INTERNATIONAL TECHNOLOGY EDUCATION SERIES

Technology Teachers as Researchers

Philosophical and Empirical Technology Education Studies in the Swedish TUFF Research School

Inga-Britt Skogh and Marc J. de Vries (Eds.)

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Scope

Technology Education has gone through a lot of changes in the past decades. It has developed from a craft oriented school subject to a learning area in which the meaning of technology as an important part of our contemporary culture is explored, both by the learning of theoretical concepts and through practical activities. This development has been accompanied by educational research. The output of research studies is published mostly as articles in scholarly Technology Education and Science Education journals. There is a need, however, for more than that. The field still lacks an international book series that is entirely dedicated to Technology Education. *The International Technology Education Studies* aim at providing the opportunity to publish more extensive texts than in journal articles, or to publish coherent collections of articles/chapters that focus on a certain theme. In this book series monographs and edited volumes will be published. The books will be peer reviewed in order to assure the quality of the texts.

Technology Teachers as Researchers

Philosophical and Empirical Technology Education Studies in the Swedish TUFF Research School

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PREFACE

In this anthology researching teachers present their research on teaching and learning Technology. The idea for the book was raised jointly by supervisors and students in the early months of 2011, when the teacher graduate students were approaching the end of their Ph.D. training. The fact that the book is now complete, is something we have many people to thank for. A warm thank you to all authors, of which I, in particular, want to mention my colleague at KTH Sven Ove Hansson and Edvard Nordlander at the University of Gavle who both have joined me in leading the TUFF adventure. A warm thank you also to the Boost of Teachers Initiative and participating municipalities who funded the TUFF project and, last but not least to Marc de Vries, my most valued co-editor, and Peter de Liefde and Sense Publishers for making our idea become reality.

Stockholm in August, 2013
Inga-Britt Skogh

INGA-BRITT SKOGH & MARC J. DE VRIES

1. TUFF AND THE VALUE OF TEACHERS AS RESEARCHERS

INTRODUCTION

This book is the outcome of a Swedish project in which a group of technology school teachers carried out a research plan that eventually led to their Licentiate or Ph. D. theses. In the past it was rare when teachers did research. Now there seems to be a certain trend towards the teacher-researcher combination, at least for the time that is needed to produce a Ph. D. thesis. In e.g. Sweden the Swedish National Graduate School in Science, Mathematics and Technology Education Research (FontD) has been running since 2002. In the Netherlands 2013 was the final year of the DuDoc project in which also a group of teachers worked on Ph. D. theses. In this introductory chapter we will describe the TUFF project and discuss some of the pros and cons concerning teachers doing research as we find them in literature. Finally we will sketch an outline of the book and show how it is structured.

THE TUFF PROJECT

In Sweden, and probably in many other countries, the perceived distance between researchers/universities and teachers/schools is considerable. Hence the implementation of educational research in ‘everyday’ school practice is and has been problematic. To bridge the gap between academies and practice the idea of doctoral programs specially designed for teachers wanting to do research up to the level of licentiate (half a PhD) was launched in Sweden in the early years of the 2000s. The ‘first generation’ teacher doctoral programs in Sweden started in 2001 (Andrea-Thelin, 2009). This first venture was followed by a number of similar doctoral programs initiated by universities and municipalities wanting to collaborate. The ‘second generation’ programs were commonly funded by the Swedish research council and (to a lesser extent) by concerned municipalities. In 2008 a ‘third generation’ doctoral program designated towards practicing teachers was launched. Ten doctoral programs in selected subject areas received funding from the Government. In this venture in total 160 teachers participated. Twelve of these teachers were admitted to our graduate school called Technology Education for the Future (in Swedish TUFF) for research projects about teaching and learning technology.

I.-B. Skogh & M.J. de Vries (Eds.), Technology Teachers as Researchers, 1–13.

Between 2008 until 2012 the graduate school TUFF was run in partnership with Stockholm University (Host University), University of Gävle and Royal Institute of Technology (partner universities). In this introductory text graduate school TUFF is presented. Within the next pages you will find information regarding the project background, the aims and goals of graduate school TUFF, choices, activities and experiences and an update of the current situation for the TUFF PhD students.

PROJECT BACKGROUND

From Centralization to Decentralization

In the 1990s, the responsibility for schools in Sweden was transferred from central government to local municipalities. State influence changed from regular management to management by objectives and from centralization to decentralization. National goals and guidelines are specified by Government and Parliament through the Education Act, curricula etc. but the responsibility for the implementation and realization of these national goals were transferred from state to municipalities. The mission to, on behalf of the government, work actively for the achievement of these national goals is laid upon the National Agency for Education (NAE). The responsibility for educational research has also changed over the years. The municipal and local level has been given greater responsibility for both school improvement and educational research. How educational research is organized, how it is administered and the decisions on what content should be prioritized is today decided by local authorities. For example, since 2003 key education authorities have neither influence nor responsibility for the initiation or distribution of research funds (Andræ Thelin, 2009). The main source of funding in educational science in Sweden today is a research-driven committee within the national Research Council. In 2012 165 million Skr was allocated by way of grants for research within educational sciences from the council’s total budget of 4.5 billion Skr (Research Council, 2013). Educational research oriented towards teaching and learning technology have only occasionally received financial support from the Council.

Educational Research, *School Practice and Teacher Education*

To what extent teachers (and teaching) are influenced by new educational research has been discussed by school authorities, researchers and politicians in Sweden for many years. Results seem neither to reach nor to involve practicing teachers as much as desired. Some even claim that there is a considerable gap between educational research and teachers’ practice. Measures to address this perceived gap have however been taken. During the last ten years efforts have been made to promote and support practice oriented educational research in Sweden. The importance of a dialogue between research, training and the educational sector has been emphasized by stake holders and policy makers. This dialogue can (and should), according to decision makers, take the shape of collaborative research thus making research results available to interested groups (Thelin, 2009, Prop. 1999/2000:81).

Teacher education is, in this context, a particularly important arena. The teacher education reform launched in 2001 led to a rapprochement between theory and practice which meant a shift from ‘know how’ to ‘know why’. A requirement for all teacher students to write a thesis based on theory and focusing relevant educational issues was also introduced in this reform. The link between teacher training and postgraduate education was however not thoroughly addressed. The European Union-harmonization of academic education through the so-called Bologna process has however opened for a clearer discussion of how teachers in Swedish can be connected to master’s programs and doctoral studies. Teacher education in Sweden was recently revised and a new teacher education in line with the Bologna process (SOU 2008:109) was launched in 2011.

The First and Second Generation Teaching-graduate Programs

In 2001 the idea of so-called teaching-graduate students was introduced in a governmental proposal (Prop. 2000/2001:3). The proposal suggested that the National Agency for Education (NAE) should support the development of a scientific base for the teaching profession by investing in teaching graduate programs run in collaboration between the NAE, one or more universities, municipalities and school authorities. The NAE identified a number of strong research environments, selected subject areas to be highlighted in the research (e.g. pupils’ learning, teachers’ work and the leadership of this) and requirements for admittance to the program was set up (teachers diploma, two years of professional experience, employed as a teacher, listed in a regular research training program, financial support from municipality and the obligation to produce a practice-oriented thesis).

