INTERNATIONAL TECHNOLOGY EDUCATION SERIES

Pre-university Engineering Education

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

SensePublishers

Pre-university Engineering Education

INTERNATIONAL TECHNOLOGY EDUCATION STUDIES

Volume 14

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.

Pre-university Engineering Education

Edited by

Marc J. de Vries
Delft University of Technology, The Netherlands and
KTH Royal Institute of Technology, Sweden

Lena Gumaelius
KTH Royal Institute of Technology, Sweden

and

Inga-Britt Skogh
KTH Royal Institute of Technology, Sweden

SENSE PUBLISHERS
ROTTERDAM/BOSTON/TAIPEI

A C.I.P. record for this book is available from the Library of Congress.

ISBN: 978-94-6300-619-4 (paperback)
ISBN: 978-94-6300-620-0 (hardback)
ISBN: 978-94-6300-621-7 (e-book)

Published by: Sense Publishers,
P.O. Box 21858,
3001 AW Rotterdam,
The Netherlands
https://www.sensepublishers.com/

All chapters in this book have undergone peer review

Printed on acid-free paper

TABLE OF CONTENTS

Preface vii

1. Pre-university Engineering Education: An Introduction 1
Marc J. de Vries, Lena Gumaelius and Inga-Britt Skogh

2. A Philosophical Basis for Pre-university Engineering Education 13
Marc J. de Vries

3. The Nature of Pre-university Engineering Education 27
Per Norström

4. Pre-university Engineering Education in Germany: Needs, Possibilities and Limits – A Description 47
Gabriele Graube and Ingelore Mammes

5. Characteristics of Pre-college Engineering Education in the United States 65
Greg Pearson

6. Engineering Education for Elementary Students 81
Christine M. Cunningham

7. Pre-university Engineering Education in New South Wales 101
Peter Thompson

8. "Are They Ready?": The Technical High School as a Preparation for Engineering Studies 121
Lars Bo Henriksen

9. PBL in the School System 141
Anette Kolmos

10. Access, Inclusion, and Heterogeneity in Pre-university Engineering Education 155
Andrea K. Agree, Anna E. Faloon and Johannes Strobel

11. Industry's Role in Pre-university Engineering Education: The UK Experience 179
David Barlex

12. Engineering Professional Societies and Pre-university Engineering Education 205
Elizabeth Parry, Pamela Lottero-Perdue and Stacy Klein-Gardner

13. The Role of Engineers in Pre-university Education: Success-Factors and Challenges 221
Anne-Lotte Masson, Tanja Klop, Patricia Osseweijer and Marc J. de Vries

14. Pre-university Engineering Education Research at a University of Technology: A Case Study of the Pre-university Engineering Initiatives at KTH 237
Lena Gumaelius and Inga-Britt Skogh

PREFACE

Pre-university engineering education has become the topic of increasing interest in technology education circles. It can provide content for the E in STEM (Science, Technology, Engineering and Mathematics) education, which is in the interest of technology educators at different educational levels as it builds the bridge between them and the science and mathematics educators. Given this growing interest it is not surprising that there is a need for publications that show how pre-university engineering education could be conceptually founded and practically given shape. The book *Engineering in Pre-College Settings*, edited by Purzer, Strobel and Cardella, was a first example of such a publication. This book, however, was strongly oriented on the USA situation. We saw the need for a book with a more international orientation.

This book is the result of a cooperation between two groups that have both teacher education and research in the field of STEM-related school subjects: the Department of Learning (DoL) at KTH, the Royal Institute of Technology in Stockholm, Sweden (the institute in which Lena Gumaelius and Inga-Britt Skogh work) and the Department of Science Education and Communication (SEC) at Delft University of Technology, the Netherlands (where Marc de Vries works). Both are groups that function in a university environments that mainly consist of engineering departments and engineering education programs and these groups take an interest in trying to use the expertise in their own environment to enrich technology education in schools with engineering elements. Given the context in which we educate teachers for schools and do educational research, to us pre-university engineering education is a 'natural' activity.

Once we had decided to work on this book, we approached a number of colleagues in different countries we knew were involved in the promotion and realisation of pre-university engineering education in their countries. To our great pleasure, they all immediately agreed to contribute to this book. We want to thank them for their interest in cooperating with us, and their willingness to write and re-write their texts for this book. We believe they have done excellent work and we are very pleased with the outcome.

We want to thank the publisher, in particular Peter de Liefde, for his agreement in having this book in Sense's International Technology Education Studies book series. Thanks also to other Sense colleagues who contributed to turning our manuscript into a book with a nice appearance.

We hope readers will find this book a source of inspiration for working on pre-university engineering education in their countries. At the moment it is still relatively in state of infancy, but there are several interesting initiatives, which we have tried to capture in this book. The coming years will show if pre-university engineering education will catch on. The trend towards STEM integrated education that today can be seen in many countries will certainly create a further need and stimulus for that to happen. Hopefully this book can contribute to such a development of both formal and informal K-12 engineering education. Not only for preparing the next generation of engineers, but also for the technological literacy of future citizens.

Lena Gumaelius, Inga-Britt Skogh & Marc J. de Vries
Stockholm/Delft, March 2016

MARC J. DE VRIES, LENA GUMAELIUS AND INGA-BRITT SKOGH

1. PRE-UNIVERSITY ENGINEERING EDUCATION

An Introduction

THE 'E' IN STEM: NEWCOMER AND CHALLENGE

Probably we would not know about pre-university (or K-12, in USA terms) engineering education if there had not been the discussion about STEM education. STEM is the acronym for Science, Technology, Engineering and Mathematics. The term started its existence as a rather political term in the mid-2000s. Politicians at a certain moment started calling for more people in STEM professions and more students in STEM disciplines. The term STEM education then began to stand for education that prepares for such professions and studies. In a way, that use of the term was not obvious. Only three of the four characters in the acronym were known. For many years already there had been science and mathematics education. Technology education was a relative newcomer as this has emancipated from crafts and industrial arts only since the 1980s and in some countries even later. But engineering education was pretty much non-existent in pre-university education (in 2008 Brophy, Klein, Portsmore & Rogers called it the 'missing E' and in 2014 Miaoulis still calls it the 'missing discipline'). Yet its reference to a professional domain seemed to justify its place in the acronym. STEM was not just chosen because it can be pronounced or because STM already stood for Scanning Tunnelling Microscope and Synchronous Transport Module. The E was seen as a necessary component in the combination of science, technology and mathematics.

The inclusion on the E in STEM did, however, raise questions. What is the difference between the T and the E? What is engineering education at pre-university level anyway? It can be imagined that such question did not really bother the politicians using the term STEM, but as soon as educators started reflecting on what STEM education might look like in practice, such questions did become meaningful and their answers were by no means obvious. Of course that question is not unique for the E in STEM. The S, T and M go through regular cycles of redefinition and reconfiguration. Currently we have the discussion on the Next Generation of Science Standards in the USA. The introduction of these Standards in educational practice will entail a rather drastic revision of science education with its new overarching themes and ways of thinking. As many people believe, it will present a much better and more realistic image of what scientists do (rather than just conveying the traditional canon of existing knowledge, as it happens in most of current science

M. J. de Vries et al. (Eds.), Pre-university Engineering Education, 1–12.

education practice, to the boredom of many pupils). A similar movement can be seen in mathematics education that for some years already is making a turn towards more context-oriented education in order to give pupils a much better impression of how the mathematical instruments are used to solve problems in other domains. It can be questioned if that does full justice to mathematics as a discipline in its own right, but at least it makes mathematics education more fun to pupils. The T also undergoes reformation, and its relative newness makes that necessary. The T still has to find its identity in the midst of the other domains. The early discussion on the philosophical basis for technology education has diminished but still some basic questions are not answered in a fully satisfactory way yet. But for the E there is no existing identity in pre-university education yet.

That would almost suggest that this book on pre-university engineering education is premature. But we think it is not. In the past decade a lot of effort has been put into developing the identity of pre-university engineering education and a practice that reflects that identity. Some caution is necessary here, as we also find slightly revised versions of technology education travelling now under the flag of pre-university engineering education. Particularly the lack of recognition for technology education creates a temptation to make technology education look more advanced by changing its name into ‘technology and engineering’ education. In the past a similar name change (in the USA: from Industrial Arts to Technology Education) for some time was in fact no more than a name change indeed. It took some time for a really new type of education to emerge. The extent to which this will happen with pre-university engineering education will depend on who will be involved. The involvement of the National Academy of Engineering (NAE) in the USA in the development of the Standards for Technological Literacy meant a substantial new momentum in the development of technology education. Fortunately the same Academy has shown an interest in pre-university engineering education, which gives rise to hope for that new type of education also. A review by the NAE has shown that there are already some initiatives to implement pre-university engineering education in the USA. In this book we have other examples of pre-university engineering being put into practice already at this moment. In that respect there is already now good reason to bring out this book. It shows that pre-university engineering education does not only exist in the head of politicians and educators or only on paper, but also in practice. Yet the discussions about what should be done and what not, and what works and what not, are in full swing now. In that situation a book that brings together the current ideas about such questions can be relevant for the further developments in this domain. Bringing out a book after all discussions have been settled can be useful as a documented reference, but bringing it out during these discussions means that it can serve as an input for those debates. With that in mind we present this book. In this introductory chapter we will briefly show what elements can be found in the current discussions, and what elements do not seem to be addressed yet. We will start with the basic question of the motives for having pre-university engineering education in the first place.

Our conviction that it was timely to bring out a book on pre-university engineering education even at this early stage, was enhanced when we took notice of the publication of the 2014 book *Engineering in pre-college settings*, that was edited by Purzer, Strobel, and Cardella. It is clear that this book has a strong USA-flavour and that there was still room for a more internationally-oriented book. Also we have included some issues that did not yet feature very strongly in the Purzer/Strobel/Cardella book. At the same time, we have tried as much as possible to avoid duplication. Therefore the books can best be read in combination.

WHY PRE-UNIVERSITY ENGINEERING EDUCATION?

The first motive for having pre-university education was already in the political origin of the term STEM in which the E featured as the newcomer. Pre-university engineering education can stimulate pupils to opt for a study and career in engineering. For that purpose it is necessary that pupils get to see what engineering is. In the traditional curriculum there is no subject in which the profession of engineering is portrayed. Even in current technology education, the focus is often so much on projects with a typical classroom character that the outside-world of engineering practice remains pretty much hidden from the pupils' view. Therefore a new impulse is needed, even if the E is integrated into technology education, as happens currently in much of the technology education developments. Not only is the practice of the engineering profession, but also the typical characteristics of engineering, as compared to technology, not really discussed. Some of these characteristics are:

- Engineering deals with the development of new products and processes, while in the term 'technology' also the user perspective is present (particularly in the term 'technological literacy');
- Engineering is a combination of qualitative and quantitative methods, while much of technology education is rather qualitative;
- Engineering design is highly methodical and structured, while much of design in technology education is rather intuitive;
- In engineering modelling plays a vital role and even though modelling is done in technology education practice, the nature of models and modelling are rarely made explicit;
- Social conditions are necessary considerations in engineering, while in technology education the projects are not embedded in a real-life social practice but have an 'internalistic' classroom character.

This means that if the E is to be integrated in technology education, it will have to mean quite something for technology education practice. Current practice is often way from these engineering characteristics and dramatic changes are needed to create a proper image of engineering in technology education. If the E is part of integrated STEM education, a learning area that does not consist of the individual subjects science, technology and mathematics, then the E can serve from the very start as a defining element in this learning area.

A second important motive for having pre-university engineering education is that it can contribute to technological literacy. A good understanding of how engineering changes our lifeworld and what implications that has for all of us, can be an important basis for our appreciation for technology, but also help us to be critical citizens that are well aware of the fact that all the devices around us are the outcome of a process of human decision making, not of logical necessity. Opening the black box of engineering can provide pupils an understanding of the importance of human and social aspects in the technological world in which we live. This, of course, has implications for the way engineering is presented. There is a temptation to present engineering as a fully rational and logical enterprise, while in fact there is more to it (see, for instance, the chapters by De Vries and Norström in this volume).

A third motive goes way beyond the previous two and relates to deeper and broader values of engineering education, namely their contribution to the general education and the 21st Century skills that currently are given a lot of attention. In their chapter in this volume, Graube and Mammes use the German term Bildung for that. Literally this term means ‘education’, but that term does not do justice to what Bildung really stands for. It is a typical Enlightenment term that refers to bringing people at a higher level of civilisation. In other words: Bildung makes better people: more creative, more communicative, more cooperative, more sensitive, more informed, more entrepreneurial and more of many other good characteristics. All these characteristics are needed for good engineering, and thus pre-university engineering crates a platform for developing those characteristics in pupils. This, of course, is a very idealistic image of what pre-university engineering education can do, and it certainly reminds us of the great promises with which the introduction of technology education was accompanied in the past and that later on appeared to be difficult to provide evidence for. One can easily shoot oneself in the foot by making such big promises. Yet, there is an element of truth in these claims that we cannot overlook. Engineering really is a very challenging activity that requires a broad spectrum of personal and social characteristics. In her chapter in this volume, Kolmos makes a plea for starting with this as early as possible. Young children are still malleable, compared to adult for whom it is often scary to come up with wild ideas and present these to others.

A fourth motive is directly related to the STEM context for pre-university engineering education. Engineering design can be a strong pedagogical strategy for teaching and learning science, technology and mathematics concepts and principles. Engineering is the activity in which all these concepts come together as necessary ingredients in the process of creating products and processes that work. Without a good understanding of the physics principles of sinking and floating, many boars that are designed by intuition will sink. Pupils who work with the intuitive notion that large objects sink and small ones float, will see their ideas falsified when turned into design principles for their boats. Learning how to design boats while simultaneously investigating the sinking and floating behaviour of prototype boats will cause a deep and versatile learning of these concepts and principles. At least, that is what we think now. This still have to be investigated in education research, but there are indications that under the right conditions and with the right behaviour by teachers it can work (see, for instance, Tran & Nathan, 2010).

These motives look sound in serving as a justification for having pre-university engineering education in the school curriculum. However, we must realise that at the moment they are mostly promises, not proven reality. That is why it is important to try out under which conditions these promises can be fulfilled. Education research is needed to support this.

SOME COUNTRIES DO IT ALREADY

A number of chapters in this book show that pre-university engineering education is already part of educational practice in some countries. In the state of New South Wales in Australia, there is even already some tradition in this (see the chapter by Thompson). In the USA there are even some impressive initiatives for pre-university engineering education in elementary education (see the chapter by Cunningham). Here realistic notions of engineering are developed, be it at a very basic level. Surveys in the USA show that also in secondary education, there are scattered initiatives (see Kaheti, Pearson, & Feder, 2009; Carr, Bennett, & Strobel, 2012; the two NAE reports in the reference list, and Pearson's chapter in this volume). Barlex in his contribution to this book describes examples from England. In the chapter by Hendriksen we get to see some of the Danish practice of pre-university engineering education. It is interesting to see that both in England and in Denmark a type of school was defined that specialises in pre-university engineering education. In the Netherlands, there is a similar development. Here the so-called Technasium has been defined as a new type of school with a science and engineering profile.

All these examples from practice show that pre-university engineering education is not a daydream, but something that can become reality. At the same time, the examples show that there is still a way to go in terms of the extent to which pre-university engineering education is a well-established part of educational practice, even in those countries where we find these early examples. Also it is clear that there is not always a clear STEM context and pre-university engineering education can be pretty isolated, a problem that can also be seen in technology education. This can put both technology and pre-university engineering education in a vulnerable position. Science and math are well-established components in the curriculum and the stronger the ties with these subjects, the better the newcomers are anchored in the curriculum. To this must be added immediately that this does not mean that technology education and pre-university engineering education can afford to give up their own identities in order to survive in a combined subject. This brings us to the next issue.

EMBEDDING IN THE SCHOOL CURRICULUM

There is a variety of ways in which pre-university engineering education can be embedded in the school curriculum. Probably the most far-reaching is to make engineering the core identity of the whole school. This is what happened in Denmark when the HTX school was initiated (see Hendriksen's chapter in this book). Previously in this chapter we mentioned the example of the Dutch Technasium schools. This of course gives engineering a great visibility. The other side of that coin is that only certain schools will have that privilege, because there is also a need for schools that have different profiles (economy and business, health and medicine, etcetera). If pre-university engineering education is left to the specialised schools, a lot of pupils will not get the dip into engineering as a contribution to the technological literacy that is needed in every profile.

