Technology Transfer - A Useful Metaphor for University Level Mathematics Courses for Engineers and Scientists

Juergen Maass
University of Linz (Austria)

Abstract
In Exeter (ALM 2, 1995) Wolfgang Schloeglmann and I presented some results of our research. One of these results is a useful metaphor: Teaching mathematics to engineers and scientists who have finished their university studies and have worked for many years in, for example, industry, is structurally similar to the technology transfer from a highly industrialized country in Europe to a so called third world or developing country in Africa. If this metaphor is correct, it is useful: we are able to learn something about chances, problems and mistakes.

What we can learn from transfer problems
I think we all have read in the newspapers of some very expensive technology transfer projects that went wrong. Perhaps it is better to construct a hypothetical example than to document one of these again. So - imagine a rich sheep farmer and wool producer who sees a photograph of a poor and hungry little child from anywhere in central Africa. He wants to help this child and thinks of a good way to do it. His idea is simple: let this family in Africa learn what a successful sheep farmer and wool producer must know and they will surely have enough to eat and always have warm woollen clothes. He engages an expert in sheep farming and an engineer for wool machines and sends them to the African family to teach them. He promises that if the family learn their lessons well he will send 20 sheeps as a gift to them. I think I can stop this story at this point. It is your task to imagine a continuation.

Transfer of technology: A theoretical outline of the problem
The term "transfer of technology" was originally used for export of technology to the so-called Third World or developing countries. In this connection, the essential problems of such a transfer are: which (adapted, environmentally and socially compatible, etc.) technologies can be transferred, and in which way? What roles do the social and economic contexts of development and use play, and what are the differences in communication between developers and users?
If the transfer of knowledge from the university to other sub-systems of society is called "technology transfer," similar questions arise. When the most common transfer route is taken, i.e., from university to industry, the problem in each particular case is how to achieve what is called in the language of system theory "the transfer of meaning" - system specific reduced complexity must be converted from the scientific communication code of "truth" into the code of the economic system: "money". The social systems (I refer to the sociological system theory by N. Luhmann) which are differentiated according to their various functions, realise from the variety of the total complexity of the world around them the information which they can process in each individual case, according to the rules which they have institutionalised in their inner structure. The typical method of processing in science, the specific way of reducing complexity, is the differentiation between true and not-true statements, and thus leads to an increase in scientific knowledge as such. If such knowledge is not further processed, it is, in itself, not necessarily usable outside the scientific system. A mathematical theory, such as linear optimization or graph theory, does not in itself help the economy; it is only when mathematical theories are converted into a computer programme controlling optimally and thus profitably the production of, for example, cabinets in factory X that the transfer can be said to be successful. It is essential

that mathematics as a sub-system of the science system (Maass 1988), for instance, can "achieve" a successful transfer, not only by working out new theories and algorithms, but more particularly by working them out in such a way that they can be usefully brought to bear on the system of application.

Technology transfer: Four ways

In what follows it may be useful to differentiate between the following methods of transfer (writing articles or math. books is not mentioned because this is an inner system communication, not a transfer):

- **Education** in the form of a course of study is the classical method by which knowledge from the university reaches systems of application. Related questions, for example, as to the meaningfulness and possibilities of orientation towards practical application, have long been under discussion in mathematics education departments. A mathematics department that organizes the curriculum with the main aim of reproducing itself (new mathematics researchers for university as orientation of study) will have some problems matching the needs of an application system like school or industry.
- **Further education**, in particular the scientific training of users of mathematics in industry, such as engineers and scientists, is a relatively new field. Didactically thought-through experience in this field, as well as in training in vocational education, is not widely available (but ALM is working to achieve it).
- **Black boxes** (Maass/Schloeglmann 1988, 1994) enable a transfer of knowledge even when the users have no idea about what is inside them. When you operate a light switch, you do not need to know anything about physics or technology. If it works it will operate well even if the user has a completely crazy theory about it. One eample: Did you know that light is the product of little animals living in wires? These animals called PHOTONS come out if the gate (light switch) is opened and illuminate the world. You do not believe this nonsense? Try it! If a black box does not work, you need help or more knowledge about it to repair it. The use of black boxes without knowledge of the inside makes the user dependent.
- **Cooperation**, for example in the form of the university and the user working out a project together, is always useful and necessary when a problem is to be solved with the help of scientific knowledge not at the disposal of the user, but which because of its complexity and variability, is not soluble through using an existing black box, or where it can only be solved by constructing a black box together.

Mathematics as technology?

The importance and the function of the university mathematics education departments for the first two methods of transfer of mathematical knowledge are obvious. Before it is useful to discuss their possible role in respect to the other two, we must think about mathematics and technology. One connection is this: the new technologies which are altering our lives so radically are essentially mathematical technologies. Computer hardware and software would be unthinkable without the mathematical theories on which they are based. But mathematics is a hidden basis of technologies. You must do some research to find for example mathematical algorithms that control a machine.

The second question is more difficult: Is mathematics itself a technology? Or has mathematics a technological aspect, too? To find an answer it is useful to read something about technology. According to a definiton by Beckmann (1777), technology is the theory of the processing of raw materials, or the science of transformating raw materials into finished products and the method of their processing. When rules for processing raw materials are described in mathematical terms, for example, as a ratio of the various elements included in a mixture, or as physical or chemical laws set out in formulas which establish the properties of substances and the fundamental principles of their ability to change, and which also necessitate a numerical solution of a system of equations in controlling a production plant, then mathematical knowledge is obviously technology in the sense of this definition. As this concerns only one aspect of mathematics (or indeed of its application), and as the use of the term "technology" suggested in the dictionary does not include one essential component. i.e., its being inseparable from its social context, we need to try once again to answer the question as to whether "mathematics" is to be regarded "as technology", or if it is at least technologically efficient. That is why, in the course of a conference on this subject in September 1988 in Strobl (Wolfgangsee, Austria), university teachers of mathematics, mathematicians from the university and industry, scientists, engineers and philosophers discussed in interdisciplinary cooperation different aspects of the question "Mathematics as Technology?" and its consequences for interaction between mathematics, new technologies, education and further education (Maass/Schloeglmann 1989).