In the years following 2001 just over thirty PhD students were admitted to the program. It should however be noted that only a quarter of these PhD-students (two men and six women) were ‘pure’ teaching-graduate students who met all the above mentioned NAE-criteria. The average age among these eight ‘first generation’ teacher-graduate students was high (48, 6 years) and they were studying Didactics (e.g. music didactics) and Educational Work (Thelin, 2009). This teaching-graduate student program was a new instrument in the field of research. The example given by authorities was followed by a number of similar ‘second generation’ PhD-programs around Sweden. In e.g. 2002 a PhD program focusing educational research in science and technology (FontD) was launched. FontD was (and still is) hosted by Linköping University, funded by the National Research Council and run in partnership with a number of universities/university colleges from all over Sweden. This and other ‘second generation’ programs were however initiated by municipalities and/or universities wanting to collaborate. On a national level the effort to promote teachers to do practice-based research was followed up in 2008 within the frames of a new professional development program called the Boost for Teachers Initiative.

The Third Generation Teaching-graduate Programs – The Boost for Teachers Initiative

In 2008 the so called Boost for Teachers Initiative was launched. By means of continuing professional development for teachers this program should *"... strengthen teacher's competence, both in the theory of their subject and pedagogical approaches to teaching"* (NAE, 2009). Specially developed 'Boost for Teachers Initiative' courses in selected subject areas were ordered by the NAE to be developed by universities and colleges. Certain requirements must however be fulfilled before a teacher could enter such a course. The teacher must be eligible, have a teaching qualification in higher education and be a practicing teachers working at any level from preschool class up to adult education. The rules of the promotion stipulate still one further requirement. Teachers' participation in the program was to be governed by the needs and priorities of the local schools/municipalities (Skogh, 2010).

Within the Boost for Teachers Initiative the government also decided to fund ten third-cycle study programs (graduate schools). The conditions of this initiative were very favorable to teachers as well as to organizers (universities). Two and a half years of study leading to licentiate level ('half a PhD'). Four days of studies and one day of teaching in school each week with full payment during the entire period of study. A state grant guaranteed 60% of the teachers' salary and participating communities/schools contributing the remaining 40%. To be eligible teachers must fulfill the above mentioned requirements (including having a signed certificate of approval from the local school organizer) and, also be assessed by the university concerned to be qualified for doctoral studies. In the autumn of 2007 universities in Sweden were invited to develop special designed graduate school programs. In March 2008 ten programs were selected by the government (via the national Research Council). One of the selected programs was TUFF.

Aims and Goals

Three overarching goals of the TUFF program were formulated from the very beginning. The graduate school TUFF should:

– strengthen the status of technology and the efficiency in compulsory school
– technology education
– strengthen the recruitment to technical studies in high school and college and
– promote gender-neutral education and gender balance in recruitment.

From these aims three objectives were extracted. Research within TUFF should address the following areas:

1. explore factors affecting recruitment to technology training and develop methods to promote recruitment,

2. develop practical methods for teaching technology education in primary and secondary education and
3. explore how gender equality can be increased in recruitment and in the teaching of technology subjects.

TUFF started March 15, 2008 and was formally closed June 30, 2012. It was run in cooperation between Stockholm University (SU), the Royal Institute of Technology (KTH) and the University of Gävle (HiG). Two postgraduate education subject areas were included: Education in Arts and Professions (SU) and Philosophy (KTH).

The result of study for each student should continuously be fed back to their schools in order to certify a practice-related research situation as well as to inject the outcome of research in school practice.

Twelve teacher graduate students (six women, six men) worked in the research school.

Choices, Activities and Experiences

We have, during our work with TUFF, been faced with many choices. Each and every one of those choices has, in different ways, affected the outcome of the graduate school. Some choices were made early on in the process and others have been made ‘along the way’. Some of the choices will be presented here.

Selection of Research Question and Development of Post Graduate Courses

To formulate research questions is painstaking and time consuming work for any researcher. To facilitate the students but also to guide research into issues of particular concern for the graduate school, we decided that we should present a list of research questions for the students to choose from (e.g. “Students’ conceptions of technology”, “Reasons for students’ choice of technology studies at higher levels”, “Assessment of pupils’ achievements in technology” and “Technology education and gender”). The program also required the development of specially designed technology education oriented postgraduate courses (e.g. Technology Didactics, The Epistemology of Technology and Technology and Gender).

Selection of Students

During May of 2008 between thirty and forty applications were submitted. The applications were reviewed and valued by the management group (one representative from each university). In the call for applications we emphasized only teachers who had been given the ‘green light’ from her/his community and school principal were eligible for the program. However, early in the process we found that many of the candidates had not understood the need for approval from her/his employer. Of the twenty applications, which we deemed interesting, there were uncertainties about the municipal financing in more than half of the applications. In particular, smaller municipalities turned out not to be able (or willing) to commit to the financial conditions of the program. Consequently several of the high ranked candidates from smaller communities could not be admitted.

The question of what qualities we were looking for is reasonable to ask. In addition to the formal requirements stated by the government and the participating universities we were looking for persons having the ability to verbally and in writing present their research interest and their choice of research question/ research area with precision and in a credible manner. We also wanted our future students to demonstrate a number of subtle personal properties that are difficult to capture in words but still are well known to all researchers; purposefulness, a clear sense of reality, good reflectivity, openness to opinions and arguments and, not least, accuracy. Research work means both solo work and group work. We were therefore keen to find individuals with self-discipline and with good interpersonal skills.

Seven candidates were finally selected in the first run starting their studies in August of 2008. A second call for applicants was made in September of 2008 and five additional, equally qualified, teachers were selected to join the program in December of 2008. Table 1 gives some basic information about the whole group.

Supervising

With regard to the supervision of the TUFF graduate students, it was decided from the start that each student were to be assigned to one of the three participating universities where a work place and other resources were made available to the assigned students. The students' main supervisor was appointed from the institution where he/she was assigned. One assistant supervisor per student was appointed from one of the other universities. To students in need of further special expertise (e.g. specific methodological support) yet another assistant supervisor was appointed. The total amount of supervisors appointed within TUFF is 9 (professors, associate professors, assistant professors). Commonly tutorials have been individual but group instructions have occurred. All graduate students and main tutors have regularly met in research seminars. External experts/researchers have been invited for presentations and discussions. At least twice a year, representatives from

Table 1. Fact about TUFF students

Average age (at admission)	*Gender balance*	*Number of students assigned*			*School level focused*
46 years (from 35–56 years)	6 female, 6 male	kth 5	su 5	hig 2	*primary:* 5 projects *secondary:* 7 projects

participating universities and municipalities, representatives from various interest groups (e.g. teacher union representatives, engineering union representatives and policy makers) and representatives from the industry have been invited to meetings (so called reference group meetings) for information exchange, discussions and presentations. When necessary (on a regular basis) supervisors have met for follow-up discussions, information exchange and tutorial support.

Students' Experiences

A minor follow-up study of TUFF was performed in 2012 (Skogh & Gumaelius, 2012). A survey was sent (by e-mail) to the twelve teachers in late May of 2012. The two part survey consisted of open ended questions. In Part 1 questions are posed about the application/ admittance procedures, working/studying conditions, the perception of goal fulfillment etc.). Part 2 consisted of questions about the students' attitudes towards graduate studies in general and to TUFF in particular (their own personal goal fulfillment, their contacts with their schools/municipalities and their future career plans). Ten of the twelve teachers answered the survey. Six teachers from each of the three participating universities were then selected for interviews. The semi-structured interviews were made in early July of 2012 via telephone. The aim of the interviews was to get a deeper understanding of statements regarding the teachers' views on their own personal goal fulfillment (having or not having completed the studies) and about their perception of interest from the municipal/ school regarding their research and future career. Collected data was systemized and thereafter analyzed through repeated readings of statements.