Another, less drastic, option is to have a separate school subject in every school, as is the case in New South Wales, Australia (see Thompson's chapter in this book). That ensures that all pupils get the opportunity to get some experience in engineering. Particularly when this is a compulsory subject, it will be guaranteed that all pupils get that experience. That is probably not a realistic ideal, as generally speaking the curriculum is already overloaded in many countries and another compulsory subject will not easily be accepted. The danger of such a subject being an isolated item in the curriculum has already been noted earlier.

The next option is to integrate technology education and pre-university engineering education. That is a logical combination and it would make the position of technology education stronger. This is the approach that is taken in de USA. The International Technology Education Association (ITEA) has already changed its name into International Technology and Engineering Education Association (ITEEA). Given the close cooperation with the National Academy of Engineering in the development of the Standards for Technological Literacy, that seemed a logical next step. Often STEM is mentioned as the direct context for technology and engineering education in the USA (this can be seen from the programmes of the ITEEA Annual Conferences). Looking at many of the technology and engineering education projects closely, however, reveals that often the science and mathematics components in those are somewhat 'artificial'. Pupils probably recognise quickly that they are not really necessary for reaching a functioning design. This seems to be the great challenge for such projects: finding such design challenges in which trial-and-error is not enough to lead to a functioning device, but in which the use of science and math are necessary for success.

The next option is having pre-university engineering education in integrated STEM education. The challenge mentioned above holds for that option even stronger than for the 'technology and engineering education' option, as the whole idea of integrated STEM education is that all four components work together in a natural way. Also the M needs to be more than just doing some calculations, as this can hardly be claimed to be real mathematics. There are still many puzzles to be solved here, but at the same time it must be said that a lot of effort goes into this and there are already interesting examples of how this can be done. An immediate threat to the development of integrated STEM is that educators will be too eager to claim that they are doing it, while actually this is not the case, and thereby become uninterested in making further progress. Therefore a critical and fair assessment of STEM initiatives, in which critique is not seen as an insult but as a stimulus for improvement, is necessary if STEM is ever to become a success.

A PEDAGOGY FOR PRE-UNIVERSITY ENGINEERING EDUCATION

A new type of education calls for a new pedagogy. Not that it needs to be 100% new of course, but there is at least every reason to ask the question what particular pedagogical needs can be identified for that type of education. Even though pre-university engineering education may be closely related to technology education, for which many ideas about its pedagogy have already been developed, there is still a need to reflect on the pedagogy of pre-university engineering education, given its distinctive features (see the previous section on motives for pre-university engineering education). Some of the issues at stake here are present in this book.

In Norström's chapter, the author points out that education can never represent the full complexity of the professional practice. That holds for engineering also. Pre-university engineering education will have to present a simplified version of engineering reality. That raises the question what should be dropped and what should be kept? What should be 'smoothened' and what should be kept 'rough'? At the same time, there must be a fair attention for the variety within engineering so that different pupils can recognise different possibilities for themselves in engineering as a possible career. Some pupils will be attracted by the rigour and systemic approach of much of mechanical engineers, while other pupils may be attracted by the 'artistic' flavour of much of industrial design and architecture. The richness of engineering (as nicely represented in the Engineering is Elementary project; see the chapter by Cunningham in this book) should be done justice to in order to enable a variety of personalities find themselves attracted to it.

A second issue is concept learning in pre-university engineering education. This gives rise to the question what concepts are critical for engineering. Some research has been done into that (summarized in Pearson's contribution in this book), and one of the obvious candidates in the concept of 'systems' that pervades all engineering domains (even though not all engineers will use this term; architects probably will not, but still they will consider their house-in-design to be a coherent set of interacting parts that together fulfil a certain main function). In some approaches this concept can even become the core of the whole programme (see the systems approach that is mentioned as an option for pre-university engineering education in the chapter by Graube and Mammes). For STEM as a context of pre-university engineering education, it would be quite relevant to seek ways of using the engineering design experience to not only learn engineering concepts, but science and mathematics concepts as well (see also the earlier section on motives for pre-university engineering education).

A third pedagogical issue is the process through which knowledge and skills are developed. One that fits well with the nature of engineering is problem and project based learning (PBL). A separate chapter in this book (written by Kolmos) has been dedicated to PBL. Design-based learning (promoted by, e.g., Kolodner) can be seen as a variant of that. This process allows pupils to experience the design and problem solving nature of engineering at least to some extent, as can be seen in the HTX schools that Hendriksen describes in her chapter. It seems to be more appropriate than the lecturing approach that strangely enough is still much of academic engineering education practice. PBL allows for collaborative and authentic learning and the acquisition of situated and yet versatile knowledge and skills.

A fourth issue is inclusion, about which Agree, Faloon and Strobel write in their chapter. In the past this topic was often reduced to the gender issue, but Agree, Faloon and Strobel are right in showing that there is much more to it than that, important as it may be in itself. The richness of engineering can again be called to the fore for this. Engineering is not just for the high IQ pupils or for those with the best dexterity, or for those who can write or draw best. Being physically handicapped does not exclude from engineering as what one's brain can offer can well compensate for what the body cannot. The other way round this holds equally well.

This list is by no means exhaustive, but it covers most of the issues that are the most popular in current educational research for the STEM disciplines.

ACTORS IN PRE-UNIVERSITY ENGINEERING EDUCATION

In all educational practice, there are at least four types of actors: teachers, pupils, school boards and parents. Looking a bit wider, governments as a type of actor that creates conditions for educational practice become visible. In pre-university engineering education, there are some other types of actors, whose involvement is important for this education to represent the reality of engineering practice. Three of those are discussed in this book: professional associations for engineering (in the chapter by Parry, Lottero-Perdue & Klein-Gardner), industries (in the chapter by Barlex), and individual engineers (in the chapter by Masson). The value of each of those actors is not immediately given with their involvement in itself. Masson reports some experiences in which the involvement of engineers even worked counter-productive, as they appeared not to have the necessary skills do work with pupils. Also the value of industrial involvement can be dramatically reduced when industries abuse pre-university engineering education to promote themselves as a possible future employer. Also for professional associations it can be a temptation to present engineering as something in which one almost has to be interested because it is exclusively fun, exciting and socially relevant. A balanced picture of engineering should be sketched and the associations, industries and individual engineers have knowledge of the backside of engineering probably better than anyone else. On the other hand, they also can speak from their heart when showing that engineering can indeed be all those positive things if it fits with a pupil's interest and abilities.

EDUCATIONAL RESEARCH

All of the chapters in this book in some way or other draw from research studies and one of the chapters (by Gumaelius and Skogh) focuses on it, but there is certainly not a well-developed research agenda for pre-university engineering education. In the book on pre-college engineering education that was edited by Purzer, Strobel and Cardella, too, we find examples of research studies, but not a systematic collection of research efforts. Such an agenda probably could be derived from experiences in the other STEM disciplines (science, technology and mathematics educational research) as there seem to be a number of common topics in these research domains (such as concept learning, learning communities, classroom interaction and the like). Another source of inspiration can be engineering research. Like education sciences, engineering sciences aim at acquiring knowledge that can be used to design new practices. That communality makes it likely that a similar approach for both can work. In engineering sciences, there is already a more or less established way of doing research. Engineering scientists work in a design-based manner. They synthesise possible prototypes as possible design solutions and then systematically vary the properties of that prototype, thereby investigating the effects of those changes on the behaviour of the prototype. Thus they acquire two outcomes simultaneously: indications for optimising the design and knowledge about the relation between physical/structural properties of the design and the functioning of the design. In aircraft design such a strategy has been used to design aircraft and to develop the scientific field of aerodynamics. A similar approach can be used in educational research and this design-based approach has in fact already been suggested by others. Here the prototype is an educational intervention (a lesson series or course material, for instance). By systematically changing the properties of that intervention (duration and intensity of the teacher involvement, presentation of the activity, etcetera), contributions to theories about teaching and learning engineering content can be acquired and ways of developing and improving pre-university engineering education can be developed. As we are dealing with engineering also in the content of education, such an approach seems to fit with what the educators are used to anyway.

WHAT WE DO NOT HAVE YET

One issues stands out as obviously lacking in this book: teacher education. The reason why it does not feature here is simple: it was not possible to find sufficient material and an author to write a decent chapter about this issue. Even in the USA, where we find several initiatives to implement pre-university engineering education, teacher in-service education to prepare teachers for that is pretty much non-existing

(Kaheti, Pearon, & Feder 2009). In this introductory chapter we note this and make a few remarks about it.

It is clear that the implementation of pre-university engineering education has substantial consequences for teacher education. In the short run, teachers of existing subjects will have to be re-educated in order to enable them to implement good pre-university engineering education. In science and mathematics education we have already become accustomed to using the term 'Pedagogical Content Knowledge (PCK) to indicate the knowledge and skills that need to become personalized with teachers for teaching these subjects. For technology education there are some first ideas about that. For engineering education at the academic level, the term seems to be 'terra incognita' as yet. So for pre-university engineering education, ideas about the PCK that teachers need to acquire in teacher (re-)education need to be explored fully yet. Some elements that a priori seem to be relevant in that respect are:

- Knowledge and skills concerning the guidance of engineering design projects by pupils;
- Knowledge and skills in the teaching and learning of quantitative methods in engineering;
- Knowledge and skills in the teaching and learning of modelling, both in terms of the modelling-related concepts (abstraction, idealisation, relation between model and reality, functions of models, etcetera) and the process of modelling a practical situation;
- Knowledge and skills in dealing with human and social factors in engineering (e.g., teaching and learning how to transform user and social requirements into technical features).

There are studies that suggest that teachers can have quite distorted views on engineering (Yasar, Baker, Robenson-Kurpius, Krause, & Robert, 2006) and therefore re-education of teachers is not a luxury article but a necessary condition for good pre-university engineering education. Some teachers feel they can do it, but it is not always clear if they have good reasons to make that claim (Heynes, 2010). A promising approach would be to educate engineers to become teachers. They have a thorough understanding of the nature of engineering and in an ideal situation also a lot of experience with the professional practice of engineering, which puts them in an excellent position to become a pre-university engineering education teacher. They would, of course, need to acquire the pedagogical knowledge and PCK to become fully equipped teachers.

CONCLUDING REMARKS

We have seen that pre-university engineering education is a domain that deserves our best efforts as it potentially is an important contribution to the education of future citizens and engineers. Also we have seen that first experiences have been gained that are promising and call for more. Some elements need further reflection, such as teacher education and research. This book shows the state of affairs in current thinking and practice. We close this chapter by showing the storyline in this book:

- We start with some theoretical chapters on the nature of engineering and (pre-university) engineering education (De Vries and Norström).
- The next two chapters discuss the rationale for pre-university engineering education (Pearson and Graube/Mammes).
- Then a number of chapters follow that describe some current practices (Cunningham on primary education in the USA, Thompson in New South Wales, Australia, and Hendriksen on Denmark; in a later chapter Barlex describes examples from England).
- The next two chapters deal with two important pedagogical issues: inclusion (Agree, Faloon and Strobel) and PBL (Kolmos).
- Three chapters describe the role of three types of actors in pre-university engineering education (industry in the chapter by Barlex, professional associations in the chapter by Parry, Lottero-Perdue and Klein-Gardiner, and individual engineers in the chapter by Masson).
- Finally the chapter by Gumaelius and Skogh shows the importance of educational research for pre-university engineering education.

There is still a long way to go for pre-university engineering education, but the content of this book shows that also a path has been trodden already. First experiences have been gained and theoretical ideas have been developed. The future of pre-university engineering education will depend on the extent to which we will be able to get a more solid research basis for doing what we do and to reach a more sustainable position in the curriculum. But engineers see no problems; they see challenges. That is the right attitude for education, too. What we aim at is important enough to put the best of our efforts into it. In the words of science communicator Neil deGrasse Tyson: "To make any future that we dreamt up real requires creative scientists, engineers, and technologists to make it happen. If people are not within your midst who dream about tomorrow – with the capacity to bring tomorrow into the present – then the country might as well just recede back into the cave because that's where we're headed." This implies having education that delivers such scientists, engineers and technologists, and STEM education with a solid E in it is the best candidate for that.

REFERENCES

Brophy, S., Klein, S., Portsmore, M., & Rogers, C. (2008). Advancing engineering education in P-12 classrooms. *Journal of Engineering Education, 97*(3), 369–387.

Carr, R. L., Bennett, L. D., & Strobel, J. (2012). Engineering in the K-12 STEM Standards of the U.S. States: An analysis of presence and extent. *Journal of Engineering Education, 101*(1), 1–26.

Committee on Public Understanding of Engineering Messages. (2008). *Changing the conversation: Messages for improving public understanding of engineering.* Washington, DC: National Academies Press.

Committee on Standards for K-12 Engineering Education. (2010). *Standards for K-12 engineering education?*. Washington, DC: National Academies Press.
Heynes, M. M. (2010). Middle-school teachers' understanding and teaching of the engineering design process: A look at subject matter and pedagogical content knowledge. *International Journal of Technology and Design Education, 22*(3), 345–360.
Katehi, L., Pearson, G., & Feder, M. (2009). *Engineering in K-12 education: Understanding the status and improving the prospects.* Washington, DC: National Academies Press.
Miaoulis, I. (2014). K-12 Engineering: The missing core discipline. In S. Purzer, J. Strobel, & M. E. Cardella (Eds.), *Engineering in pre-college settings: Synthesizing research, policy, and practices* (pp. 21–34). West Lafayatte, IN: Purdue University Press.
Tran, N. A., & Nathan, M. J. (2010). Pre-college engineering studies: An investigation of the relationship between pre-college engineering studies and student achievement in science and mathematics. *Journal of Engineering Education, 99*(2), 143–157.
Yasar, S., Baker, D., Robinson-Kurpius, S., Krause, S., & Roberts, C. (2006). Development of a survey to assess K-12 teachers' perceptions of engineers and familiarity with teaching design, engineering and technology. *Journal of Engineering Education, 95*(3), 205–216.

Marc J. de Vries
Delft University of Technology/Royal Institute of Technology
The Netherlands/Sweden

Lena Gumaelius
Royal Institute of Technology
Sweden

Inga-Britt Skogh
Royal Institute of Technology
Sweden

MARC J. DE VRIES

2. A PHILOSOPHICAL BASIS FOR PRE-UNIVERSITY ENGINEERING EDUCATION

INTRODUCTION

In this book, two chapters provide philosophical reflections on pre-university engineering education. In this chapter the focus will be on engineering. In the chapter by Per Norström the focus will be on education about engineering. Norström's chapter has a summary of philosophical efforts to define and conceptualise engineering. In my chapter I will give the full account for this (yet leave out some issues that Norström's chapter has). I will start with a short discussion on terminology: how does engineering differ from related terms, such as technology and engineering science? Then I will discuss the five main domains of philosophical inquiry concerning engineering one by one: the nature of reality in which engineering operates, the relation between engineering and (natural) science, the nature of engineering knowledge, the engineering design process and values in engineering (engineering ethics). I will finish with some concluding remarks on the value of philosophy of engineering for pre-university engineering education.

PHILOSOPHY OF ENGINEERING: A LATECOMER

The history of philosophy of engineering is shorter than the history of philosophy of technology. The latter emerged in the late 1950s when social concern about the impact of engineering on society and the natural environment arose. Philosophers like Jacques Ellul (France) and Martin Heidegger (Germany) started writing with great concern about the way technological developments gained a seemingly autonomous dynamics (Ellul, 1964; Heidegger, 1977). Many people felt 'imprisoned' in technological developments as it seemed that no control was possible any more that could set boundaries to the rapidly growing amount of technological devices in society, both in private and professional life. As a consequence, the focus of the upcoming discipline of philosophy of technology was entirely on the effects of technology on humans and society. Often this was accompanied by a tendency to talk and write about technology and extremely generalising terms. The term 'technology' was used without any feeling for the variety of different technologies and the threat of being controlled by technology was associated with all technologies. No distinction was made between the electrification of society, the 'informatisation' of society, the increasing urbanisation, the strongly increasing possibilities to manipulate (human)

M. J. de Vries et al. (Eds.), Pre-university Engineering Education, 13–25.

life, or any other specific technological development. The autonomous control nature was ascribed to 'technology' in general. Only in the Marxist view this autonomous nature was regarded as positive, as it was expected to bring about the desired change in social structure and to lead to a society dominated by the working class. But for other ideologies, the autonomous nature of technology meant a threat to the dignity and safety of humans.