I can only outline a few selected examples of their findings here. From the point of view of philosophy, the question of the relationship between mathematics and technology first comes up against the problem that mathematics is not an empirical science. So, for P. Ruben, the "posing of the problem of 'mathematics as technology' is a pre-condition, and we mean by 'technology' not only the theory of techniques, but also the totality of theories of real and possible production processes and the cooperation between mathematics and each specific technology" (Ruben 1989:146). H. Huelsmann believes that this division in the preconditions of "the technological formation" (Huelsmann 1985) of society emphasises too much the formal aspects and does not stress the formative aspects enough. If mathematics is thought of as "mathesis universalis", as Leibniz has it, and thus has the identity of scientific knowledge in mind, e.g., logic, arithmetic, geometry and mechanics, the formal aspect is by no means empty of content, but it is rather a possible approach to a reality which as such represents a structural connection, a unity, a world. It seems important to me here that in its technological form, each individual science should not be understood and determined on its own. This mathesis universalis is concrete and real. This is shown by the fact that it is no longer a matter of the operation of a single science, but that the operation of knowledge must be understood as technological totality, as it realises its technological form in all the disciplines" (Huelsmann 1989:124).

A second result of the discussion in the working group, "Consequences for School", was that a consensus was reached according to which the technological aspect, i.e., "laying stress on the technical-instrumental aspects of mathematics, including the consideration and weighing-up of the conditions and implications of these aspects" (Doerfler/Blum 1989:175) should be an integral component of the mathematics curriculum. This reamins to be achieved, for although a corresponding formulation of aims is to be found in the preamble to almost all syllabuses, the usual mathematics teaching in practice suffers from great stress being laid on method and calculation (and, in the upper forms, teaching is largely orientated to the teaching common at university). As possible steps towards change, subjects such as methods and content, meaningful use of the computer, orientation to extra-mathematical application, open, and even non-numerical problems, etc. etc., were discussed.

The working group, "Consequences for University Studies", discussed on the one hand courses of study initiated or planned over the last few years, such as "Technomathematics" (Kaiserslautern, BRD), or "Industrial Mathematics" (Linz, Austria), and, on the other hand, corresponding partial study programmes or lectures within the framework of "normal" course of study terminating in a diploma, as well as for mathematics for teaching.

In new courses of study, technical sections are explicitly planned. But even in traditional courses of study, problem seminars in which students solve practical problems in industry can provide essential steps towards training geared to real life situations.

The contribution of mathematics education departments at the university to the transfer of technology
No complete answer can be given here to the question of new challenges to mathematics education departments participating in construction of black boxes and in industrial projects. Yet it is clear that these departments can make a positive contribution to these two methods of transfer too, by utilizing their knowledge about, and experience with transfer and learning processes. Typical transfer problems, such as the sensible organisation of a technology or, more concretely, of a user surface in a black box, can be solved with the help of typical didactical knowledge.

In addition, I remind you of the result of a discussion some years ago in Western Germany about "polyvalence and flexibility" in the training of teachers. In view of the growing number of unemployed teachers, certain politicians in the educational field, as well as managers, demanded that the curriculum be altered. Pedagogics and specialised didactics were to be dropped, so that there was more time for attaining specialised qualifications. According to these proposals, only those graduates who actually teach in a school should learn didactics and pedagogics at the university (Maass/Rahmann 1985). This proposal proved to be impractical for a number of reasons. One of these reasons is especially important for our present considerations. Research carried out by the German Ministry of Labour's Institute for Research into the Labor Market and Employment (Havers et.al. 1983) showed that teachers who could not find work in a school were very often given employment in industry because of their pedagogical and didactic abilities. Their new employers appreciated their non-specialised qualifications, which enable them to get on well with people, as something very valuable for their companies.

We suggest that precisely this ability - compared in general with the "typical mathematician" - is a feature of most teachers working in mathematics education departments. People who have above-average linguistic and communicative competence can, when cooperating with industrial mathematicians, be helpful in crucial situations, for instance, when
- before the beginning of a project a contact has to be established and it must be made clear to prospective customers what the possibilities and limits of using mathematical methods would be,
- in the course of a project provisional results and additional information necessary to the project processing have to be given,
- at the end of a project, the results have to be presented in a form understandable to the mathematical layman as well (e.g. the manager responsible).

As Wolfgang Schloeglmann's and my research into the acceptance of mathematical technology has shown, all three points are by no means irrelevant to success.

New tasks for university mathematics education departments in research and training
The task of doing research into the transfer of mathematical knowledge as a whole appears to us even more important than the possibility of working in cooperation with industrial mathematicians. Such research demands specialised knowledge of mathematics and its application, but also an awareness of the methods of social science and empirical methods, as well as contacts to industrial mathematics. This combination cannot be expected of either mathematicians or of social scientists. Even if not all people employed at mathematics education departments have the relevant abilities and possibilities at their command at present, I believe that our branch of science is the most likely to be able to fulfil all the necessary conditions.

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