According to findings all TUFF-students have found their graduate studies valuable for their own personal devolvement. They all found their working tasks during their studies stimulating, mainly because of the significant change in their working conditions. As researchers they found time for reflection on teaching methods and subject development, which has not been the case when working in school. Six out of ten students express that they would like to continue their graduate studies to doctoral level. The opportunity to join this research school was a personal choice, which opened up the possibility for a new carrier. Several students point out that applying for admittance themselves and thereafter anchoring the application with their employer was the only way to do it as the time from when the positions were announced until time for application was very limited. Municipality and school management simply had no time to learn about this project in advance.

After completion of their study period most TUFF-students express that the quality of their own teaching has improved after the study period. Not more than four students believe that the quality of education in their respective schools/ municipalities has increased as a result of their education.

There are some negative statements mentioned by the TUFF-students. Most informants fear that their acquired competence will not be put to use in the school environment. Six students cannot see that their knowledge and competence will be used *at all* when/if they go back to their position as schoolteacher. This has caused a lot of frustration among the students as they themselves see great possibilities to make a difference in school. The four students who do feel that they are supported by school management or by their municipality have a much more positive attitude towards going back to school after finishing their thesis and they also think that their knowledge will be put to good use. Two out of ten students feel they have had a good relationship with their school management and/or with the responsible persons in 'their' municipality during their graduation studies. Only one student decided to participate in the TUFF research school as a result of a discussion and in collaboration with the municipality.

The students also found the available time for studies (2.5 years) too short. Since they all had to go back to a fulltime job after the time period had expired, it has, according to the teachers, been difficult to complete their theses even though they are work wise close to graduation.

None of the students think the requirements are set too high, but they admit that the high requirements has been one reason why they have not fulfilled the goals on time. (At the time all students had published articles in international journals, taken 45 units of courses, participated in national and international conferences and contributed to a Swedish anthology.) Several students feel that the requirements for this research school have been higher than for other similar research schools. On the other hand they appreciate this and are proud of this ambitious research school. They also feel that the step to reach the doctorate level is not so big.

A third factor that is often mentioned in the interviews is that it has been disrupting to work in school 20% of the time during the 2.5 years of study. Some felt that it was difficult to restrict the working time to 20%. It seems like the students who are most satisfied with this combination are the ones who has done their school duties in periods where they have spent more than 20% in school (in other words concentrated to fewer but longer periods of time). Finally most TUFF students express that it would have been even better to take a doctorate degree at once as this degree is more accepted in the academic world. However the students do acknowledge the difficulties in this arrangement for the school/municipality as 2.5 years are already seen as a long time period to be away from the position in school.

Lessons Learned

In retrospect there are obvious lessons to be learned. The requirement for each student to produce a compilation thesis with (preferably) internationally published articles in English is one such issue. This has without doubt delayed the students' examination. However the long term benefit of being published in international journals (by our judgment) does justify this requirement. There are other lessons to be learned. Let's look at the investment as a whole. What opportunities have been opened up – and for whom? Teachers have been able to do research. Municipalities and schools have gained additional didactic and research competence that they can use in the development of schools. Universities have gained extended research resources (academically and economically). The hypothetical possibilities are undoubtedly good. The problem is that the needs of the different parties (individual, municipality, university) are not compatible. It is rather the opposite. It seems like the needs for one of the actors risks becoming a restriction for one or both of the others. When a teacher is given the opportunity to do research, the demands from her/his municipality, school, university and from the teacher her/himself are tangible and obvious. However the benefit of successful studies (or the burden to having failed) primarily concern the teacher her/himself. From the municipalities' point of view successful research studies leads to a probable risk of losing a competent teacher to the university. The universities are in most cases the winners as they gain economic resources as well as access to qualified researchers. There are however limitations regarding the amount of available positions also at universities. The lesson learned for future investments in teacher graduate schools could be formulated in the following way: the opportunities of the individual teacher must be accommodated within the same constraints that surround municipalities and universities. This means that the planning, organization and implementation of teacher graduate schools must be coordinated more carefully by all concerned parties and span over a longer period than previous initiatives and projects.

CURRENT SITUATION FOR THE TUFF STUDENTS

Today (2013) five of the twelve teacher graduate students within TUFF have completed their studies receiving a licentiate degree. Four of these five students are admitted for further graduate studies towards a 'full' PhD exam. The remaining seven students have partly or fully returned to their respective schools/employers. Some have been appointed to positions where they are responsible for developing technology education in their municipality. Others have been involved in occasional or more long-term assignments as guest lecturers at universities. They are all expected/expecting to complete their studies – some in the coming semester, others in coming years.

TEACHERS DOING RESEARCH: PROS AND CONS IN LITERATURE

As stated before, TUFF is an example of a larger trend towards teachers doing academic research. As remarked before, the idea behind that is that it might help reduce the gap between educational research and classroom practice. Let us first see what causes this gap. In the first place the fact that teachers traditionally only serve as the people who provide pupils and classes to the researchers but otherwise are not involved in the research creates a lack of commitment to using the outcomes. In the second place, many studies have research questions that are not relevant for teaching practice but only have theoretical meaning. In the third place, the experimental research set-up requires a control over the variables that normally is not available in a classroom situation and therefore artificial situations have to be created that hamper transfer of the outcomes to normal situations. In the fourth place, the outcomes are usually published for researchers and are unreadable for teachers.

The effect is that a lot of educational research remains unused in practice (Broekkamp and Van Hout-Wolters 2007). This complaint is heard for many school subjects. In technology education, research is relatively young, but also in this domain it is not easy to identify a research study that really had a substantial impact on teaching. Having teachers themselves become researchers is seen as a possible solution. Success, however, is not guaranteed due to a number of barriers. In the first place, teachers often are insufficiently qualified to do research at the level that is required to publish in academic journals. They may have had a course in research methodology during their teacher education, but that may be long ago. A second barrier is that their school environment does not have the infrastructure that is needed for doing research: often access to scientific literature is not present, there is no community of researchers that they can discuss with, and they lack resources like time and money, as research is not the primary goal of the school and therefore only little resources are dedicated to that. Methodologically, there is a danger that when a teacher investigates interventions in his/her own practice/school, there is insufficient objectivity. As a result the outcomes of many studies done by teachers in their own school are of insufficient quality (Vrijnsen-de Corte 2012): validity and/or reliability are insufficiently warranted, and generalizability is questionable.

Even when the outcomes are such that they cannot really be called ‘academic research’, the experience of doing research can still be a useful activity for teachers. It is a form of professional development that can make a teachers more motivated to continue teaching. After all, many teachers leave school before the normal retirement age because the treadmill of daily teaching practice has made them loose interest in school life. Doing research as a side-activity can refresh them and give them opportunities for innovating their own teaching practice. It would be more appropriate, however, to call this ‘professional development’ rather than ‘academic research by teachers’ (West 2011).