In this atmosphere there was no fertile ground for philosophical reflection on the nature of engineering 'from the inside', i.e., for seeking out how exactly technological developments can be characterised with a more empirically informed basis. This would come much later, in the 1980s, when philosophers with also an engineering (or science) background started reflecting on the nature of specific technologies and used historical and sociological studies as a starting point for their philosophical reflections rather than the more theoretical control or systems view that had been so popular before. This so-called 'empirical turn' in the philosophy of technology later, in the 2000s, raised also an interest in reflecting more on engineering. The new dimension was that philosophers from then on were not only interested in differences between the impacts of different technologies (as empirically studied in the historical and sociological writings), but also in the nature of engineering as the discipline in which technologies were developed and produced.

One of the elements in the philosophy of technology on which this had an impact, was on the way the relation between engineering and science was perceived. Until then there was a generally felt discomfort with the traditional view of technology as 'applied science', but it was not quite clear how technology was different from applied science. By delving deeper into the nature of engineering and engineering knowledge, a much better nuanced view on the relation between science and engineering emerged. Another development was the new interest in the nature of engineering sciences. It became evident that the philosophy of science was mainly based on reflections concerning the nature of natural sciences. Only later the philosophy of human and social sciences developed and the engineering sciences were in fact the last type of sciences to be studied in the philosophy of science (and of course in the philosophy of technology/engineering). One could ask why it took so long to start philosophising on engineering and engineering sciences. Probably this has to do with the fact that the natural sciences for a long time were seen as the model for all knowledge-developing activities in society. In fact, this bias can still be recognised in current popularisations of science. It does not do justice to the fact that different sciences have different natures and that there are other non-science activities that can yield equally reliable and valuable knowledge than scientific knowledge. The knowledge of experienced technicians is an example of that.

TERMINOLOGY

Let us now turn to the issues of the often confusing use of terms in the debates about technological developments. I will suggest how to use the terms 'technique', 'technical', 'technician', 'technology', 'engineering' and 'engineering science' in a way that offers a clear distinction between those terms. I hasten to add that there is a certain 'hopelessness' in this, because in popular literature like newspapers and television programmes, the distinctions I suggest are not made and terms will remain to be used randomly. Nevertheless, for the purpose of getting a clear view on what this book is about, it makes sense to reflect on terminology. Let me add also that the editors have strived for consistency in terminology in this book, but there is no guarantee that exceptions to the rules will be found. A loose use of terminology is so much part and parcel of the way we communicate about technological developments that a simple paragraph in a book will have no substantial impact on this word use at all. We have to be realistic here in our ambitions.

Let me start with 'technology' because I would like to suggest this to be the term with the broadest content. Technology is the human activity that aims at changing the environment to serve human and social needs. In order to do so, knowledge is used and developed and natural and artificial resources are used. New products and processes are designed, made, used and assessed. This activity involves the involvement of engineers, consumers, technicians, industries, governments and other social actors. It is part of culture and the human effort to develop expressions of values such as languages, economies, art, and religion.

The terms 'technique', 'technical' and 'technician' refer to the experience-based part of technology, in contrast to the part that involves more abstract knowledge. A 'technique' is a way of doing things that has been learnt by doing it often or by copying someone else's behaviour. Note that the term 'technique' also applies to ways of acting outside technology. An experienced piano player also has a certain 'technique'. A technician is someone who makes or repairs artefacts on the basis of experience or copying from an experienced person. 'Technical' is the adjective that relates to these non-theoretical ways of acting in technology.

The term 'engineering' is used for that part of technology in which artefacts and processes are designed and manufactured. The user part of 'technology' is not included in the term 'engineering'. A further narrowing down of the term is that it is not every type of designed and manufacturing but one in which the use of theory and models is crucial. A third characteristic of 'engineering' as compared to 'technology' is that is involves professionals, not lay people. Technology can also involve creative individuals who invent practical things and make them, but who do not do that as a profession. Those people are not 'engineers' strictly speaking.

Finally we have the term 'engineering sciences'. That term refers to activities that aim at developing knowledge primarily, as compared to engineering which aims at developing and making products and artefacts by professionals and based on more or less abstract knowledge. The engineering sciences develop knowledge that goes beyond individual artefacts and processes, which is characteristic for all sciences. Later we will see that engineering sciences are more restrictive in generalising than many other sciences, but they will always entail some degree of generalisation. Often the term 'engineering' is taken in a broad sense, whereby also what here we called 'engineering sciences' are included. It can make sense, though, to have different terms for the practical activity of developing and producing artefacts and processes in the way engineers to that and for the theoretical activity of developing knowledge to be used by engineers.

This account works reasonably for the English language. There are important differences with other languages. I will only discuss European languages here, as I am insufficiently acquainted with other languages. In several European languages the difference between words similar to 'technique' and 'technology' is not as in English. 'Technik' in German, 'technique' in French and 'Techniek' in Dutch are mostly used in the way 'technology' is used in English: it is the activity of changing the environment for practical purposes. The word 'technologie' (common for French, German and Dutch) is the study of that activity. This is a literal use of the '-logy' part of 'technology', as the Greek word 'logos' means 'word' or 'study of knowledge of something'. In English we use that in words like bio-logy, psycho-logy, socio-logy, and musico-logy. So it is a theoretical reflection of the practical activity of Technik/technique/techiek. It is almost like a kind of science. This European use of the word 'technology' is confused by the fact that there are also terms equivalent to 'engineering sciences' (Ingenieurswissenschaften in German, sciences d'ingénieur in French and ingenieurswetenschappen in Dutch). But still a distinction can be made when we take 'technology' (in the European equivalents) to be any theoretical reflection on the practical activity and 'engineering sciences' (in the European equivalents) to be the professional activity that involves developing knowledge of a scientific nature that directly serves the practice of engineering.

In this book we are in fact dealing with engineering and engineering sciences. We have only used the term 'engineering' in the title for practical reasons ('tongue-in-cheek', we could say that our own names would not fit on the book cover if we would use the proper full terminology) and also because many readers will take 'engineering' to include 'engineering sciences' anyway.

ENGINEERING ONTOLOGY

Ontology is the philosophical sub-domain that deals with different ways of 'being'. Elsewhere I have written about the dual nature of artefact perspective that entails two different ways of being inherent in every technical artefact: a physical/structural one and a functional one (de Vries, 2005). The two are different in that one cannot be derived from the other. The physical nature is inherent in the artefact and the functional nature is of a relational kind (there must be a relation with a designer or user in order for an artefact to have a function; see also Vermaas & Garbacz, 2009). The functional nature makes the artefact inherently normative, both at type and token level (Franssen, 2009). But here I want to focus on a different aspect on engineering ontology, namely the nature of reality in which engineering takes place. In fact, this is an extension of the dual nature approach. It is an extension in that one can claim that a technical artefact has multiple ways of being (that can be 'summarised' in two, as in the dual nature approach). One can say that technical artefact exists in many ways of being: a numerical one, a spatial one, a physical/chemical one, a biotic one, a psychic one, etcetera. Stated differently: a technical artefact is a numerical thing, a spatial thing, a physical/chemical thing, a biotic thing, a psychic thing, etcetera. The Dutch philosopher Herman Dooyeweerd has elaborated this idea into even fifteen different ways of being (Verkerk, Hoogland, Van der Stoep and De Vries [2016] have applied this to engineering). That number, of course, may not be entirely arbitrary, but neither it is fixed. One could say it strikes a balance between a very simple approach (like the dual nature perspective) and a very complex one (in which perhaps even a thousand different ways of being are distinguished; see also Simons' (2009) plea for a broad ontology in engineering). Table 1 shows the fifteen ways of being in the Dooyeweerdian approach. Not that the artefact is acting itself in all these ways of being. Let us take a bridge as an example. It is numerical in that it has a number of component. It is active in this way of being in that it has this number of components itself, but it can also be the object of someone counting this number. It is a spatial thing because it has a certain span, for A to B. It is active in that it itself takes space. As a biotic thing, it does not live itself, but it may be in contact with living beings (maybe algae growing on it). In fact, in all other ways of being, it can only be the object of someone else's actions (it can be bought, but not buy itself; it can be found beautiful, but not find beautiful itself; it can be the object of legislation but not make laws itself, etcetera). This way of seeing a technical artefact is very important for engineers and more and more engineering education reflects this view. If it is true that any technical artefact exists in all these different ways, engineers have to take that into account when designing and making this artefact. The list of requirements will have to reflect this. It must be designed to have an optimal number of parts (not too few so that each of them becomes very complex to make, but also not too many so that the assembly process becomes too complicated). It must be designed to be long enough to reach from border A to B. As for the physical aspect: it has to be designed so that it will not be too heavy and the engineers also have to take into account the forces that work on it (gravity, cars that cross it, the wind, etcetera). It will have to be able to 'survive' what living beings do to it (the algae growing on it) and it should not to harm to living beings that use it (for instance, it should be safe for pedestrians to hold the bridge while walking on it). Likewise, it should be not too expensive, in accordance with legislation, look nice and … look trustworthy (the 'trust' aspect).

This can make the list of requirement very complicated and therefore it is useful to look for ways of establishing priorities in this list. One can do so by observing the most important functions of the bridge. The most basic function for a bridge is that it connects the two borders (the spatial aspect). If this is no in order, one can hardly speak of a bridge. The second most important function can be called the 'qualifying' function: what is the ultimate aim for having the bridge? This depends. The bridge that was built to connect the former villages Buda and Pest has connected two communities that together are now called Budapest. Clearly, this bridge is qualified

Table 1. The fifteen ways of being according to Herman Dooyeweerd

Way of being	*Application to artefacts*
1. Numerical	Artefacts have a certain number of parts.
2. Spatial	Artefacts occupy a certain space.
3. Kinematical	Artefacts can move or be moved.
4. Physical	Artefacts can interact by mechanical cause-effect relations.
5. Biotic	Some artefacts live or are a part of other living beings' environment.
6. Psychic/sensitive	People can observe artefacts.
7. Logical/analytical	People can reason about artefacts.
8. Cultural/developmental	People develop artefacts.
9. Symbolic/linguistic	People represent artefacts by names or other symbolic representations.
10. Social	People can share artefacts.
11. Economic	People can sell artefacts.
12. Aesthetic	People can appreciate artefacts for their beauty.
13. Juridical	People can make laws in which artefacts feature.
14. Ethical	People can assess artefacts from an ethical point of view.
15. Trust/faith	People can trust artefacts.

by its social function. But one can also think of a bridge that connects a railway station and an industrial area. That bridge will be used primarily by commuters to get from and to their work. This bridge is economically qualified. A bridge can also be aesthetically qualified. In that case, it ultimate reason for existing is to be admired as a piece of art. In the Netherlands, near Schiphol airport, there are three small bridges designed by the famous Spanish architect Calatrava. They make an insignificant contribution to the traffic flow around Schiphol, but that is not what they are for anyway.

As this view on reality and its consequences for engineering is already becoming more and more accepted in academic engineering education in that it has led to an increasing number of interdisciplinary courses in which students have to take into account many aspects of reality in their project work, its seems logical that also in pre-university engineering education this perspective is used.

ENGINEEERING AND SCIENCE

The whole idea of having pre-university engineering education in the school curriculum often feature in the context of STEM education: the combination or even integration of education in science (physics, chemistry and biology, either as separate subjects or integrated), technology, engineering and mathematics. In the NAE's first report on K-12 engineering education, the use of knowledge from (natural) science was seen as one of the characteristics of engineering design, as distinguishing that from more intuitive design as often practiced in technology education.

Given that context, the relation between engineering and science as seen by philosophers of engineering is of course something one definitely wants to be informed about. Much has already been written about the old ‘technology as applied science’ paradigm being no longer seen as an appropriate perspective on technology (see, a.o., Radder, 2009 and Norström’s chapter in this book), I want to focus here on some recent, more sophisticate ideas about the engineering-science relation. Let me first remark that ‘science’ here means” natural science. From the ontology section it can be derived that there can be relations between engineering and all sciences, as each of those deals with a different aspect of reality and all those aspects are relevant for engineering. Here we look at the relation with natural sciences specifically. Others have written extensively about the mutual influences between natural sciences and engineering in that natural sciences deliver knowledge that can support (not determine!) engineering design processes, and that engineers provide instruments and data processing equipment for natural scientists. Less has been written about the comparison between engineering sciences and natural sciences. One of the most striking features is the extent to which these sciences claim possibilities for generalizing what has been found from experiments and other empirical experiences (like designing and making artefacts). Natural sciences, generally speaking, aim for the highest possible degree of generalization. The ‘holy grail’ is a ‘grand theory of everything’ that, according to Stephen Hawkins would enable us to know the ‘mind of God’. John Horgan called it ‘the end of science’ and although others denied that, it is clear that natural scientists would see this as a very fundamental piece of their discipline. This is different for engineering science. Engineers feel that the abstraction and idealisation that are needed to reach such a general theory would make the theory less relevant and useful for engineering design. Walther Vincenti in his book What Engineers Know and How They Know It showed that engineers in designing aircraft had problems applying general theories in thermodynamics and developed a sort of ‘in between’ concept (control volume) that engineers found more useful than the abstract concepts in thermodynamics as natural science had developed. Elsewhere I wrote about different types of generalisation in engineering sciences and showed that the extent to which engineers are interested in generalizing is more modest than that of natural scientists. Engineering sciences are somewhere in the middle of the nomothetic (sciences striving for general ‘laws’ or universals) to ideographic sciences (sciences striving for descriptions of specific ‘facts’ or particulars) spectrum. Probably that is one of the reasons engineering sciences are often seen as ‘less scientific’ than natural sciences.

An important shared activity in engineering and natural sciences is modelling. There is now a small, but growing body of philosophical literature about modelling in engineering sciences. Here, too, we can see the normative dimension of engineering theories in that models in engineering can have the function of showing how the design will have to be in certain respects. For instance, a system diagram for an artefact that is yet to be designed has this normative function: it shows what sub-systems will have to be realised with what sub-functions. This normativity is not present in models in natural sciences (see also Boon and Knuuttila 2009, who write about models in engineering not just representing a reality, but serving as epistemic tools to reflect on a not-yet-existing reality).

ENGINEERING KNOWLEDGE

A 'classic' book about knowledge in engineering is Walther Vincenti's *What Engineers Know and How They Know It*. This book is quoted often and I will not repeat its content again here. Some important points that are raised by Vincenti are:

- Only certain types of engineering knowledge can be derived from scientific knowledge;
- Many types of engineering knowledge are based on direct experience in designing and making artefacts (see also Floridi, 2011);
- Some engineering knowledge types are normative (for instance knowledge of requirements; knowledge of ways to tackle a design problem effectively; see also Houkes, 2009).

The normativity in engineering knowledge leads to a few further characteristics (Meijers & De Vries, 2009):

- Engineering knowledge can be context-dependent, as in one situation a norm can make perfect sense, while in another situation a different norm works better;
- Engineering knowledge that is normative can arise out of agreement rather than empirical evidence because norms are also a matter of agreement. Another way of stating that is that engineering knowledge can be acceptance-based rather than belief-based (as in 'classic' epistemology knowledge is assumed to be). Of course norms are not randomly chosen but can be empirically tested for effectiveness and in that sense all engineering theories can be said to have 'truth value' in some sense (Lipton, 2010).

Another feature of much of engineering knowledge is that it is of a 'knowing-how' character. That means that it cannot be represented by propositions. An experienced engineer knows how to tackle a design problem by experience, but (s)he cannot express that in a sequence of steps that make visible the decisions that (s)he takes implicitly in such a process. This knowledge often does not come from science but from experience, by designing or making things (Floridi, 2011).

All these features illustrate that engineering knowledge can be of a different nature than knowledge in natural science. In natural science there are norms *for* knowledge but not norms *in* knowledge. In natural science, knowledge must be context-independent. In natural science, agreement among scientists is needed to reach new knowledge, but this agreement is based on empirical evidence. The discussion can only be about the solidity of the evidence, not about the content of the knowledge.

