based careers.

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