The remedy for this seems to be to create communities in which teachers work closely together with qualified researchers at universities. This is the basis for creating research schools like TUFF and FontD in Sweden and DuDoc in the Netherlands. By creating such communities the advantages of school teachers doing research can be harvested without suffering the barriers mentioned. This requires, of course, active involvement of both parties. Teachers need to commit themselves to not wasting precious academic research and time and academic supervisors need to commit themselves not to cause irritation with teachers and sloppy supervision by seeing this supervision as less important than their own research activities.

Research by teachers fits well with a trend towards new types of research that have more potential of applicability in practice. Action research, design-based research, and in general, practice-oriented research are quickly emerging in the research arena and teachers are in a good starting position for that (apart from the barriers mentioned above), as they have their own teaching practice directly at hand to be used a ‘experimentation garden’ (Cochran-Smith and Lytle 2009). In fact, one would expect that teachers, when becoming involved in research school like TUFF, FontD and DuDoc, would have a strong preference for those types of research, as they offer immediate possibilities for improving their teaching practice. The strange thing is that both in TUFF and in FontD this is not the case. This book reflects that, too. Many of the research topics have no direct practical relevance for teaching practice. One may wonder why teachers still opt for such a topic. No research has been done into that, but one could guess that this has to do with teachers’ perception of what academic research is. It may well be they the traditional image of research as something that has to be either on a macro-level or has to be in a rather artificial ‘scientific’ setting, and that almost by definition has to be large-scale and quantitative, dominates teachers’ perception of what they ought to choose as a research topic in order to make it Ph. D.-worthy. This is something that needs to be worked on in the future and hopefully the traditional image of research will erode once sound action research and design-based research Ph. D. studies by teachers become published and used in practice. What is also needed is more attention for research capabilities in the teacher education programs in those cases where this attention is still small. Of course, this will always remain a minor element in the whole teacher education program. Teacher educators can be frustrated by the fact that it is almost impossible to bring future teachers up to a level of ‘qualified researcher’ in the little time that is available for research courses. Maybe a different content for those courses may improve this. Normally, the student teachers are required to do a (small but still) full research study in the course of the program. It is extremely unlikely that this will result in any serious research study given the fact that it is the teachers’ first experience. Maybe a more fruitful approach would be to have the student teacher do a sort of ‘apprenticeship’ with a professional researcher in the program. That may have as a consequence that the student teachers is not actively involved in all phases of a research, but the experience (s)he gets with the limited part of the whole research study probably is much more in-depth. To compensate for the parts of the research process the student teachers has not been actively involved in, (s)he may be required to at least read about that and perhaps in his/her apprenticeship report writes about it to show that (s)he does have gained an understanding of the whole research process.

STRUCTURE OF THE BOOK

TUFF has resulted in a variety of thesis topics, all related to technology education. One of the interesting aspects of the TUFF program is that it combined philosophy of technology and technology education research. The philosophy of technology generates perspectives on the nature of technology that are very useful for developing education about technology. Section 1 of the book is dedicated to the philosophy of technology. The three papers in this section deal with the nature of technological knowledge and contain contributions from the field of philosophy of technology. Sven Ove Hansson introduces some aspects in the nature of technological knowledge that make this type of knowledge different from knowledge in science. Per Norström shows that explanation and prediction, as knowledge-related activities in technology, also have some distinctive features in the technological domain. One of the aspects of technological knowledge that make it special is the importance of knowledge representation in pictures. Being able to understand those is therefore an important element in technological knowledge. In the chapter by Anna Stenkvist this type of knowledge is investigated theoretically. Implications for technology education are also presented.

Section II is about technology education research at national level. Inga-Britt Skogh first introduces the development of technology education in the Swedish curriculum and some previous study about its practice. Edvard Nordlander and Maria Cortas Nordlander present a study into the Swedish National Testand the way it deals with problem solving, a core activity in technology, but also in other domains. Joachim Svärd investigated an inquiry-based national support system for teachers. This and the previous chapter show that national interventions may not always work out what they intended. In particular for a relatively vulnerable school subject like technology education this can cause all sorts of problems. Another educational concern at national level is the extent to which girls have equal opportunities with boys. This gender issue is the topic dealt with in Gunilla Rooke's chapter. Although Sweden has been very active in this respect traditionally, the chapter shows that still further action is needed.

Section III is about engineering education. The first chapter builds a bridge between the macro-level of Section II and the micro-level in the remainder of section III. Håkan Ahlblom studied the way students make choices between regional engineering education programs. Several factors influencing this choice were identified in the study and those can be used to promote engineering education. Patricia Kingdon focused on one such factor, namely the image that young people have of engineers. It is evident that unattractive images of engineers will distract people from a study in engineering and therefore creating an attractive image in technology education is of great importance. Equally important is to know what engineers and designers themselves think they do and what they have to learn in engineering education. This is investigated in Helena Isaksson Persson's contribution.

Having seen the national level (curriculum) perspective and the students' perspective, it is logical that we also looked for the teachers' perspective. This is what section IV is about. There are two papers in this section. The first, by Eva Hartell, describes teachers' perspectives on assessment in technology education. The outcomes show that assessment is still by no means unproblematic in technology education and a lot of opportunities for improvement remain still unused. The final chapter, by Lennart Rolandsson, is about teachers' beliefs regarding programming education, which deals with a particular technological skill and for that reason is often seen as part of technology education. The study, together with Kingdon's earlier text, is a nice example of how relevant it is to know the ideas pupils are teachers hold, as this can be used to tune educational intervention better to where people are mentally seen.

The whole set of chapters nicely illustrate the variety of technology education studies one can find nowadays. Some are more theoretical, others are more empirical; some are outspoken quantitative, others and very much qualitative and there are also mixed-method studies. Also the different perspectives of curriculum teachers and pupils are represented. The TUFF experience shows that a well-orchestrated effort to develop a collection of research studies in technology education with teachers as researchers can be successful. This is promising for the future of technology education. Research studies can be an important support for the development of a school subject that still is not reckoned with the traditional undisputed elements of the school curriculum. Such support is most welcome in that vulnerable situation. Educating future citizens in such a way that they have developed a sound technological literacy is well worth the effort of preserving technology education in the school curriculum in some form. Hopefully the TUFF project has made a contribution to that.

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SECTION I

PHILOSOPHY OF TECHNOLOGY

SVEN OVE HANSSON

2. WHAT IS TECHNOLOGICAL KNOWLEDGE?

INTRODUCTION

As usual, Joanne goes to work by bicycle. She is an engineer in a medium-sized company in the automatic control industry. The first thing she does after putting down her bag in her office is to make a pot of tea for herself and her closest colleagues. She pours four teaspoons of black tea into the pot, one for each person and one for the pot. After bringing a cup of tea to her own desk she begins the day's work. Her first task is to study a report from the company's laboratory. The technicians have tested the first prototype of a new thermostat that she has designed. Unfortunately the device did not respond rapidly enough to changes in temperature. In order to solve the problem she pulls out a couple of handbooks in thermodynamics from her bookshelf and starts to calculate the effects of several alternative designs.