ENGINEERING DESIGN

A lot has been written about model flowcharts for design processes. The sense and nonsense of such schemes is a matter of continuing debate and in Norström's chapter in this book there is a more extensive reflection on that. In any case it seems wise to take into account that such schemes are a generalisation and that each individual design situation may have specific needs that require at least adaptation of the scheme to make it fit with the particular situation. Less has been written about the same sort of fitting that is necessary to use design methods, such as Quality Function Deployment, Design for Manufacturing and morphological charts. Each of these methods assume the user of the method to have certain knowledge (for instance, QFD assumes knowledge of what customers want and what technical features are than can be fitted to these needs; see de Vries, 2009).

Much less has been written about the types of reasoning that are used in design processes. To discuss these, I want to relate to John Gero's model for design in which he distinguishes between function, structure and two types of behaviour namely expected behaviour and behaviour derived from structure (Gero, 1990). In fact, his 'expected behaviour' can also be called 'behaviour derived from function' to show its meaning even more clearly. To get from one element in Gero's scheme to another requires two types of reasoning. One is what engineering has in common with natural sciences: cause-effect reasoning: if this happens, then that will (necessarily) happen. That type of reasoning can be used to derive behaviour from structure. If a part of an artefact is round, it will roll when put on an inclined surface. The other type of reasoning is: means-ends reasoning: if I need this, then I can take that to accomplish it. If I need an artefact to roll on an inclined surface, I can take a round part to reach that goal. Note that there is no necessity here: I can also make the surface almost frictionless and that will probably also work. Logically the two types of reasoning are not the same. One is called deduction (the cause-effect type) and the other is called abduction (the means-ends type). Deduction is truth-preserving (if all premises are true, the conclusion is true by necessity), abduction is not. There is a third type of reasoning called induction, which is also not truth-preserving. Induction is the type of reasoning that is used in science to get from individual observations to a general claim about reality (for instance, from measurements of volume and pressure for a gas in a box to Boyle's law for gases). Such a reasoning is also used in engineering sciences, when engineers want to learn from one particular design experience for next design challenges. There is also a difference between theoretical and practical reasoning that is very much related to this. Theoretical reasoning ends in a claim about reality. For instance, when I reason from one design experience to a theory that could hold for similar (future) experiences. Practical reasoning ends in a directive about what to do (Hughes, 2009). Here again we have normativity involved (what *should* I do when I want to reach a certain goal?).

So far we have been speaking of normativity primarily in terms of functional normativity. But normativity goes wider: it also entails moral normativity. That takes us to the next sub-domain: engineering ethics.

ENGINEERING ETHICS

It is tempting to think of engineering ethics as just a type of applied ethics. In that perspective developing engineering ethics is just a matter of applying the classic approaches of virtue ethics, duty ethics, consequentionalist ethics and combinations of those to the domain of engineering. This, however, is too simple to be true. In order to see this, we first have to make a distinction between analytical ethics and normative ethics. In analytical ethics we analyse the specific characteristics of engineering ethics and identify a number of issues that are specific for engineering. In normative ethics we seek answers to the question of what is morally right and what is morally wrong, and then the classical approaches come in, but the values that we use in those approaches are specific for engineering.

In analytical ethics of engineering there is firstly the issue of the blurring of boundaries between categories that we traditionally use to distinguish between right and wrong. Technologies often have the effect of causing such blurring. For instance, the distinction that we make between natural and artificial is blurred by new technologies in which we can imitate nature so perfectly that the difference between natural and artificial is invisible. We used that distinction to differentiate between right and wrong. This is, by the way, an example where our appreciation has shifted in time. In the pre-WWII period, we tended to think that artificial was better than natural, as the artificial was more controllable than the natural. Margarine was better than natural butter because we could determine exactly what was in it. Now we tend to think the opposite. Bio-products are seen as good because they are more natural than what comes out of the factory. In a similar way the distinction between humans and machines is blurring. The extreme of this is the cyborg, but less extreme versions of this are already among us: persons whose bodies are filled with artificial limbs and organs. The connections between human body parts and machines become more and more intimate. We can even connect a computer directly to a human brain or connect the brain with a wheelchair. We used the human-machine distinction for valuing both: human life was more protect-worthy than artificial life. But how to appreciate the Cyborg then? A third boundary that gets blurred is that between healthy and sick. With the new possibilities to make direct DNA analyses with little blood by using lab-on-chip technologies, we move towards a new sort of position in between being healthy and being sick, namely the position of being permanently potentially ill. We used to think that healthy was better than sick, but how to appreciate this new status of being permanently potentially ill? Engineers have to think about this when developing these new technologies and such considerations will determine the fate of their products in society.

Another issue in analytical ethics that is raised by new technologies is the moral status of artefacts. That used to be fairly unproblematic in the past as artefacts were seen as not having the ability to make decisions and therefore there moral status was purely passive. Now we have technologies that do have the possibility of making decisions (that is, it looks as if they have that). The traffic light decides for us when it is right to pass the crossing and when it is wrong to do so. In that case the technology can be said to be 'persuasive' but it cannot force us to obey. It is, however, not so difficult to extend that to a higher moral status. It is not difficult to build a car that has a sensor that measure the alcohol percentage in our breath and will block the engine from starting when it is too high. Apparently as a society we do not want this (yet?). We tend to think that this responsibility should be with the driver, not with the car. But the debate whether or not we want to give a moral decision power to the technology is one that has emerged particularly in our time, as we can make artefacts that are more and more sophisticated. Engineers will have to decide what decisions to put into the artefacts and what decisions to leave to the users.

Finally there is the issue of engineering being a very complex matter in which it is very difficult to identify who is responsible for what. The example of the Challenger accident illustrates that. It was extremely difficult to analyse whose decision was the ultimate cause of the accident. It was an entanglement of different actors and different responsibilities. This 'collective' responsibility is part and parcel in most contemporary developments and makes it very difficult to get clarity about who should be hold responsible in case of negative effects of technologies. The normative practice approach (see Van Burken & De Vries, 2012; Harandi, Nia, & De Vries, 2015) can be used to make such analyses, but even more important, to reflect on how rights and responsibilities can be defined so that there are no clashes between interests and actions.

In the normative engineering ethics, we deal with values that have in principle always existed, but can be threatened so much by new technologies that they receive more and more public attention: privacy, risk and safety (Hansson has written extensively about this; see for instance Hansson, 2009), sustainability and human dignity. The latter is particularly important in medical technologies when humans almost become like machines that need repair (rather than living beings that need care). In engineering ethics considerations concerning such values can be included in what is often called 'value-sensitive design' (van de Poel, 2009). This means that engineers include such values explicitly in the requirements for the new artefact.

CONCLUDING REMARKS

In this chapter some recent insights in the philosophy of engineering have been described. Although this sub-domain in the philosophy of technology is fairly recent, there is a lot of development going on in it. More and more the term 'engineering' features in the titles of books in the Springer series titled: *Philosophy of Engineering* *and Technology* (for instance in volume 20 and 21 on Engineering Education and volume 22 on Engineering Ethics). Philosophy of engineering can help us recognize what it means to have ‘engineering’ as the content of teaching. This is particularly relevant when we want to see what makes pre-university engineering education distinct within the wider domain of technology education. This can lead to certain characteristics of pre-university engineering education, such as in Pearson’s chapter in this book. It is important that curriculum developers, teachers and teacher educators take the outcomes of philosophy iof engineering into account when constructing and realizing pre-university engineering education if we really want that education to represent engineering in a fair way. It seems that pupils in upper secondary education already have a reasonable idea of the main features of engineering (Koycu & De Vries, 2015), but we also know that in lower secondary education there are often distorted views on technology (De Vries, 2005) and for engineering it will be no better. There is a real challenge in giving pupils an opportunity of getting some experience with engineering, maybe not in its full complexity (see Norström’s chapter in this book), but certainly with its most important characteristics well represented. The importance of engineering for the technological society in which we live makes that effort absolutely worthwhile.

REFERENCES

Boon, M., & Knuuttila, T. (2009). Models as epistemic tools in engineering. In A. W. M. Meijers (Ed.), *Philosophy of technology and engineering sciences* (pp. 693–726). Amsterdam: North Holland.

de Vries, M. J. (2005). *Teaching about technology. An introduction to the philosophy of technology for non-philosophers*. Dordrecht, The Netherlands: Springer.

de Vries, M. J. (2009). Translating customer requirements into technical specifications. In A. W. M. Meijers (Ed.), *Philosophy of technology and engineering sciences* (pp. 489–512). Amsterdam: North Holland (Elsevier).

Ellul, J. (1964). *The technological society* (John Wilkinson, Trans.). New York, NY: Knopf.

Floridi, L. (2011). Constructionism, the maker’s knowledge tradition and knowledge engineering. In The Royal Academy of Engineering (Ed.), *Philosophy of engineering. Volume 2 of the proceedings of a series of seminars held at the Royal Academy* (pp. 26–31). London: The Royal Academy.

Fransen, M. (2009). Artefacts and normativity. In A. W. M. Meijers (Ed.), *Philosophy of technology and engineering sciences* (pp. 923–952). Amsterdam: North Holland (Elsevier).

Gero, J. S. (1990). Design prototypes: A knowledge representation schema for design. *AI Magazine*, *11*(4), 26–36.

Hansson, S.-O. (2009). Risk and safety in technology. In A. W. M. Meijers (Ed.), *Philosophy of technology and engineering sciences* (pp. 1069–1102). Amsterdam: North Holland (Elsevier).

Harandi, M. F., Nia, M. G., & de Vries, M. J. (2015). Water management: Sacrificing normative practice subverting the traditions of water apportionment—Whose justice? Which rationality? *Science and Engineering Ethics*, *21*(5), 1241–1269.

Heidegger, M. (1977). The question concerning technology. In M. Heidegger (Ed.), *The question concerning technology and other essays* (pp. 3–35). New York, NY: Harper & Row.

Houkes, W. (2009). The nature of technological knowledge. In A. W. M. Meijers (Ed.), *Philosophy of technology and engineering sciences* (pp. 309–350). Amsterdam: North Holland (Elsevier).

Hughes, J. (2009). Practical reasoning and engineering. In A. W. M. Meijers (Ed.), *Philosophy of technology and engineering sciences* (pp. 375–403). Amsterdam: North Holland (Elsevier).

Koycu, U., & de Vries, M. J. (2015). What preconceptions and attitudes about engineering are revalent amongst upper secondary school pupils? An international study. *International Journal of Technology and Design Education*, *26*(2), 243–258.

Kroes, P. (2009). Foundational issues in engineering design. In A. W. M. Meijers (Ed.), *Philosophy of technology and engineering sciences* (pp. 513–542). Amsterdam: North Holland (Elsevier).

Lipton, P. (2010). Engineering and truth. In The Royal Academy of Engineering (Ed.), *Philosophy of engineering. Volume 1 of the proceedings of a series of seminars held at the Royal Academy* (pp. 7–13). London: The Royal Academy.

Meijers, A. W. M., & de Vries, M. J. (2009). Technological knowledge. In J. K. Berg Olson, S. A. Pedersen, & V. F. Hendricks (Eds.), *A companion to the philosophy of technology* (pp. 70–74). Chichester, UK: Wiley-Blackwell.

Radder, H. (2009). Science, technology and the science-technology relationship. In A. W. M. Meijers (Ed.), *Philosophy of technology and engineering sciences* (pp. 65–92). Amsterdam: North Holland (Elsevier).

Simons, P. (2011). Ontology in engineering. In The Royal Academy of Engineering (Ed.), *Philosophy of Engineering. Volume 2 of the proceedings of a series of seminars held at the Royal Academy* (pp. 21–25). London: The Royal Academy.

van Burken, C. G., & de Vries, M. J. (2012). Extending the theory of normative practices: An application to two cases of networked military operations. *Philosophia Reformata, 77*(2), 135–154.

van de Poel, I. (2009). Values in engineering design. In A. W. M. Meijers (Ed.), *Philosophy of technology and engineering sciences* (pp. 973–1006). Amsterdam: North Holland (Elsevier).

Verkerk, M. J., Hoogland, J., van der Stoep, J., & Vries, M. J. (2016). *Philosophy of technology. An introduction for technology and business students*. New York, NY: Routledge.

Vermaas, P., & Garbacz, P. (2009). Functional decomposition and merology in engineering. In A. W. M. Meijers (Ed.), *Philosophy of technology and engineering sciences* (pp. 235–272). Amsterdam: North Holland (Elsevier).

Vincenti, W. G. (1990). *What engineers know and how they know it*. Baltimore, MD: Johns Hopkins University Press.

Marc J. de Vries
Delft University of Technology/Royal Institute of Technology
The Netherlands/Sweden

PER NORSTRÖM

3. THE NATURE OF PRE-UNIVERSITY ENGINEERING EDUCATION

INTRODUCTION

The nature of pre-university engineering education is a complex expression, as both ‘nature’ and ‘engineering’ are controversial terms. In this context, *nature* means something like an essence, a purpose, and a set of defining (or at least typical) characteristics. For a subject in school, its nature can largely be captured by answering the following questions: *What* should pupils learn? *Why* should they learn it? *How* should the education be organised for the learning to take place?

This chapter is based mainly on curricula and policy documents. Therefore, the ‘how’ question is not as prominent as the other two. ‘How’ is a matter of method, and is in most cases solved by individual teachers, teacher educators, and textbook authors rather than on the curriculum level. That said, there are strong implications and implicit recommendations in numerous curricula and policy documents, as will be seen later, and some examples from textbooks and research about teaching practice have been taken into account.

Engineering concerns the design and manufacture of technical artefacts, and the term is mainly used when professional engineers are involved (see Marc de Vries’ chapter in this book). Details about its core characteristics, as well as its delimitation from other human activities have been discussed by philosophers, sociologists, and historians of technology during the last decades, and no definition that is generally agreed upon in every detail exists. It is a broad concept, and the contents of pre-university engineering education can thus vary considerably.

Koen (1985, p. 10) described ‘the engineering method’ as ‘the strategy for causing the best change in a poorly understood or uncertain situation within the available resources.’ This ties in well with the experiences of many engineers: the customer or client commonly has vague or even incorrect ideas about what the problem is and/or what needs to be done. Therefore, the first phase of the engineer’s work often consists of figuring this out and it often needs to be re-negotiated during the work process (e.g. Vinck, 2003). Another important aspect of Koen’s definition is ‘the best change’. What constitutes ‘the best change’ is clearly context dependent. Best for whom? What is best for the customer is not always best for the engineer. What is best for the operator is not necessarily what is best for maintenance personnel. There are many possible solutions to a given engineering problem—for a problem of sufficient complexity and/or generality there are incredibly many. The engineer must

M. J. de Vries et al. (Eds.), Pre-university Engineering Education, 27–46.

strive to find the solution that causes the 'best change' given all kinds of restrictions: functional, temporal, economical, aesthetical, legal, etc. Therefore, engineering cannot be merely a problem solving activity, but also one of decision-making (Kroes, 2012; Vermaas et al., 2011).

Engineering activities and engineering skills are about (or are closely related to) creation and creativity. The quality of an engineering design process depends on its result (product or process) and the amount of resources (economical, temporal, material, …) that were used. This is commonly referred to as its *effectiveness* and its *efficiency* (Franssen & Bucciarelli, 2004; Kroes, 2012). To move a large stone by dragging it on the ground can be an effective method. So can moving it by putting it on a cart. But using the cart is more efficient as it demands less force, less time, and fewer people involved. As part of an engineering process, using the cart would therefore in most cases be regarded as a superior method.

Compared with 'nature' and 'engineering', 'pre-university … education' is fairly easy to decipher. By education we mean activities and processes intended to aid learning, mainly in schools and similar institutions. In this article, we limit it to schools. 'Pre-university' means simply that it takes place before university, and may prepare for university. Trying to apply this to a wide range of countries can be difficult, as the role of universities varies slightly. What is studied at university level in one country can be studied at a polytechnic or *Fachhochschule* in another. For the purpose of this article, those differences are not really interesting. The main focus is compulsory schooling attended by children and adolescents until their late teens, guided by a prescriptive curriculum laid down by some state authority or similar body.