In this short episode we find examples of four types of technological knowledge. The first is her ability to ride a bicycle. Most cyclists cannot tell how they keep balance on a bicycle (Jones, 1970). Such knowledge is called tacit. It has an important role in many types of craftsmanship and professional knowledge. Painters can seldom explain the hand movements by which they even out a surface much faster, and with much less spackling paste, than an amateur. The skilled lab nurse will find it equally difficult to explain to an inexperienced colleague how to take blood samples from patients with difficult veins.

When Joanne made tea she applied a traditional rule for measuring out tea leaves. Probably she does not know its background. She uses it because it works (gives suitably strong tea). This can be called practical rule knowledge. It differs from tacit knowledge in being expressible in words. She has in fact taught it to her five year old son (who is still not able to ride a bicycle). Joanne also makes abundant use of rule knowledge in her work as an engineer. When she designs a load-bearing part she always makes it strong enough to carry twice the intended load. This is a practical and reasonably simple way to ensure that her constructions do not break, but there is no theoretical ground for choosing 2 as a safety factor. (Doorn and Hansson, 2011).

When she studies the lab report she (and her colleagues in the laboratory) apply scientific methodology to investigate a technological object. This is technological science. Advanced engineering often proceeds in this way, i.e. technological constructions are investigated with scientific methodology. This means that the same methods are used as in the natural sciences to ensure a reliable result: control groups, randomization, blinding, control measurements, well-calibrated measurement

I.-B. Skogh & M.J. de Vries (Eds.), Technology Teachers as Researchers, 17–31.

instruments etc. But technological science differs from natural science in having man-made rather than natural objects of study.

Finally, when she applies thermodynamics to design a better thermostat she makes use of natural science to solve a technical problem. This is a type of problem solving that her education has made her well prepared for. Engineering education includes considerable amounts of natural science and training in its application to technological problems. But ten years ago, when working so hard with her course in thermodynamics, she had no idea that one day she would apply it almost on a daily basis.

FOUR TYPES OF TECHNOLOGICAL KNOWLEDGE

In summary we have four major types of technological knowledge: tacit knowledge, practical rule knowledge, technological science, and applied (natural or social) science. This is by no means the first attempt to classify technological knowledge; quite a few typologies and catalogues have already been published. (For an overview, see Houkes (2009, pp. 321–327) There are two major reasons why I have chosen to propose a new typology instead of applying one that is already available. One reason is that previous typologies have been based on mixtures of several criteria for the classification; some typologies contain both types defined in terms of what is known and types defined in terms of how something is known. The present proposal focuses on how we know, not on what we know. (I will return below to the possibility of combining these two crossing distinctions to obtain a more detailed typology.)

The other reason is that previous typologies did not seem to be well suited to educational needs. As we will soon see, the four types in this typology are acquired by different learning processes, which makes the typology relevant for studies of teaching and learning.

As shown in Figure 1, the four types can be linearly ordered in terms of how practical or theoretical they are. Tacit knowledge is decidedly non-theoretical. It is followed by practical rule knowledge that is somewhat more ”theoretical” since it is expressed in words. The two types of science represent more theoretical types of knowledge. Since technological science is focused on making things work, we can describe it as less theoretical than natural and social sciences that focus on explanations.

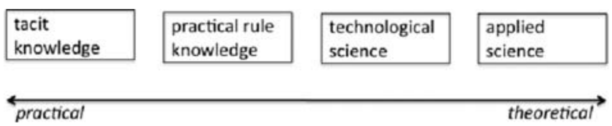

Figure 1. The four types of technological knowledge, ordered in the practical–theoretical dimension.

TACIT KNOWLEDGE

The expression ”tacit knowledge” is fairly new; it was introduced by the Hungarian-British chemist and philosopher of science Michael Polanyi (1891–1976). His book The Tacit Dimension from 1966 is still the starting-point of many discussions on tacit knowledge. However, his main interest was natural science rather than technology or technological science. He wanted to show that a strictly rule-bound road to scientific knowledge does not work; there is always an element of intuitive human judgement.

Today, technological knowledge is at the centre of the discipline of knowledge management that was established at the beginning of the 1990s. The Japanese researcher Ikujiro Nonaka (born in 1935) has had a leading role in applying Polanyi’s concept to practically oriented management and organization research. His main focus is on how tacit knowledge can be transferred from one person to another. There are two major methods for this. One is apprenticeship: the learner observes and tries to imitate someone who already possesses the tacit knowledge. In this way she can often herself develop the same type of tacit knowledge. The other method is based on prior articulation (externalization) of the tacit knowledge, i.e. it is described in words so that others can learn it more easily. (Nonaka and Takeuchi 1995. Nonaka and von Krogh 2009.)

Nonaka and his co-workers emphasized the latter method, the articulation of tacit knowledge in language. They provided a famous example of this: the development of the first bread-making machine for household use that was launched in 1987. (Nonaka och Takeuchi, 1995) The early prototypes did not produce bread of sufficient quality. In order to improve the machine, the designers had to find out how to knead a dough. Unfortunately this could not be learnt from books; it was tacit knowledge that one has to learn from a baker. To solve the problem a member of the design team apprenticed with a master baker at a luxury hotel. The baker was unable to tell her in words what to do, but she tried to imitate him and in this way she gradually learnt the right movements. Finally she managed to express what she had learnt in words: a “twisting stretch” was required. She and her colleagues in the design team managed to construct a machine that performed a twisting stretch and baked (sufficiently) good-tasting bread.

The articulation of tacit knowledge in the form of instructions and descriptions has been performed with at least three different purposes. The first of these is examplified by the bread-making machine: the mechanization and automatization of a work process. Since the industrial revolution, the articulation of tacit knowledge has been an important part of the mechanization of work tasks previously performed by craftspeople. Today, such articulation of tacit knowledge often takes the form of computer programming. The first step in programming is often to develop a detailed description of how a human expert performs a task. This description can then be codified into a computer programme.

The second purpose is to facilitate teaching and learning. Learning a craft or profession would be incredibly inefficient and time-consuming if every learner had to repeat the mistakes of her predecessors. Suppose that the tasks to be performed in the control room of a nuclear plant could only be learned in an intuitive, trial-and-error fashion. It would then be a much more precarious task to train a new generation of operators than if most of the knowledge they need is available in written form. The authors of textbooks for crafts and professions spend considerable efforts on articulating the tacit knowledge of experienced practitioners as far as possible.

The third purpose of articulating tacit knowledge is to control other people's work. Ever since the industrial revolution employers have systematically divided qualified tasks into simpler subtasks, most of which can be performed by cheaper labour. The extensive (tacit and explicit) knowledge of highly qualified workers has been codified and divided into small tasks that can more easily be taught and learnt. The assembly line is the most well-known example of this process. The American Frederick Taylor (1856–1915), the pioneer of the so-called scientific management movement, saw this dequalification of labour as a major purpose of new management practices. "All possible brain work should be removed from the shop and centered in the planning or laying-out department" (Taylor [1911], 2008, p. 50). But ever since the early days of the industrial revolution, critics, including Adam Smith (1776, V:i:ii) and Karl Marx (1867, I:12.5), have warned against the resulting deterioration of the quality of working life. (Cf.: Braverman, 1974; Campbell 1989, p. 226; Wood, 1982; Wood, 1987) However, it should be noted that this criticism has not been targeted at the articulation of tacit knowledge but at the use of this articulation to change the work process in ways contrary to the interests of workers.