The Engineering Design Process

At the heart of engineering is the engineering design process (also known as the product development process)—the process of creating a product that can be of use or causing the 'best change' (Koen, 1985) by implementing the 'intended function, economics of operation or safety to life and property' (as put by ECPD, 1947). Throughout the years, there have been numerous attempts to describe such processes and to prescribe how they should take place. A typical, classical model of an engineering design process looks something like the one in Figure 1. This type of process can be found in many engineering textbooks. The contents are general, the design processes tend to look almost the same no matter if they are about software engineering, electronics design, or mechanical engineering.

The process starts with some kind of demand or wish. From these wishes, a requirement specification is designed; the wishes and needs are formalised as a list of evaluable requirements. Based on this list, a few conceptual design solutions are produced. The suggested design solutions are evaluated and the best one is picked. The best solution is implemented in a prototype that is tested, and modified if

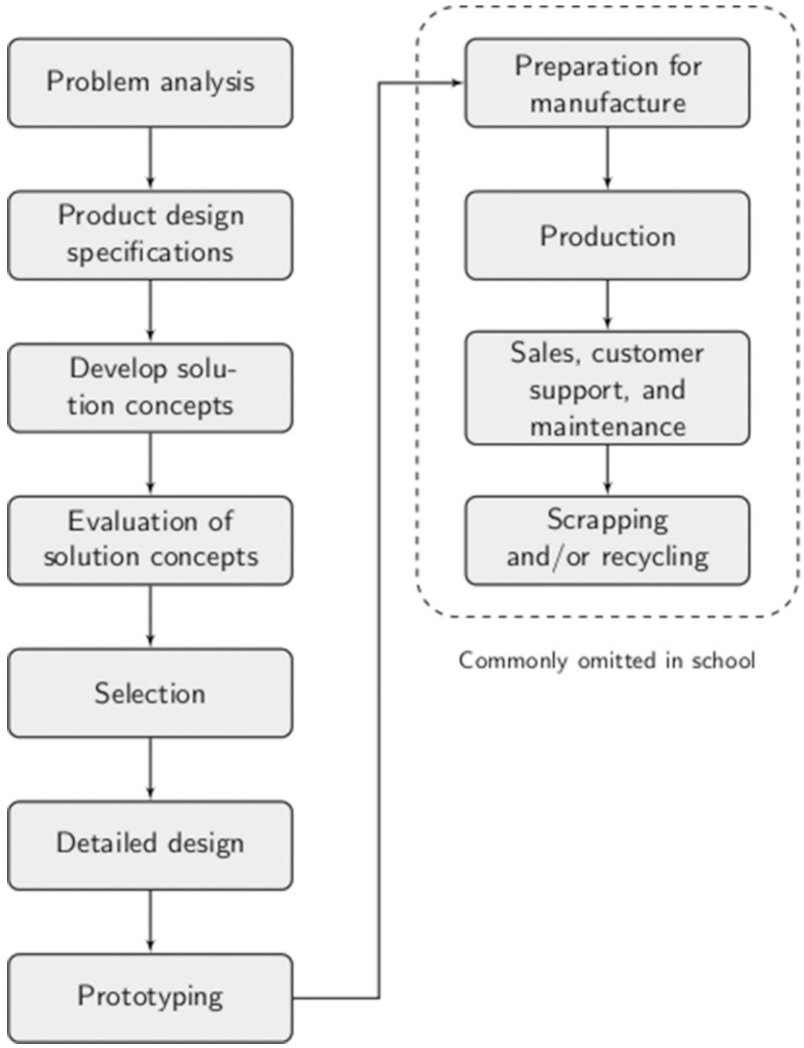

Figure 1. Block chart of a linear engineering design process. Similar charts can be found in hundreds of books and articles, e.g. Denayer et al. (2003). School engineering projects commonly end with prototyping

necessary. Based on the prototype, the final product is designed, and manufacturing can start. After manufacturing and delivery, the product enters a phase of service and maintenance, and when worn out it has to be recycled or scrapped in an environmentally friendly way.

This kind of naïve descriptions of an idealised engineering design process fits well with a functionally organised company. The marketing department collects needs and wishes from existing and potential customers and leave them to a senior design engineer. The senior design engineer writes the specification and leaves it to the junior design engineers. They produce drawings, circuit diagrams or similar documents which they leave to the manufacturing unit. And so on. After having done one's duty, the product is never seen again. Somewhat jokingly, it has been called 'over the wall engineering'—when you have finished your part you throw it over the wall to the next in line and never see or hear about it again (Eppinger et al., 1994). It is a linear process from wish or need, via design, manufacturing and use, to recycling. You never turn back.

That these idealised models do not always work perfectly is well known. If a designer is not an expert in manufacturing methods s/he can accidently design a product that is not feasible to produce, for example. In those cases, the smooth, linear model of development must be modified and another iteration of the design phase be allowed. It can also happen that customers change their preferences during the months or years that pass while the product is developed. If there is no way to change the requirements during the process, the company will end up with unwanted products. Because of reasons like these, there have been strong objections to the linear model of engineering design, and especially since the 1990s many alternatives have been suggested. One such category of design models are called *concurrent engineering*, and use multi-disciplinary teams so that e.g. manufacturability and maintainability can be built into the design already from the beginning (Eppinger et al., 1994). Another group of design process models are called *agile methods*. They were first used in software development projects and are characterised by customers' taking part in the project all the way through, many deliveries of functioning sub-systems, and flexibility concerning the change of requirements and design specifications. Well-known examples include *Extreme programming* and *Scrum*.[1]

Non-linear development models are used efficiently and effectively by many different companies active in different engineering areas. In some branches it is however not feasible to do it as there are rules and regulations prohibiting it. One obvious example is pharmaceutical products, which have to be designed, tested, produced, and documented according to strictly regulated procedures (Tobin & Walsh, 2008).

So, even though there are similarities concerning how engineering design takes place—it includes phases and activities such as prototyping, testing, formalising requirements, etc.—there are also great differences. It could well be argued that the differences are so great that we should not speak of *The Design Process*, but rather of a multitude of similar (but not identical) processes.

Summing up:

- Engineering is about creating or modifying products and processes according to somebody's (typically a manager's or a customer's) wishes.
- Engineering is a problem solving activity
- Engineering is a decision making activity
- The engineering design process …
  - can vary considerably between companies, branches, and technological domains
  - includes typical phases—prototyping, testing, formalising requirements—that are common to most (or all) technological domains
  - can be linear
  - can be iterative
  - can be organised with active customers and many partial deliveries
  - can be structured for maximum effectiveness and efficiency
  - can be structured according to branch-specific rules and regulations
- The quality of an engineering design process, method, or piece of knowledge is determined primarily by its effectiveness and its efficiency: Did it lead to a useful result? (*Was it effective?*) How much resources were spent while doing it? (*Was it efficient?*)

PRE-UNIVERSITY ENGINEERING EDUCATION

Pre-university engineering education covers a broad range of activities and learning objects: from young children building models from cardboard and clay to teenagers making calculations for how to balance an amplifier circuit; from craft-like skills to elementary engineering science; from designing for aesthetics to designing for advanced functions.

Where to Find the Engineering Education

Through scrutiny of curricula and policy documents from various countries, it is easy to find engineering elements, i.e. teaching and learning of skills related to engineering and the engineering design process. They seldom make up a subject on their own; *engineering* is not a common subject. Instead, the engineering elements form parts of other subjects, subject strands, or learning areas, e.g. *technology* (Sweden, New Zealand), *sloyd* [*crafts*] (Finland), *design and technology* (England, Scotland), *science and technology* (Northern Ireland), *science and technology/engineering* (Massachusetts), *science* (in *The Next Generation Science Standards*, 2013).

The reasons for this are often historical. The emphasis on engineering in school came up to speed in the 1990s, and as school systems are different the new contents were introduced in different ways. Naturally, the way the engineering contents are packaged affect how it is implemented. In Finland, where engineering is included in a crafts subject, the making aspects are strongly emphasized. In England, aesthetic design aspects are put forward. Connections to the natural sciences are held to be important in the American *Next Generation Science Standards* (2013).

Why Should Pupils Learn about Engineering?

A multitude of reasons for including engineering in the curriculum exists:

Modern citizenship. ITEEA's *Standards for technological literacy* state that technological design 'provides tools essential for living in a technological environment' (p. 90). The Swedish technology syllabus stresses the necessity for learning about how technology affects society and its development (Skolverket, 2011, p. 254). The New Zealand curriculum (2007) emphasizes pupils' ability to 'participate in society as informed citizens' (p. 32). The English curriculum has a slightly different take on the same theme, saying that 'High-quality design and technology education makes an essential contribution to the creativity, culture, wealth and well-being of the nation' (Department for Education, 2013, para. *Purpose of study*).

Everyday skills. In the Finnish syllabus for technical sloyd it is stated that pupils should develop 'an understanding for technical phenomena in everyday life' (Utbildningsstyrelsen, 2004, p. 240, my translation). English pupils are provided with the opportunity to 'develop the creative, technical and practical expertise needed to perform everyday tasks confidently' (Department for Education, 2013, para. *Aims*) through the study of design and technology. The National Academy of Sciences (Quinn et al., 2012) claims that education in science, engineering, and technology helps pupils to 'to make informed everyday decisions, such as selecting among alternative medical treatments or determining how to invest public funds for water supply options' (p. 7).

Problem solving and other general skills. A strong belief in pupils' ability to use skills, such as problem solving, gained in engineering education in other areas is expressed in some of the curricula. In Massachusetts, skills 'such as the ability to work through difficult problems, to be creative in problem solving, and to think critically and analytically will serve students in any setting. When students work toward high expectations in these areas, they develop the foundation they need for success after graduation' (Massachusetts Department of Education, 2006, p. 16). Finnish pupils develop their self-confidence and their skills in problem solving and group work through their sloyd projects (Utbildningsstyrelsen, 2004, pp. 240, 242). The Scottish curriculum promises that 'The skills that learners acquire by successfully completing this Course [National 3 Design and Technology, level 3] will be valuable for learning, for life and for the world of work' (Scottish Qualification Authority, 2012, p. 2). They will also develop 'perseverance, independence and resilience; responsibility and reliability; and confidence and enterprise' (p. 2). In addition to all this, design and technology is also said to be the most suitable subject for the study of sustainability and consumption of finite resources (Morgan et al., 2013). There are obviously strong beliefs in (or strong hopes for) how engineering practice in school can improve learning, work, and life in general.

Future careers in engineering and technology. The National Academy of Sciences (Quinn et al., 2012, p. 10) states explicitly that one of the purposes for science and engineering education is to provide a firm ground for future studies in the field. In New Zealand, '[l]earning for senior students opens up pathways that can lead to technology-related careers. Students may access the workplace learning opportunities available in a range of industries or move on to further specialised tertiary study' (New Zealand Ministry of Education, 2007, p. 33). This is in stark contrast to the curricula of e.g. England and Sweden, where future studies or careers in engineering are not explicitly mentioned.

Engineering also provides opportunities for collaborations between schools and industries (Banks & Barlex, 2014). Pupils can work with real engineering problems, or those based on real engineering problems, which can provide inspiration for and knowledge of possible future careers.

Learning in other subjects. Engineering as part of a larger cluster of educational areas is an essential part of the STEM concept, where *science, technology, engineering,* and *mathematics* are taught and assessed together (Banks & Barlex, 2014). If everything works out as intended, the traditional subject-boundaries are resolved and all unite into one coherent whole. To use technical artefacts and technical problem solving to illustrate concepts of school science has a long tradition. Especially physics textbooks tend to contain loudspeakers, steam engines, and aeroplane wings, used to explain sound and electro-magnetism, heat and pressure, and turbulence, respectively. To do things the other way round—to let the creation of technical artefacts lead to the necessity of finding out about scientific concepts—is prescribed in some technology and engineering curricula and policy documents. It is strong in The National Academy of Sciences' (Quinn et al., 2012) framework, where a long chapter is dedicated to the integration of science and engineering and how different practices, concepts, and core ideas can cross-fertilize: 'from a teaching and learning point of view, it is the iterative cycle of design that offers the greatest potential for applying science knowledge in the classroom and engaging in engineering practices' (p. 201).

Using knowledge from the science subjects in engineering design for mutual benefits is also stressed by *The Next Generation Science Standards* (2013, p. 81), where examples of how scientific concepts like biodiversity, chemical reactions, and forces during collision, are used in educational engineering design projects for the benefit of all.

Even ITEA's *Standards for technological literacy* puts forward engineering and technology education as a vehicle for school subject integration. Examples include not just science, but also for example history. They suggest history studies where the lives of yesteryear's people is understood through the technologies they used (p. 6 f.).

The reasons for learning engineering in school varies slightly between countries, but the ones mentioned above are common in curricula and similar documents. There is obviously a widely held belief of the usefulness (or even necessity) of engineering education in school: it teaches pupils general skills, it makes them understand modern society, and it helps them to learn mathematics, science, and other subjects.

What Should Pupils Learn about Engineering?

At the core of the engineering education that is described in the various syllabi and policy documents are design processes. These go under a variety of names:

- *crafts process* (Sweden—Skolverket, 2011, p. 204)
- *design* (Northern Ireland—Council for the Curriculum, Examinations and Assessment, p. 1)
- *design process* (Scotland—Scottish Qualification Authority, 2012, p. 2; United States—International Technology Education Association, 2007, p. 4)
- *engineering design process* (United States—Massachusetts Department of Education, 2006, p. 10; National Academy of Sciences, 2012, p. 46; *Next Generation Science Standards*, 2013, p. 23)
- *iterative process of designing and making* (England—Department for education, 2013, para. *Subject content: Key stage 3*)
- *phases of technical development* (Sweden—Skolverket, 2011, p. 256)
- *sloyd process* (Finland—Utbildningsstyrelsen, 2004, p. 240)

There are of course slight differences between these processes. In Sweden, for example, there are two similar processes: one in the subject crafts and one in the subject technology. They share common concepts like development of ideas and the necessity for communication, but differ e.g. in the role of manual work. Differences concerning the role of science, which tools that are used, the role of ICT in the development process, etc. varies. There is however a common core—identification of a problem, need or wish; development of solution suggestions; evaluation of these; etc. Whether the product shall be actually built (or implemented in some other way if it is an ICT or a biotechnology project) depends on what the learning objectives for the specific project consists of.

In the studied documents, very few details about the engineering design process models and their phases are to be found. In the Swedish technology syllabus, they are listed as 'identification of needs, investigating, proposing solutions, designing and testing' (Skolverket, 2011, p. 256). Pupils in Massachusetts use the following process: 'identify problem, research problem, develop possible solutions, select solution, construct a prototype, test the solution, communicate the solution, redesign' (Massachusetts Department of Education, 2006, p. 84). This is then followed by multiple cycles where the old redesign problem becomes the new design problem. The International Technology Education Association (2007, p. 123 f.) describes the design process thus: identify the design problem, identify criteria and constraints, refine a design by using prototypes and modelling, evaluate the design solution, develop and produce a product or system, evaluate final solutions and communicate results. These are all described in general terms, and supposedly useful for all kinds of engineering design projects within most technical areas. They all resemble the generic engineering design process in Figure 1.

The rough overviews of the engineering design processes from syllabi and general documents on engineering education are then worked out in detail in textbooks and similar materials for schools. On this level, significant differences can enter the process. Johnsey (1995) scrutinized and compared 17 different English design process models and showed that there many similarities, but also significant differences. The main phases of identifying problems and suggesting solutions are everywhere, but they are organised differently with some linear models and some organised with loops—allowing or even encouraging repeated try-outs. Concerning the process skills, there are also differences. Some identified 'planning' as a process skill, while other did not. Some identified the introductory 'research' as a process skill, while other did not. And so on. Even though most process models contained phases that were easily identifiable in pupils' work, the different models suggest important differences in what pupils are supposed to do and what they are supposed to learn.

How Should Pupils Learn about Engineering?

The ability to follow and implement an engineering design process is a set of skills, which commonly (but not exclusively) are said to include planning, technical drawing, technical reporting, testing, making, and evaluation. Many skills are difficult (or even impossible) to learn from books or instruction but must be practiced. This view permeates the notices about how engineering education should be organised in schools; there is a strong emphasis on pupils' actual designing and making, rather than just reading about it (McCormick, 2007). Pupils partake in product development projects that to some degree resemble real engineering design projects, but use other materials (cardboard, Styrofoam, and ice cream sticks rather than metals and concrete) and solve design problems that are different, easier, and do not lead to any severe consequences if they fail.

In most of the studied curricula or syllabi, there are few or no instructions concerning the 'How?' question. This is most likely a deliberate choice made to respect the autonomy of teachers and also to make the text withstand the passing of time better. A text that just states which skills (testing, planning, drawing, …) that pupils are supposed to learn will most likely be useful even ten years from now, something that one which states the tools to be used cannot count on being. For example, in a Swedish technology curriculum for secondary school from the early 1970s (Skolöverstyrelsen, 1970) large parts of the subject contents—technical drawing, solid mechanics calculations, characteristics of steel and concrete, etc.—are still relevant, but the suggestions for illustrating technical problems and phenomena using flipcharts or flannelgraphs are hardly so. Therefore, specific tools and teaching methods are seldom mentioned in curricula, and when specific activities are discussed, they are listed as *suggestions* or *examples*. To find out how engineering should be taught in school, we must therefore turn to other sources, such as handbooks and textbooks.

Various kinds of model cars are the objectives of many a school engineering design project. ITEA (2007, p. 122) describes an example where the teacher Ms. C.'s pupils are to build a model car from a limited set of materials including a sheet of paper, four wheels, axles, and some adhesive tape. The car is to roll down a slope and stop in a winner's circle. To solve the problem, pupils will have to work in teams, systematically test, improve, and re-test their suggested design, and put their knowledge of force, motion, and aerodynamics to use. Another example is provided by Johnston (2005) whose pupils build model cars that are powered by mousetraps. Pupils are to make the car move as far as possible, with 9 m set as the minimum. During the design process, they will have to use their knowledge about friction, transmissions, leverage, and similar mechanical principles and gadgets. A third example is listed in the syllabus of Massachusetts (Massachusetts Department of Education, 2006, p. 89). The model car in this project carries a passenger in the form of an egg. The major challenge for the pupils is to design a safety belt and deformation zones so that the egg remains unharmed if the car crashes into something.

These car model examples show another common aspect of school engineering projects: competition. Ms. C.'s pupils' cars are timed as they roll down the inclined plane towards the goal-circle; Johnston's pupils strive not just to make their mousetrap cars move the minimum length but also to be better than the others'. National and international competitions on technological themes, intended for children and adolescents, are common. Sometimes they are incorporated into engineering education. Two international engineering competitions that are popular in Sweden are First Lego League (with more than 25,000 participating teams from 80 countries in 2015, each consisting of up to 10 children) and Future City (originally an American competition, but now with national and regional offshoots all over the world).[2] First Lego League is centred on a specific theme each year, and the teams have to solve problems and work out ideas connected to this theme. The best known activity within the project concerns the designing, programming, and building of a Lego robot that is to move around a track, manipulate objects, etc. Other parts consist of coming up with ways to solve global problems and present the solutions to a jury. The engineering design process is emphasized in the Lego sub-project, and technology for the betterment of the world permeates the whole project. In Future City, pupils are to design a city or suburb. The competition varies between countries, but tend to include physical modelling in the form of buildings made from cardboard and *papier-mâché*, as well as virtual models produced in the Minecraft framework. Here too an engineering design process is practiced, and the use of technology for the betterment of society is highlighted.

SCHOOL ENGINEERING IS NOT ENGINEERING

In Garratt's (1996) textbook *Design and Technology*, intended for use in England, a strong emphasis is placed on the engineering design process (called 'the design process'). The process is described as a predominantly linear problem solving activity, starting with an investigation of the situation, which is followed by design suggestions, testing, etc., and results in a product that solves the problem or a prototype of such a product. It is similar to how linear engineering design processes outside of school are commonly described (Figure 1).

The engineering design process is illustrated by a story about Pauline and Nick, two clever and well-behaved pupils in their teens (Garratt, 1996, pp. 6–17). Pauline and Nick know an old lady, Mrs Brown, who finds it difficult to ascend and descend the stairs in her house. To help Mrs Brown, Nick and Pauline decide to design her a stair lift. They start with interviewing Mrs Brown and taking measurements of her house. Then they suggest design solutions, evaluate them, make drawings, and finally construct a reduced scale model and write a report about their work. The design project has finished successfully. This is a quite advanced, but in many ways typical engineering design task from pre-university education.

Nick's and Pauline's work would however not have been typical were they real engineers. There are multiple reasons for this. Nick and Pauline have not solved Mrs Brown's problem. The small-scale prototype made from wood and a small electrical motor cannot move a human being but is better suited for a small doll. It is therefore not of any use for Mrs Brown, and there are no plans to build the real thing. Furthermore, there is something most peculiar about their work process. They have forgotten one very useful method, namely to use other people's work. If Nick and Pauline had googled 'stairlift' they would have found that several products fulfilling Mrs Brown's needs are available on the open market.[3] They are modular and easy to fit into existing buildings. They also have all kinds of national and international safety certificates, and are not even particularly expensive. To make a new design from scratch for a one-off stair lift without any special features is not rational from an engineering point of view. It will be more expensive, less safe, and the project will take longer time—both process and product will most likely be less effective and less efficient.

So, even though Nick's and Pauline's project must be seen as a failure or at least a sub-optimal solution as an engineering project, it is put forward as a model example in a commonly used textbook. How can that be? The reason is simple. What Nick and Pauline partake in is not *engineering*, but *school engineering*. The purpose of engineering work is to fulfil needs and solve problems. The purpose of school engineering work is that pupils should learn a set of skills that can be useful in various situations, such as when doing real engineering work. Nick and Pauline learnt how to write reports, make technical drawings, build models, and perform tests. Therefore, they were successful even though their project was very time-consuming and no real problem was solved. The nature of school engineering is inherently different from the nature of engineering, and must so be.

The quality or rationality of a school engineering project does not concern the effectiveness and efficiency of the development or use of a product, but rather the effectiveness and efficiency of pupils' learning. One may very well occur without the other; if Nick and Pauline had bought a stair lift off the shelf that would have been efficient and effective problem-solving, but very little learning would have taken place. Similar situations can occur on higher levels of the educational system. Edin Grimheden (2013) describes how the introduction of Scrum—an agile product development method—has increased his university level mechatronics students' opportunities to learn through increased interaction with clients and greater opportunities to improve preliminary designs. At the same time he emphasises that even though the method is great for learning it is not suitable (or even allowed) in all real product development contexts. Enhancing learning does not necessarily lead to increased quality of the product or process.

This fundamental difference in purpose also seeps into other aspects of school engineering. It is not about developing products, but about developing knowledge and attitudes according to what is stated in the syllabus. This has led to the following common characteristics of school engineering projects:

Develop a new solution, even though old ones exist. A common first step of an engineering project is trying to find similar or identical products which can provide solution suggestions or inspiration. Perhaps it is not even necessary to develop a new product, maybe it can be bought off the shelf.

It is not unknown that teachers use the same tasks for the pupils year after year. In those cases pupils can often find good solution suggestions by asking older friends or siblings. While this would be called rational and efficient in a real engineering design project, it is commonly referred to as cheating in school.

Peculiar requirements. To avoid that pupils can base their design solutions on existing ones and make sure that they get the right kind of challenge, requirements of kinds that are seldom found outside of the school world are often used: the driving force of the model car must come from a mousetrap even though more suitable power sources exist; the model bridge must be a suspension bridge even though another type would be cheaper and better. Etc.

You can succeed even though your product does not work. When solving real engineering problems, the ultimate sign of success is generally a happy customer that is willing to pay for your work. In school, that is not always necessary. If your drawings are nice and tidy, your idea is well developed, and your final report is in accord with the provided template, you may pass (or pass with distinction) even though the product does not function as it was meant to.

Inefficient groups are encouraged. In real engineering work, experts tend to work within their fields of expertise. In school engineering, team members are often encouraged to do things that they do not already know. Learning, not efficiency in product development, has the highest priority.

Limited in scope. Mechanical, electrical, and electromechanical projects dominate school engineering in most countries. Biotechnology and chemical technologies are not common. The image of engineering that is purveyed through school engineering seldom give a representative picture of the whole field of engineering.

School engineering projects are nice and kind. Several school engineering syllabi stress that pupils should become environmentally aware and active, responsible citizens. This is often reflected in the themes for school engineering projects. They are almost never about weapons, and seldom about combustion engines or other such evils, but kind and nice. The stair lift project of Nick and Pauline (Garratt, 1996) is typical in this sense. So is a project about designing a shower for a developing country described by Denayer et al. (2003) and the themes for the First Lego League competition: improving schooling and learning (*World Class Learning Unleashed*—2014), avoiding natural disasters (*Nature's Fury*—2013), improve and maintain the quality of life for the elderly (*Senior Solutions*—2012), etc.

School engineering is not engineering, and cannot be engineering as the purpose is different. It must however be related to engineering for pupils to be able to use the skills and knowledge gained from school engineering projects in real engineering projects, future studies, and their everyday lives. The design of effective and efficient engineering education is not trivial, and neither is pupils' transfer of school engineering knowledge to engineering knowledge.

COHERENCE AND ALIGNMENT (OR LACK THEREOF)

The nature of engineering education can be studied and evaluated on multiple levels. Is it the wording of curricula, how teachers interpret them, or what pupils actually learn that is most interesting? In this article, it is mainly about the formal, curricular level. This choice has been made because the curricular level is reasonable stable. While classroom practice may change when a new, free CAD program is released or when the price of 3D printers drops, the curriculum can stay the same (or almost the same) for a decade or more. Another reason is of course that the curricular level is easily available for study, which classroom practice is not. A study of classroom practice can consider a handful of teachers, while a curriculum study can cover countries or continents. At the same time, it must be admitted that it is slightly unsatisfactory to leave the actual teaching and learning out. This is especially disturbing as engineering is a skill-based area of study. Engineering is learnt by practicing school engineering, and pupils' knowledge in the area must be assessed by studying their work. Thereby, the delimiting line between the 'What?' and the 'How?' becomes blurred—teaching method and subject contents cannot easily be separated. This is also obvious from engineering and technology curricula, where methods and activities show up in the contents descriptions (albeit as 'suggestions' or 'examples').

For a subject to form a coherent whole, contents ('What?'), methods ('How?') and purpose ('Why?') must fit together. If the purpose of the subject is to turn the pupils into brilliant problem solvers, then problem solving related contents should be included, and suitable activities to increase the likelihood of learning how to solve problems should take place in the classroom. This is really common sense. Nevertheless it is not always the case and lack of alignment between these different aspects of a subject occurs on all levels of the educational system (Biggs & Tang, 2011; Jönsson, 2010). In Sweden, the School Inspectorate has shown that the activities that take place in many technology classrooms are badly aligned with the curriculum—they do not reflect the subject's purpose of prescribed contents as many projects are too simple, their purpose is unclear to pupils as well as teachers, and reflection on one's own work and its relation to society is lacking (Skolinspektionen, 2014). The 'What?' and the 'Why?' in the curriculum are reasonably well aligned, but the 'How?'—the implementation—fails. Therefore, it can be controversial to make statements about the nature of a subject or area of learning without studying how teachers and pupils really work with it.

Figure 2 shows the most important dependencies for engineering in school. The two-headed arrows within the subject itself illustrates the interdependencies between the central aspects; what is to be learnt affects how it should be taught, but what can realistically be taught (due to matters of security, economy, available time, etc.) also affect which contents that are listed in the curriculum, for example. These relations determine the inner coherence of the subject.

The subject or area of learning is referred to as school engineering (engineering design, technology, design, …) and should in some way represent the engineering of the world outside of the school walls. School engineering is based on engineering, but engineering is not in any palpable way affected by school engineering. Engineering affects what should be learnt in school engineering as school engineering skills should be useful in real engineering. It also affects how school engineering should be taught, as many engineering skills are best learnt by doing them. Furthermore, it affects why school engineering should be studied, as it has to be realistic; there

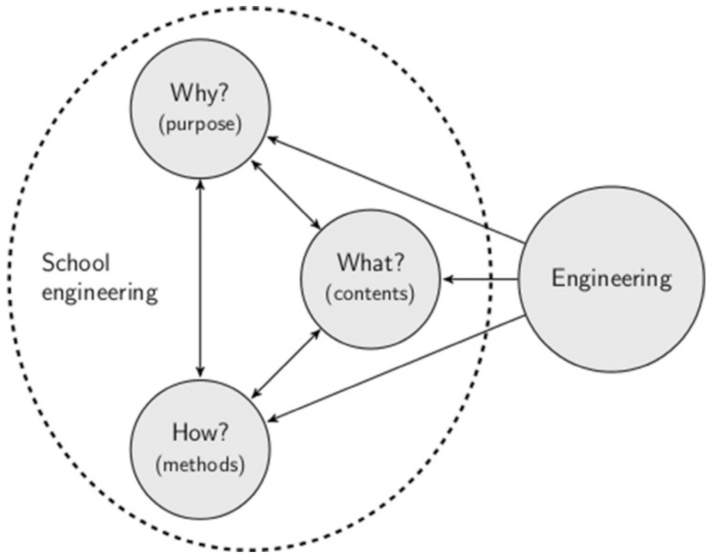

Figure 2. How different aspects of school engineering depend on each other and on real engineering

has to be a relevant mapping of what *should* be achieved in school engineering with what *can* be achieved in real engineering. From this follows that teachers must be knowledgeable about engineering. If the central aspects of school engineering are not strongly connected to the domain of engineering, its relevance for learning engineering can be questioned and it should really be called something else.

There are obvious similarities between the skills that pupils are supposed to learn through education in school engineering and some of the skills that engineers use. Teamwork, systematic problem solving, testing, and writing reports are all skills that are typical of engineering as well as of school engineering. The requirements are different, and many of the engineers' professional skills must be left out, but this is a normal part of the didactic transposition process—of making a teachable and assessable school subject out of something that is practiced outside of school (Chevallard, 1991). What is left out depends on the purpose of the particular subject; if the application of science has the highest priority, the use of standard procedures or methods based solely on experience should be discouraged and left out. If on the other hand the development of problem solving strategies are the ultimate purpose, the use of experience-based, non-scientific methods can be encouraged.

Just as it is easy to find similarities between engineering skills and school engineering skills, it is easy to see that school engineering classroom activities resemble engineering activities, at least on a surface level. The focus on making is in some countries (Finland, England) stronger in school engineering than in the typical engineering office outside of school. The tools are also somewhat different. The glue gun is probably more frequently used in Swedish technology classrooms than in any engineering design bureau in the whole world, and mathematical models are less frequent.

Whether school engineering is coherent, so that its purposes, methods, and contents can be united in a whole where the different aspects fit together and support each other, can of course not be answered once and for all. First, the subjects differ between countries, so any conclusions on the general level cannot be said to hold for an individual curriculum. Second, the methods—the 'How?' part—varies from school to school and from teacher to teacher.

THE TRANSFER PROBLEM

By comparing syllabi from different countries, it is obvious that great faith is put into pupils' abilities for transferring knowledge and skills from one domain to another. Pupils in Lake Norman High School (Mooresville, North Carolina) spend their engineering lessons designing catapults for ping pong balls and building towers from pipe cleaners.[4] They do this according to a prescribed engineering design process, similar to the first part of Figure 1. It is highly unlikely that any of them in their everyday lives will ever be approached by somebody asking: 'I don't know how to build a high enough tower from pipe cleaners, can you help me?' or 'I have a problem. I don't have a suitable piece of equipment for throwing a ping pong ball as far as possible. And it has to be constructed from ice cream sticks and rubber bands.' And if they are approached with such questions, they are probably being asked by another pupil in Lake Norman High School. For the skills learnt by designing and building pipe cleaner towers to be useful in the situations prescribed by the stated purposes of school engineering (everyday problems, future engineering studies, …), pupils have to repurpose their skills, which is not necessarily a trivial task. For this transfer to take place, many pupils will have to be guided by teachers making the similarities between school engineering and engineering explicit (*cf*. Banks & Plant, 2013).