On some occasions, tacit knowledge has been romanticized and described as a better type of knowledge that should be kept tacit rather than being articulated. In my view this is not a tenable position. We humans have developed language in order to convey insights, instructions, and other messages to each other. By articulating previously tacit knowledge we make it accessible to criticism, evaluation, and improvement. If physicians choose treatment methods intuitively (which previously was the ideal, cf. Wootton, 2006) it will be exceedingly difficult to evaluate and improve their treatments. In contrast, if they apply precisely described criteria for diagnosis and treatments, then such evaluation and improvement can be performed in a systematic fashion. Both tacit and explicit knowledge can be in error, but explicit knowledge is more easily corrigible since it is more accessible to critical discussion and evaluation.

In other words: Tacit knowledge that is valuable does not become less valuable when expressed in words. To the contrary, language is needed to transmit, evaluate, and improve knowledge. In some cases complete articulation may not be possible, but partial articulation may still be better than no articulation at all.

PRACTICAL RULE KNOWLEDGE

The second main form of technical knowledge is practical rule knowledge. Much technical knowledge is taught and learned in this form, not least in practical crafts. The practical knowledge of electricians is a good example of this. There are many rules for how to connect wire. Many of these rules have a theoretical justification, but in practical work the electrician does not refer to these justifications but to the rules that are based on them. There are for instance good reasons not use certain types of cable for tensions above 250 V, but the electrician applies the rules, not the underlying theory. Furthermore, many of these rules are based on a combination of theoretical justifications and convenient conventions. There are good reasons to use one and the same colour code for all earth wires, but the choice of green and yellow for that purpose is a convention that cannot be derived from physics.

Rules of this type are often called “rules of thumbs”. A major characteristic of such rules is that they are easy to memorize and apply. The term “rule of thumb” has been in use at least since the latter part of the 17th century. Its origin is unclear, but one plausible hypothesis is that it derives from the use of the thumb as a unit for length measurement. (At least since the seventeenth century an inch has also been called a “thumb’s breadth”. In many languages, including French, Spanish, Swedish and Dutch, the word for “inch” is derived from that for “thumb”.)

Although rules of thumb are used extensively in practical technical work, surprisingly little has been written about the ways in which they provide us with knowledge. Per Norström (2011) has recently compared rule of thumb knowledge with other forms of technological knowledge. He started out from his own experience as an engineer working with PID controllers (proportional–integral–derivative controllers) that are used to regulate the flow of liquids through pumps. On his former workplace there were two experts in the calibration of PID controllers, Paul and Nils. Both were highly skilled, but they worked in very different ways. Paul had remarkably accurate intuitions about the instruments, but he could never explain his intuitions or tell others how to calibrate an instrument. Nils performed the work with the help of mathematical calculations that he was happy to teach anyone who wanted to learn them, but that learning process would take some time. On one occasion when neither of them was available, Per had to step in and calibrate a PID regulator. Since he had neither Paul’s intuitions nor Nils’s skill in calculation methods he consulted a handbook. It contained a simple rule in the following style:

Set all parameters in zero position. Raise the Kp control until oscillation starts. Then lower the Kd control until the oscillations stop….

Thus, Per employed a rule of thumb that had the considerable advantage that it could be learnt quickly. But he was aware that if something unusual happened, or if he were confronted by another type of regulator, then the rule of thumb could not be trusted. Chances would be much higher that Nils could have solved such a situation with his calculations. Rules of thumb tend to have a much smaller area of application than scientific knowledge.

Rules of thumb can have different origins. Some of them are the result of articulation of tacit knowledge. Others have been obtained through simplification of scientific knowledge. In yet other cases they are based on a combination of scientific knowledge and experience-based safety margins. This applies for instance to many of the rules that are used in engineering design.

TECHNOLOGICAL USES OF SCIENCE

Technological science, in the limited sense in which I use this term here, is science that systematically investigates different technological solutions in order to find out their properties. Just as natural science, technological science employs experiments as a primary source of knowledge. In fact, technological experiments have a much longer tradition than experiments in natural science. They can be traced back to the experimental traditions that have been found among indigenous peoples. The Mende people in Sierra Leone even has a special word, "hungoo", for experiment. A hungoo can for instance consist in planting two seeds in adjacent rows, and then measuring the harvests in order to determine which seed was best. Hungoos are probably a native tradition, not one brought to the Mende by visiting Europeans. They are definitely technological experiments, not natural science experiments, since their purpose is to find out how to achieve certain practical ends, not to understand nature. Similar experiments also occur in other parts of the world. (Richards, 1989). Through the centuries, technological development has largely been driven by craftspeople systematically trying out different constructions and methods.

The experimental tradition among craftsmen was one of the major sources of modern scientific methodology. Galileo Galilei (1564–1642) and other scientific pioneers learned much from skilled workers on the art of extracting information from nature by manipulating it, i.e. making experiments (Drake, 1978; Zilsel, 1942). But from the very beginnings experiments in the natural sciences had another goal than technological experiments. Craftspeople made experiments in order to solve technical problems, natural scientists in order to find out the workings of nature.

The experimental tradition in the crafts continued to develop in parallel with natural science. In the 18th and 19th century millwrights performed advanced experiments and measurements, but they had little or no contact with the academic science of their times (Layton, 1978). It was not until the latter part of the 19th century that natural science was employed on a large scale to develop new technology. The chemical and electrotechnical industries were the pioneers in this new development. Important inventions such as the telegraph were the outcomes of discoveries in university laboratories. (Böhme, 1978; Kaiser, 1995.) But in some technological areas, technology development continued well into the 20th century to have little or no contact with natural science. This applied for instance to metallurgy; new methods were tried out and tested in ironworks, based on experience rather than on principles and ideas from the natural sciences (Knoedler, 1993).

In the 19th and early 20th century, schools of engineering fought to obtain the same status as universities. To prove their case they had to base their teaching of technology on a scientific basis. Two different strategies were adopted to achieve this. One was to use results from the natural sciences to investigate the workings of machines and other technological constructions. Formulas from mechanical science were used to characterize the movements of machine parts, and the theory of electromagnetism was applied in the construction of electric machines and appliances. New disciplines, such as structural mechanics, were developed that broadened the basis of this type of calculations. This development has intensified over the years. Today, new physics and chemistry give rise to more and more sophisticated technology. The technological use of biological science is increasingly common, and so is that of the social and behavioural sciences (for instance in the construction of entertainment technologies and human-machine interfaces).

The other strategy was to apply scientific method directly to technological constructions. Machines and machine parts were built, and measurements were made on alternative constructions in order to optimize their performance. (Faulkner 1994. Kaiser 1995.) In many cases, this was the only way to solve practical technological problems. (Hendricks et al, 2000) The processes studied in wind tunnels were usually too complex to allow for a mathematical solution. Direct testing of technological constructions has continued to be an essential part of scientific engineering. Without crash tests, automobile safety would have been much worse. Even when a construction is based on relatively simple, well-known principles, it has to be tested in practice. Endurance tests of furniture and household appliances are among the best-known examples of this.

These two traditions, technological science (in a strict sense) and applied natural science, are still alive and well at technological universities. Today few would deny that they are both needed and that they complement each other.

Even if we run technologies on a daily basis with tacit knowledge and/or practical rule knowledge, when something goes wrong we tend to turn for science for a solution. A scientific approach or at least a science-based understanding of mechanisms is often necessary in troubleshooting. An operator in the control room of an advanced technological system cannot respond adequately to unforeseen deviations unless her knowledge of the system goes far beyond practical rule knowledge.

CHARACTERISTICS OF TECHNOLOGICAL SCIENCE

Technological science is much less discussed than natural science, and it is often seen as a variant of natural science. In fact it differs from natural science in several important respects. These can be summarized in the form of six distinguishing characteristics of technological science. (Hansson, 2007)

First and perhaps most obviously, the technological sciences differ from most of the natural sciences in that their study objects have been constructed by humans, rather than being objects from nature. This is a basic difference, but a clarification and an exception have to be made.

The clarification is that this difference refers to the ultimate study objects of the respective disciplines. Natural scientists often study objects that have been modified for the purpose of measurement or experiment, but this is done only as a means to understand objects or phenomena that occur naturally. As one example of this, in order to determine the structure of a protein it is often useful to produce a crystallized form of it. Spectroscopic studies are then performed on the crystallized protein in order to determine its structure. Obviously, the crystallized protein is not a naturally occurring object but one that has been modified by humans. However, for the biochemist the crystallized protein is not the ultimate study object. It is studied in order to understand the structure and the workings of the naturally occurring protein. In contrast, the human constructions studied by technological scientists, such as machine parts and computer programs, are their ultimate study objects.

The exception is chemistry that differs from the other natural sciences in this respect. Most of the substances studied by chemists are not known to occur in nature.

The second characteristic is closely connected with the first one: The design of new technological objects is an essential component of engineering. Design is also an important part of the work of many academics in the technological sciences. Technological scientists do not only study human-made objects, they also construct them.

Again, a caveat concerning chemistry is needed: Synthetic chemistry is similar to the technological sciences in that it aims at the construction of new objects (in this case, new chemical substances). (Schummer, 1997) There is, however, an important difference between chemical synthesis and engineering design. Chemical synthesis is aimed at obtaining a substance with a specific, predetermined molecular structure. In contrast, engineers designing a new product work with a complex and often not fully explicit list of design specifications or goals. The ideal outcome of the design process would be a product that fully satisfies all the design goals. In practice, however, such an outcome is seldom achieved. Compromises and trade-offs between conflicting design criteria have to be made in the course of the design process. (Asimov 1974. Vincenti 1990. Vincenti 1992.)

Engineering design has an important role in the development of new experiments in the natural sciences. It is common for new experiments to depend crucially on the design and production of new experimental equipment. From this point of view, the natural sciences are in part based on the technological sciences, just as technology is in part based on the natural sciences. (Janich 1978. Kroes 1989. Lelas 1993.)

The third characteristic is that the study objects of technological science are largely defined in functional terms. In order to determine if an object is a screwdriver we have to determine whether it has the function of driving screws. Therefore, screwdrivers are a functional category. The same applies to object categories such as saws and diodes, ladders and lamps, refrigerators and particle accelerators. These are all functional categories. The functions that define these and other classes of technical objects serve as conceptual bridges between human intentions and the physical world. (Kroes and Meijers 2002. Hansson 2002. Hansson 2006. Vermaas and Houkes 2006. Kroes 2006,)

Again, an exception has to be made. There is one of the natural sciences, namely biology, in which functions have a central terminological role. Concepts such as fin, eye, gland, stem, flower, and food are all defined according to their functions for the organism. The major difference is of course that whereas technological functions have been intentionally assigned to objects, biological functions are our way to describe the outcomes of evolutionary processes.

The fourth characteristic is that the conceptual apparatus of the technological sciences contains a large number of value-laden notions. (Layton, 1988) Concepts abound that have a clear value component, such as “user friendly”, “environmental friendly”, “risk”, “safety”, and “disaster”. We have explicit technological norms in the form of written codes and standards that provide us with detailed specifications for a wide variety of technological products, practices, and procedures. Most importantly, evaluations of technological objects have a central role in technological science and research. We perform research in order to construct better bridges, cars, computers, computer programs, medical implants, etc. Contrary to natural scientists, technological scientists freely evaluate their study objects in value terms. In this respect they are close to medical scientists, who feel no need to make their science value-free by eliminating references to “better” treatments or “bad” developments of a disease. In this respect, technological science is also closer to the social than the natural sciences. Value-laden concepts such as “justice”, “welfare” etc. have a central role in several of the social science disciplines.

The fifth characteristic is that technological science has less room than the natural sciences for idealizations. In the natural sciences, far-reaching idealizations are made in order to isolate natural phenomena from each other. (McMullin, 1985) A physicist who studies electromagnetism uses models of electromagnetic phenomena in which gravitation is absent. Similarly, in studies of gravitation she will use models in which there are no electromagnetic forces. Often, scientific experiments are performed under specially constructed conditions that are tailored to suit such simplified models. Physical experiments are often performed in vacuum in order to correspond to theoretical models in which the impact of atmospheric pressure has been excluded. Chemical experiments are performed in gas phase in order to ensure that each pair of reacting molecules has no interaction with other molecules. This brings these experiments into closer correspondence to theoretical models of reaction mechanisms.

All this works well in the natural sciences, but it does not work for engineering. The physicist can use a theory of electromagnetism that does not take gravitation into account, but the engineer who constructs an electric motor for an elevator cannot disregard the effects of gravitation – unless the machine is intended for use in a space station. Similarly, theoretical mechanics does not take weather conditions into account. In the construction of a suspension bridge the same idealization can lead to disaster. (Layman, 1989)

The sixth and last characteristic concerns the attitude to mathematical problem-solving. Both in the natural and technological sciences, many problems refer to measurable quantities and require a mathematical solution. There is, however, an important difference in the very nature of the precision requirement. The precision that the engineer needs is always obtainable by means of a sufficiently good approximation. Thus, if the choice of wire dimensions for a suspension bridge depends on the solution of a complex system of equations, the engineer does not need an analytical solution of the system; if a solution has been obtained with a sufficient number of decimals the problem has been solved. In this she differs for instance from an astrophysicist or a population geneticist who needs to solve an equally complex system of equations. For the purposes of the natural sciences, an analytical solution is always preferred (although there are areas, such as quantum chemistry, in which it is seldom obtainable). This may partly be a matter of the aesthetic qualities of the solutions, but it is also a matter of their explanatory qualities. There is a good chance that the insights obtainable from an exact solution can contribute to the solution of other similar problems in the future.

TRANSFORMATIONS BETWEEN THE FOUR KNOWLEDGE TYPES

As already indicated, the four types of technological knowledge can be ordered linearly according to how practical or theoretical they are. This also makes it possible to systematize the different ways in which one type of knowledge can be transformed into another. This is illustrated in Figure 2.

We can divide knowledge transformations into two major groups depending on whether they transfer knowledge to a more theoretical type (a movement to the right in the diagram) or a more practical type (a movement to the left).

One type of transformation to more theoretical knowledge has already been mentioned, namely the articulation of tacit knowledge that then becomes practical rule knowledge (arrow 1 in the diagram). When a transformation in the theoretical direction results in (technological or applied) science, we can call it a scientification of knowledge. An explanation of bicycle riding in terms of physics is a case of scientification (arrow 2 in the diagram). Another example is the development of theories about heat engines into more general of thermodynamic theory (arrow 3 in the diagram).