The purpose of engineering (to solve problems and create products) and the purpose of school engineering (to make pupils learn) are inherently different. To be discussed here is if, how, and to what extent school engineering is related to the engineering outside of school. The above list of reasons for including school engineering in the curriculum contains such varied suggestions as increasing pupils' autonomy in the modern world, and helping them understand natural science. Is school engineering in its present incarnations really effective relative to these purposes? Do pupils develop the desired general skills and personality traits through practicing school engineering? At the time of writing (January, 2016), the sad answer is probably that nobody knows. I have been unable to find any conclusive evidence in the available engineering and technology education research. We have been teaching pupils about engineering in the hope of turning them into better, more responsible, entrepreneurial, and reflective human beings for over two decades, hoping, but not knowing for sure, that it actually works.

To determine the actual long-time effects of educational efforts is difficult. That said, it should be fairly easy to determine whether training in engineering skills is of help in everyday life and creates individuals with a stronger sense of responsibility. To do this, we could study engineers. They are trained in real engineering, which school engineering is based on. If knowledge about the engineering design process leads to people being entrepreneurial problem-solvers with a great deal of autonomy, engineers should possess these traits. Furthermore they should have excellent everyday practical skills, and the abilities necessary to select the right medical treatments and determine how to invest public funds for water supply options (*cf.* Quinn et al., 2012, p. 7). They should also have great understanding of the natural sciences and easily learn about history and complex aspects of society. Unfortunately, I have failed to find any evidence of engineers possessing these abilities and personality traits. If engineers, who are experts in engineering, do not possess them, what reasons are there to believe that pupils should develop them by learning engineering skills?

CONCLUDING DISCUSSION

Pre-university engineering education—or school engineering—is not, and cannot be, engineering. While engineering design projects strive primarily to produce great products, school engineering projects are focussed on pupils' learning rather than the product quality. Nevertheless there are similarities. Even though the tasks are different and the materials used are different, commonly school engineering design processes resemble idealised, linear engineering design processes. The expected and desired learning outcomes vary between countries, but tends to include general skills such as teamwork and systematic problem solving, as well as the application of knowledge from school science and an understanding of our technology-based society. It also often includes changing attitudes toward future studies in technology and science in a positive direction, as well as increasing autonomy and creativity. It clearly can be a varied and very challenging subject.

To what extent school engineering succeeds in what it is set out to achieve is an important question that has not yet received enough attention. Judging from international tests and attitude surveys concerning pupils' relationship with science and technology (Ardies, de Maeyer, & Gijbels, 2015; Sjøberg & Schreiner, 2010; Skolinspektionen, 2014) there have not been any dramatic increases in pupils' interest or abilities during the last decades when engineering has entered the curricula of many countries. Have the pupils become more creative? Have they developed a stronger sense for the environment? Are they better at teamwork outside of the engineering classroom? Can they apply a systematic problem solving approach to everyday problems? That is very difficult to say.

It is absolutely clear that school engineering is very demanding for the teacher. Changes in society, and changes in technology, makes continuous professional development absolutely necessary if the connection to real engineering shall be upheld. Teachers have to be knowledgeable about real engineering. Otherwise it is very difficult to guide the pupils' transfer of knowledge from the school engineering domain to the engineering domain. If you are to design a project about building mousetrap cars so that pupils develop useful general skills while participating is difficult in itself. To make the pupils understand how these skills can be of use when developing something else, such as a database system, is even more difficult. You cannot possibly do it without knowing what a database system is and what a database engineer does for a living.

The last word on *The Nature of Pre-University Engineering Education* has not yet been spoken. Whether school engineering actually can fulfil its many intended purposes is an empirical question which has not been thoroughly studied. Whether a general problem solving method that leads to effective and efficient solutions for a wide variety of problems exist, and can be learnt through school engineering, is also an empirical question that awaits an answer. And if it exists, why isn't it always used by teachers and curriculum designers when planning and executing engineering education?

NOTES

1 See http://www.extremeprogramming.org and http://www.scrum.org respectively.
2 See http://www.firstlegoleague.org and http://futurecity.nu respectively.
3 There was no Google when the book was published in 1996, but they could have used AltaVista, visited the library, or asked an organisation for elderly or disabled people.
4 http://iss.schoolwires.com/Page/55686

REFERENCES

Ardies, J., de Maeyer, S., & Gijbels, D. (2015). A longitudinal study on boys' and girls' career aspirations and interest in technology. *International Journal of Technology and Design Education*, *33*(3), 366–386. doi:10.1080/02635143.2015.1060412

American Engineers' Council for Professional Development (ECPD). (1947). *Canons of ethics for engineers*. Engineers' Council for Professional Development.

Banks, F., & Barlex, D. (2014). *Teaching STEM in the Secondary School*. Oxon, United Kingdom: Routledge.

Banks, F., & Plant, M. (2013). Transferring knowledge versus knowledge through technology education. In H. E. Middleton & L. K. J. Baartman (Eds.), *Transfer, transitions and transformations*. Rotterdam, The Netherlands: Sense Publishers.

Biggs, J., & Tang, C. (2011). *Teaching for quality learning at university*. Maidenhead, United Kingdom: Open University Press.

Chevallard, Y. (1991). *On didactic transposition theory: Some introductory notes*. Retrieved from http://yves.chevallard.free.fr/spip/spip/IMG/pdf/On_Didactic_Transposition_Theory.pdf

Council for the Curriculum, Examinations and Assessment [in Northern Ireland] (no year). *Technology and design: Statutory requirement*. Retrieved from http://www.nicurriculum.org.uk/docs/key_stage_3/areas_of_learning/statutory_requirements/ks3_tech_design.pdf

Denayer, I., Thaels, K., Vander Sloten, J., & Gobin, R. (2003). Teaching a structured approach to the design process. *European Journal of Engineering Education*, *28*, 203–214.

Department for Education [in England]. (2013). *Design and technology programmes of study: Key stage 3*. Retrieved from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/239089/SECONDARY_national_curriculum_-_Design_and_technology.pdf

Edin Grimheden, M. (2013). Can agile methods enhance mechatronics design education? *Mechatronics*, *23*, 967–973.

Eppinger, S. D., Whitney, D. E., Smith, R. P., & Gebala, D. A. (1994). A model-based method for organizing tasks in product development. *Research in Engineering Design*, *6*(1), 1–13.

Franssen, M., & Bucciarelli, L. L. (2004). On rationality in engineering design. *Journal of Mechanical Design*, *126*(6), 945–949.

Garratt, J. (1996). *Design and technology*. Cambridge: Cambridge University Press.

International Technology Education Association (ITEA). (2007). *Standards for technological literacy*. Reston, VA: ITEA [In 2010 the organisation changed its name to International Technology and Engineering Educators' Association, ITEEA]. Retrieved from http://www.iteea.org/TAA/PDFs/xstnd.pdf

Johnsey, R. (1995). The design process—does it exist? *International Journal of Technology and Design Education*, *5*, 199–217.

Johnston, J. (2005). Practice drives theory: An integrated approach in technological education. In R. Alsop, L. Bencze, & E. Pedretti (Eds.), *Analysing exemplary science teaching*. New York, NY: Open University Press.

Jönsson, A. (2010). *Lärande bedömning* [*Learning Assessment*]. Malmö, Sweden: Gleerups.

Koen, B. V. (1985). *Definition of the engineering method*. Washington, DC: American Society for Engineering Education.

Kroes, P. (2012). *Technical artefacts: Creation of mind and matter*. Dordrecht, The Netherlands: Springer.

Massachusetts Department of Education. (2006). *Massachusetts science and technology/Engineering curriculum framework*. Malden, MA: Massachussetts Department of Education. Retrieved from http://www.doe.mass.edu/frameworks/scitech/1006.pdf

McCormick, R. (2007). Design aspects. In M. J. de Vries, R. Custer, J. Dakers, & G. Martin (Eds.), *Analyzing best practice in technology education* (pp. 169–177). Rotterdam, The Netherlands: Sense Publishers.

Morgan, R., Jones, L., & Barlex, D. (2013). *New principles for design and technology in the national curriculum*. London: Education for Engineering (E4E), Royal Academy for Engineering. Retrieved from http://www.educationforengineering.org.uk/reports/pdf/e4e_report_feb2013.pdf

New Zealand Ministry of Education. (2007). *The New Zealand curriculum for English-medium teaching and learning in years 1–13*. Wellington, New Zealand: Learning Media Ltd. Retrieved from http://nzcurriculum.tki.org.nz/content/download/1108/11989/file/The-New-Zealand-Curriculum.pdf

Next Generation Science Standards. (2013). Washington, DC: Achieve Inc. Retrieved from http://www.nextgenscience.org/sites/ngss/files/NGSS%20DCI%20Combined%2011.6.13.pdf

Quinn, H., Schweingruber, H., & Keller, T. (2012). *A framework for K–12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: The National Academies Press. Retrieved from http://www.nap.edu/catalog.php?record_id=13165

Scottish Qualification Authority. (2012). *National 3: Design and technology course specification*. Retrieved from http://www.sqa.org.uk/files/nq/CfE_CourseSpec_N3_Technologies_DesignandTechnology.pdf

Sjøberg, S., & Schreiner, C. (2010, March). *The ROSE project: An overview and key findings*. Report from the University of Oslo, Norway. Retrieved from http://www.roseproject.no/network/countries/norway/eng/nor-Sjoberg-Schreiner-overview-2010.pdf

Skolinspektionen [The Swedish School Inspectorate]. (2014). *Teknik – Gör det osynliga synligt* [*Technology: Make the invisible visible*]. Stockholm: Skolinspektionen. Retrieved from http://www.skolinspektionen.se/sv/Beslut-och-rapporter/Publikationer/Granskningsrapport/Kvalitetsgranskning/Teknik–gor-det–osynliga-synligt/

Skolöverstyrelsen [Swedish National Board for Education]. (1970). *Läroplan för gymnasieskolan Lgy70* [*Curriculum for secondary school Lgy70*]. Stockholm: Liber Utbildningsförlaget.

Skolverket [Swedish National Agency for Education]. (2011). *Curriculum for the compulsory school, preschool class and the recreation centre 2011*. Stockholm: Skolverket. Retrieved from http://www.skolverket.se/publikationer?id=2687

Tobin, J. J., & Walsh, G. (2008). Good manufacturing practice. In J. J. Tobin & G. Walsh (Eds.), *Medical product regulatory affairs* (pp. 209–235). Weinheim, Germany: Wiley-VCH Verlag.

Utbildningsstyrelsen [The Finnish National Agency for Education]. (2004). Slöjd [Sloyd]. In *Grunderna för läroplanen och den grundläggande utbildningen* [*Foundations for the curriculum and fundamental education*] (pp. 240–244). Retrieved from http://www02.oph.fi/svenska/ops/grundskola/LPgrundl.pdf

Vermaas, P., Kroes, P., van de Poel, I., Franssen, M., & Houkes, W. (2011). Technical designing. In *A philosophy of technology: From technical artefacts to sociotechnical systems* (pp. 21–37). San Rafael, CA: Morgan & Claypool.

Vinck, D. (2003). Socio-technical complexity: 'Redesigning a shielding wall'. In D. Vinck (Ed.), *Everyday engineering: An ethnography of design and innovation* (pp. 13–27). Cambridge, MA: The MIT Press.

Per Norström
School of Education and Communication in Engineering Science
KTH Royal Institute of Technology
Sweden

GABRIELE GRAUBE AND INGELORE MAMMES

4. PRE-UNIVERSITY ENGINEERING EDUCATION IN GERMANY

Needs, Possibilities and Limits – A Description

INTRODUCTION

Increasing mechanisation of our world of living requires qualification of young academics by professional education as well as pre-university engineering education accessible for anyone. Germany, as a technically-responsible society under construction, faces the following challenges:

Changes in work, culture and spare time behaviour: The impact of technical development on work, culture and spare time behaviour is increasing. The development is fast moving and leads to constantly changing products in these sectors. These products are more and more often backed up by the results of scientific research and development. At the same time people develop a consciousness for technical consequences which makes them overestimate the consequences of certain technologies and underestimate the consequences of others. This shows for instance in the discourse on the energy crisis and the involved usage of constantly energy-consuming devices.

Economic state in the context of technical development: Germany is known as a high-technology country whose strength is based on its economy and scientific knowledge – especially on technological clusters. Industry 4.0 is currently discussed as a new topic of economic development with Germany being the country to give industry important impulses. At the same time many different positions broach different messages on the issue of the current skills shortage. However, encouraging and fostering offspring remains essential as offspring for future development and innovation is needed at all times.

Changes in problems and their solutions: Problems have changed. Today and in future times we will not only have to face environmental problems and the issue of an increasing shortage of resources. All societies face problems dealing with mobility, communication, climate/energy, health/diet and safety. As technical problems have a hybrid nature we need to act on the assumption that their solutions can only be developed in a cooperation of several disciplines. Thus, technical solutions often become an expression of interdisciplinarity between engineering and natural sciences, also including mathematics. This form of complex challenges requires a conscious examination of technology: pre-university engineering education.

M. J. de Vries et al. (Eds.), Pre-university Engineering Education, 47–63.

DISCOURSE ON PRE-UNIVERSITY ENGINEERING EDUCATION IN GERMANY

The German Concept of Education

The conception of education being an acquirement of selected knowledge is nowadays being rejected just as much as simplifying education to instructions being aimed at gaining usefulness and skills. The educational ideal of "people's disposition of themselves" (Heydorn, 1980, p. 162f) can already be found in theories of Wilhelm von Humboldt (1767–1835) and later also in works of Wolfgang Klafki. Klafki (1985) defines education as an objective in means of ability of self-determination, representative participation and solidarity. In this process he develops a general educational conception which consists of three characteristics and still has validity in Germany:

- Everyone's right to be educated.
- Universalism and versatility of human development.
- Dealing with topics that concern the bigger part of the population (society's key problems).

Jörissen and Marotzki (2009) carried this thought on and developed a modern conception of education that is not based on defined contents but asks for "people's place within the total arrangement of current socio-technical systems" (p. 15). Considering especially the excess of technical choices they point out the necessity of orientation and flexibility in order to be able to shape society responsibly.

In view of the educational process, asking for self-determination and heteronomy comes naturally. Education in view of self-determination "aims to generate people's growing self-presentation and self-disposition, to develop people's power and tendencies, in short: education in the sense of modern spirit targets at the constitution of subjectivity" (Pongratz & Bünger, 2008, p. 111). This means individuals should be able to take the matters of their skills into their own hands. Further, individuals should be self-governed and mature, should be able to differentiate, criticise and reflect.

But education is always as well heteronomous. Society's norms and demands also define educational contents and objectives. If both requirements have significance and relevance for society it should eventually only be about seeing the term of education not in its difference but in its total, making both options possible. This means that a balance between self-determination and heteronomy should be created: "Thus, education means absorbing society's contradiction between demanded independence and inflicted restraints and working with it…" (Pongratz & Bünger, p. 111).

School as an Educational Instance

The school itself is a social institution and therefore needs to administer an extensive educational mission. It can and has to take responsibility for the development of autonomy and maturity of every individual in the framework of its social embedment. Advancement of personality, social basic knowledge, as well as naturalistic knowledge and skills in the 21st century are important parts of education.

But school hasn't been the only home of education for a long time. In the age of life-long learning a system of manifold homes of education and offers for education has established itself along people's life courses. This requires a return and a modern, critical understanding of education plays an important, yet not an exclusive role in school. This role, however, needs to be defined precisely. This question can be answered by distinguishing three basic sectors of education. These sectors relate the "self" to society (von Hentig, 2003):

- Personal aspects of education: people's ambition to accomplish things is strongly influenced by the culture they are surrounded with. This ambition is independent from society.
- Applicatory aspects of education: consists of everything that helps individuals with orientating themselves, survive and being useful in a society. Part of this are knowledge, skills, attitude and behavioural patterns.
- Political aspects of education: Everything an individual has to yield in order to make a community sustainable. This counts in perceiving the need for common welfare, goals and means, rights and duties within the community, handling power and restricted resources as well as making decisions concerning these.

Hentig (2003) assigns public schools especially to the task of political education. Personal education and applicatory education could also be developed differently and at different places. Learners at school experience a heteronomy of their education. This means school has the task to create a balance between "individual ways of development and socially, pedagogical demands" (Lindemann, 2006, p. 197).