Next, let us consider transformations in the other direction, i.e. to more practical knowledge. An important group of such transformations are those that result in tacit knowledge. It is usually practical rule knowledge that is starting-point for such a transformations. It can be called a routinization (arrow 4). One typical example is when a young car-driver learns to gear up or down without thinking of it. Another

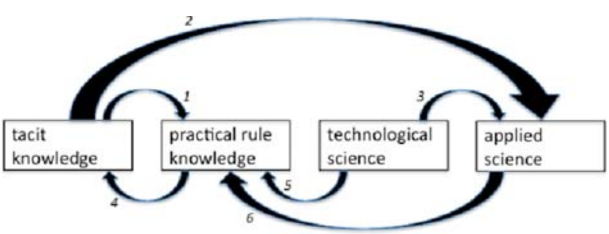

Figure 2. Transformations of technological knowledge: articulation (1), scientification (2 and 3), routinization (4) and application (5 and 6).

example of routinization is learning to play a musical instruments. In these and many other cases the routinization of practical rule knowledge is necessary to make us able to perform various tasks without too much delay or effort.

Other transformations in the theoretical-to-practical direction are those that result in practical rule knowledge or in technological science. These transformations can be described as the application of science. The rules of thumb that Per Norström used to calibrate a PID regulator must have originated in application of either technological or natural science (arrow 5 or 6).

LEARNING

The four knowledge types differ substantially in how easy or difficult they are to learn. This is schematically illustrated in Figure 3, where the thickness of arrows illustrates the ease with which the different knowledge types are learnt. It must be emphasized that actual learning processes are much more complex than the transfer of a piece of knowledge from teacher to student that is depicted in the diagram. The communication between student and teacher is almost always bidirectional, and communications with others than the teacher (such as fellow students) are often essential for the learning process. However, the diagram illustrates one central feature of learning, and one in which the four types of technological knowledge differ in important respects.

As indicated in the diagram, practical rule knowledge is by far the knowledge form that is easiest to learn. It is followed by technological and applied science. Learning science takes much more effort than learning rules of thumb. All these three can be taught by conventional methods in which verbal instructions and explanations have a central role. By far the most difficult type of knowledge to learn is tacit knowledge that cannot be taught by verbal instruction. As discussed above, tacit knowledge can be acquired through imitation attempts in apprenticeship, but in many cases that is a difficult and uncertain procedure.

Fortunately, there is an alternative way to learn tacit knowledge: In many cases it can be articulated to practical rule knowledge, which is then taught in the usual way in which verbal instruction has an essential role. This results in practical rule knowledge

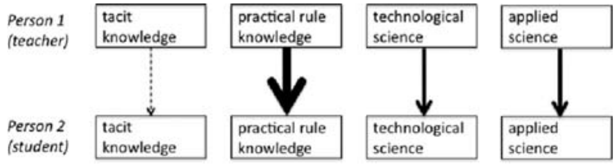

Figure 3. Schematic representation of direct learning processes for technological knowledge. The dashed arrow represents imitation whereas the solid arrows represent methods in which verbal instruction has an essential role. A thicker line denotes more efficient learning.

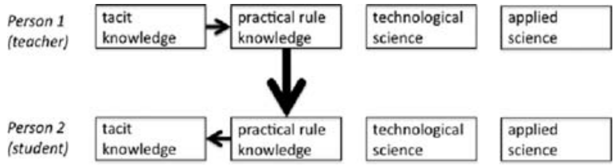

Figure 4. Schematic representation of an indirect learning process for tacit knowledge.

that can then finally be routinized through training. This three-step procedure for acquiring tacit knowledge is illustrated in another schematic diagram, Figure 4.

In summary we have five learning processes for technological knowledge:

- Tacit knowledge through imitation. (Leftmost arrow in figure 3.)
- Tacit knowledge through articulation, verbal instruction, and routinization. (Figure 4.)
- Practical rule knowledge through methods in which verbal instruction has an essential role. (Second arrow in figure 3.)
- Technological science through methods in which verbal instruction has an essential role. (Third arrow in figure 3.)
- Applied science through methods in which verbal instruction has an essential role. (Rightmost arrow in figure 3.)

A COMBINED CLASSIFICATION SCHEME

The fourfold classification of technological knowledge refers to how one knows, not to what one knows. Alternatively, we can classify technological knowledge according to its contents, i.e. to what one knows. Such a classification would have to contain categories such as: knowledge about how to construct an artefact, knowledge about how to use an artefact, knowledge about (and ability to explain) how an artefact works, etc. Table 1 gives an indication of how these two ways to classify technological knowledge can be combined. As the table illustrates, some knowledge contents can be known in different ways. It is proposed that this two-dimensional classification can be useful for practical teaching. You need to know what type of knowledge you want the student to acquire in order to determine how to teach. The reader is invited to add more rows to the column, illustrating different types of technological knowledge that students are required or encouraged to acquire.

DISCUSSION

In summary we have identified four major types of technological knowledge: tacit knowledge, practical rule knowledge, technological science and applied (natural and social) science. Technology educations differ in the relative emphasis that they

Table 1. Combined classification of technological knowledge, referring both to how the person knows and what she knows. "+" denotes appropriate, "(+)" partly appropriate and "–" inappropriate form of knowledge for the knowledge contents in question.

	Tacit knowledge	*Practical rule knowledge*	*Technological science*	*Applied science*
ability to ride a bicycle	+	–	–	–
ability to shift gears in a car	+	(+)	–	–
ability to construct a suspension bridge	–	+	+	(+)
ability to determine the aerodynamic properties of a new car model	–	–	+	(+)
ability to explain how one rides a bicycle	–	–	–	+

put on each of these knowledge forms. Education for practical crafts will usually put more emphasis on tacit knowledge and practical rule knowledge, whereas engineering education puts more emphasis on the two scientific knowledge forms. Basic technology education in compulsory schools should presumably aim at some sort of balance between the four in order to provide a basic understanding of how practical and theoretical knowledge is combined in technology. Within the limited time allotted to technology in most educational systems, this is no easy task.

One of the factors that complicate this task is the lack of technology teachers who are sufficiently acquainted with all four types of technological knowledge. In Sweden, the introduction of technology education in primary school led to a conflict between crafts (sloyd) teachers and physics teacher, who both wanted to teach the new subject. This was a clash between teaching professions that represent different types of technological knowledge. Crafts teachers represent both tacit knowledge and practical rule knowledge. Learning how to hit the nail and not your own fingers with the hammer is for the most part an acquisition of tacit knowledge. Learning which types of saw or knitting needles to use for different purposes is much facilitated by rules of thumb. Physics teachers, of course, represent natural science. A physics teacher is well equipped to teach students how the laws of physics can be used to understand and predict the behaviour of technological objects such as electric motors, binoculars, and pulleys. Neither crafts teachers nor physics teachers tend to be knowledgeable in technological science. And most importantly, neither of them has the education needed to teach how the four types of knowledge meet in technology.

But this is a difficulty that can be turned into a strength. Technology education can become a meeting place for different types of knowledge. It can be a place where students begin to understand the relationships between theoretical and practical knowledge. It can thereby also become a source of understanding and respect for the different types of knowledge that are needed to build a society. For this to succeed we need technology teachers with broad knowledge and understanding of both the theoretical and the practical forms of technological knowledge.

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