The general-educating school thus is an instance of socialisation which has the social mission to influence learning processes of learners in order to make them socially capable of acting.

This social task differs school from family, which is being viewed as a primary instance of socialisation, and other instances of socialisation (for instance institutions, associations, peer groups, attachment figures). Socialisation as a "life-long acquirement and examination" is being understood as an active form of a life-long examination of one's own self with a social surrounding (cf. Hurrelmann, 2006). If the individual is being surveyed, school represents social environmental factors which make individuals build personalities which are capable of acting socially. This is achieved by a constant examination of naturally individual factors and the ascertained academic environment. To this effect school cannot impart knowledge and the individual cannot just acquire socially desired skills. School builds the framework for each individual process of dealing with the surrounding.

Therefore, school is just one of many instances of socialisation which thus has a social educational mission. It should enable individuals to gather personal, applicatory and especially political education in terms of Hentig (2003).

Technology and Pre-university Engineering Education

Humans have always placed technology in between themselves and nature. Technology is understood as a world in between which has been created by humans in order to guarantee self-preservation and self-development. In addition to a direct function technology allows many more goal establishments (Roth, 1965). This means different needs (to the point of forms of expression in art) can be satisfied and accordingly new needs develop on the basis of present technology.

In order to name aims of pre-university engineering education and assess them against the background of educational tasks, technology itself needs to be defined. In this matter terms of different reach are being discussed (cf. Weber, 1921/1972; Banse, 2013). In the context of this work the socio-technological character of technology is in focus. Thus, it is acted on the assumption of a modern understanding of education which asks for people's positioning in the scene of surrounding socio-technological systems (cf. Jörissen & Marotzki, 2009).

Therefore, technology is understood as a system of material means and methods which is created and used by human action in order to satisfy society's and individual needs (cf. Schmayl, 2010; Wolffgramm, 2006; ITEA, 1996). Focusing on needs is also called final orientation of technology. This final orientation can be separated into two lines of action, each with its own anticipation, participation and reflection for target achievement and for this purpose needed knowledge and skills:

- Presentation and creation of technical instruments which is meant for a certain purpose: This form of technical activity is characterised by creativity in order to connect physically feasible actions with technically feasible actions. Therefore, a general and specific basis of knowledge and skills is needed (cf. Urban, 2004). The creative process and its outcome are also influenced and limited by the technical and natural environment.
- Application of the technical instrument for immediate target achievement: This form of technical activity needs operational and applicatory knowledge. It is characterised by utilisation of the technical instrument and its hereby emerging limits.

Both lines of action are connected. Thus, technology is a created and deployed relation of purpose and instrumentation. Technical artefacts therefore are an expression of human skills, of society's values and norms, of social negotiation and of physical causality. At the same time they lead to changes in the social world as well as in the natural environment. Pre-university engineering education can now, as a continuation of the previously named differentiation of educational areas (cf. Hentig, 2003), be described as following:

- Personal pre-university engineering education: Individuals' striving for making the cultural area of science and technology accessible in the means of his own interests.

- Practical pre-university engineering education: Anything that helps individuals as social beings to orientate, survive and be useful in in a socio-technologically embossed society. This includes technological knowledge and skills concerning the use of technical systems as well as attitude and behavioural pattern in the context of science and technology.
- Political pre-university engineering education: Anything that an individual needs to yield in order to grant the community in the means of its technological interdependence sustainability. Aims that are reached by the use of technological instruments as well as referring decisions on limited resources and needed expertise for solving connoting problems have to be phrased and questioned in view of general public interest. This includes the perception of science and technology as a cultural phenomenon inside society as well as the wide development of technical/technological basic skills. In an instrumental-economic sense these skills are essential for the development of specialised knowledge for the creation of technical instruments (cf. Buhr & Hartmann, 2008).

If one follows an understanding of education in view of a community's sustainability and school's special responsibility it must be asked how especially political pre-university engineering education can be granted in school. Further, what it needs to intend and include. This question is closely connected with the identification and generalisation of universal premises and concepts which are required for the development of understanding and skills as well as for the participation in communication in a constantly changing scientific-technological world (cf. Tenorth, 1994; Baumert, 2007).

PRE-UNIVERSITY ENGINEERING EDUCATION IN GERMANY

The Setting of Pre-university Engineering Education

On a national and international scene, many different kinds of schools with different graduations can be found due to different education policies, history and philosophical and sociological conditions. At the same time problems with appreciation and implementation of pre-university engineering education occur at general-educating schools. This has already become apparent in contributions at national and international meetings on pre-university engineering education (cf. e.g. Uździcki & Wolffgramm 1999; Graube & Theuerkauf, 2002; Graube, Theuerkauf, & Dyrenfurth, 2003).

The implementation of an engineering subject or even a whole sector on technology is also different and disputed throughout Germany. In view of this there are many different perceptions on the aim and importance of this educational sector. In the context of a discourse that lasted for almost 50 years Roth sounded a note of caution in 1965, saying that pedagogics needed to be responsible especially for this sector of education: "Include technology in our human overall understanding and our ethical responsibility from an early age and integrate it; there is no other human way out for us" (Roth, 1965, p. 17). Also Dohmen (1989) points out that people "need to be put into operation by appropriate education, need to reflect their aims and life sense in a world of nature, culture and technology reasonably, responsibly and aware of limits in order to then decide and act actively and purposeful" (ibid., p. 53).

The discussion on pre-university engineering education goes along with a critical examination of the traditional German term of education. Roth detects difficulties of humanistic education within the education's position towards technology. "The crisis of humanistic education reveals itself when it leaves technology to uncontrolled growth or labels technology as a scapegoat" (Roth, 1965, p. 18). Almost 50 years afterwards, Euler (2008) criticises the current state of education as one of the central barriers of innovation. Also the Nabatech-study indicates: "the relation of technology and natural sciences seems to be redefined under the growing transdisciplinarity aspects that haven't merged in the scientific and professional routine a long time ago has not yet been reflected in the educational system" (acatech/VDI, 2009, p. 15). Similar to the STEM discussion in the anglophone world is German's MINT discussion which started a few years ago and is currently on the upswing. Discussed topics are MINT-skilled labour, tertiary MINT education, general MINT education, MINT schools, extramural MINT learning locations, teachers' MINT education and the questions of gender in MINT degree programs. The discussions lead to opposed results as participants bring in different intentions and a different level of depth.

Thus, the German federal ministry for economic affairs and energy (BMWi) demanded a broader general pre-university engineering education for everyone subsequent to a seminar on "education and technological open-mindedness" in 2014. Further they stated that technology and engineering should be topics to deal with at school (BMWi, 2014). Also associations and organisations discuss MINT. Thus, an international VDI expert conference on "interdisciplinarity as a challenge for subject-specific pedagogy" concerning general education took place in 2013. Also DGTB (German Association for pre-university Engineering Education) broached the issue of MINT in 2014 and discussed chances and risks with different outcomes.

At the same time there are study results that focus on MINT, for instance a Delphi study on "concepts and contexts of ETE" (Rossouw, de Vries, & Hacker, 2010), a European comparative study on MINT education (Renn et al., 2012) and a Delphi study on "future visions of out-of school MINT education" (Huck & Haan, 2013). The recently published Telekom study (Ralle, 2012) for instance deals with MINT pedagogy in Germany. This experts' evaluation on the current situation surprisingly works without including representatives of pre-university engineering education. Also the result reflects the negating of technology and engineering, its scientification and the excluding of the international debate on pre-university engineering education.

The result states that subject-specific pedagogy were on the right path and how the pedagogy of several sections would be a serious problem for future development of quality in means of teacher training. It is obvious that international debates are being blended out and that engineering education and its subject-specific pedagogy is not noticed and accepted as a discipline.

All in all there seems to be a certain agreement on MINT having to have a significance in the educational system. However, the term MINT remains undiscussed throughout large parts of Germany and merely functions as a label for a field that subsumes mathematics, computer sciences, natural sciences and engineering uncritically (Graube, 2013, 2014).

Academic Learning Opportunities

The implementation of technology into school brings the difficulty of technology having many features. Thus, it can be assigned to different subjects and fields of education. This led to technology only seldom appearing as an independent subject within the traditional core subjects (German, Mathematics and e.g. Physics). In addition to a rarely independent subject of technology there are also fields of studying holding technical contents (e.g. economy and work, economy and technology, nature and technology). State-specific orientations, the different assignment of these subjects, the implementation of fields of studies as elective or required subjects and the assignment to different levels of education and age groups additionally make a contribution to Germany's "patchwork rug".

A measure catalogue of KMK (2009) allots strengthening mathematic-natural scientific education. This catalogue emerged from the background of needing to build up problemsolving competences in view of school and especially in regard of PISA results (cf. OECD, 2001, 2003, 2010). Thus, continuous classes of natural sciences are scheduled for grades five to ten. It is either taught in integrated natural-scientific engineering classes or interdisciplinary classes (cf. KMK, 2009).

Pre-university engineering education in primary schools seems to play an inferior role in KMK's recommendations. A reason might be that classes at primary schools are orientated holistically. Primarily the examination of natural sciences and technological sciences is assigned to the subject of Social Studies throughout most German states. Upon analysing different framework plans, Mammes and Schäffer (2014) found out that technology is absolutely fixed as a field of study, a topic or a perspective. Hereby, the distribution of contents as well as of quantity remain heterogeneous. It should be noted that several states explicitly offer the subjects Crafting or Crafting Education in addition to Social Studies. Hereby, engineering contents are imparted to some extent. However, the subject is primarily about conventional crafting, so to say creating and building with matter and building material. Technological connections and effectiveness are seldom part of the examination (Mammes & Schäffer, 2014). Technological contents are hardly implemented in primary school classes, if anything it happens unsystematically and sporadically. This seems to be connected with German teachers' training which does not include training in the fields of natural sciences or technological sciences.

Accordingly, competences concerning the implementation of pre-university engineering education seem to be missing (Mammes & Tuncsoy, 2013; Mammes et al., 2012).

In the fifth and sixth form, MINT is framed by schedules of German educational policy. In that, mathematics and natural sciences are assured and indisputable fields of study. For computer sciences as well as for technology there are gaps in the types of schools, in the continuation and the positioning. The implementation of technology is hereby highly diverse and incomplete (Hartmann, Kussmann, & Scherweit, 2008). Also for the recently introduced subjects on nature and technology in the sixth form a high diversity can be asserted as a reaction of the federal states on the KMK recommendations (Graube & Mammes, 2013). In a study on the sixth form entry subjects' denotations are analysed on the appearance of the following terms in subjects' titles: biology, chemistry, physics, technology or engineering sciences, nature or natural sciences and computer sciences or computer. The determined subject terms appear to be greatly heterogeneous and all in all contain 13 different denotations. The results of analyzing teaching manuals show that professional training has a high significance. Subject combinations are handled differently: there are different subject combinations of natural sciences, of nature/natural sciences and technology. The subjects' denotations alone do not allow any conclusions on professional contents. This leads to reductions in content, especially in physics and technology. Further, a divergence between title and content can be observed (e.g. Baden-Württemberg's subject denotation "natural phenomenons" includes the topic of technology) (ibid.).

Thus, school does not fulfil the task of future-oriented education by its traditional core subjects. Upon contemplating the situation of pre-university engineering education, which can and should have a share in the capacity for innovation, it becomes apparent that the implementation of pre-university engineering education, especially in grammar schools, is still unsatisfying: technology in schools is neither taught continuously nor comprehensively. In Germany pupils can pass through an educational background that should prepare them for academic studies without ever getting into contact with pre-university engineering education (Mammes & Schäffer, 2014).

In addition Germany has manifold and extensive offers apart from school that are addressed to children and adolescents as well as schools. According to BMWi (2014) there are more than 15,000 MINT initiatives. However, they remain uncured, not geared and therefore only represent fragments for individuals. A continuous course of education is an exception. The quality and the content of MINT initiatives are incumbent on the provider and are not evaluated in a standardised way in most cases. As these offers are mostly based on voluntariness of learners only individuals with an indigenous interest in technology are reached. Individuals whose potential should be recognised and promoted because they avoid the examination of technology, e.g. due to lacking confidence in their own skills and abilities, are not reached (Mammes, 2014).

Social agents further design forms of admission from schools for their input in the field of MINT. For instance labels, such as MINT school or MINT EC, are assigned or junior engineering academies (Telekom foundation) are established.

TRADITIONAL TECHNOLOGY SPECIFIC PEDAGOGY

Different pedagogies that deal with topics of pre-university engineering education (aim, content, methods) have formed in a long process of development in Germany. The traditional focus for common pre-university engineering education has solely been on crafting and therefore on practical skills for a long time. It was assigned with the specifications of either technological or artistic crafting in school. Further development of pedagogic approaches on technology as well as the introduction of several subjects differentiated clearly between the two German states from 1949 to 1989. In the former Old Federal States a subject on technology developed from technological crafting while on the other side a subject on work-orientated approach as a preparation for the working and business world was introduced, containing technological aspects. These teaching manuals, however, were neither continuous nor obligatory in all types of schools and federal states. In contrast, the former GDR introduced polytechnic classes that are continuous and obligatory for all pupils. After the reunification the former GDR introduced school political rearrangements – also on adopting either the classes on work-orientated approach or on engineering, according to the West-German example.

In conjunction with these changes in educational and school policies, different pedagogic concepts on technology, different models and different approaches formed. The basic approaches are:

- The general technological approach (also system theory approach).
- The multi perspective approach.
- The work-orientated approach.
- The polytechnic approach.
- The systemic approach.

The methodological debate in Germany is partly led controversially. This is justified by the discussion on different models in technology-specific pedagogy that have developed in Germany. Thus, different representatives of technology-specific pedagogy differentiate between subject-specific, multiperspective and socially oriented models, whereat they pay special attention to the West-German development by reflecting it academically (cf. Schmayl, 1992; Schmayl & Wilkening, 1995; Schmayl, 2010). The polytechnic approach which was leading in general-educational schools in the former GDR is not taken into account. This is suggested by Meier (1999), who demands to integrate the different pedagogic approaches. For the development of models and theories in subject-specific pedagogy this means that “advantages of individual models should be bundled cumulatively and disadvantages should be eliminated gradually” (ibid., p. 125). To him, comparing the models like

Schmayl and Wilkening (1995) do it seems problematic due to “obviously confining opposing elements to each other that are hardly comparable” (ibid.).

The System Theory Approach

The system theory approach is based on the development of a common technology as a metascience for technology (cf. Wolffgramm, 1994; Ropohl, 1999). The essential element is a system theoretical view of technology. It says that matter, energy and information are target-orientatedly changed by technological systems. Lessons throughout grammar-schools in North Rhine-Westphalia have been taught according to this approach since 1981 which is determined to connect mathematics and natural sciences (Schmayl, 2010). Critics, however, view this form of pedagogy as a reductional form (Sachs, 1999) and as a restriction of technology from perspective of technological sciences (cf. Schmayl, 1992; Schmayl, 2003; Schmayl, 2010). They criticise a “lacking pedagogic concretion”, an insufficient consideration of learning requirements, a missing “perspective of sense and values” as well as a “qualified theory, developing during the process, as a sole basis” (Schmayl & Wilkening, 1995, p. 64f).

The effort for a scientific foundation of the subject of technics as well as the emphasis on the “claim on the matter” are viewed as ground-breaking. To Meier (1999) the model “primarily reflects the level of content of the educational process and fixates or structures the subject of acquisition” (p.125). In a technical-scientifically minted society the system theoretical basis seems to be particularly important from the current view.

The Work-Orientated Approach

The work-orientated approach focuses on the social dimension of technology. Connections between society, politics and economy form the context which gives the basis for technology. Working becomes the unity-giving principle in order to connect the parts of this integrative approach (Schmayl, 2010). In the process, the term of working is separated into professional, private-domestic and politic-public areas of life. It especially deals with critically illuminating technology and its social context (Schmayl, 2010). If a part of education in general is part of political education in the sense of Hentig (2007) this would be the exact element to examine further.

The targeted focusing of work in an engineered world as well as carving out a sociotechnical character in technology and preparing for an industrial-technical job are said to be ground-breaking (cf. Schmayl & Wilkening, 1995; Meier, 1999). The constitutive correlation of work and technology per se prevents a technicistic view (Schmayl, 2010). Critics, however, notice a restriction of pre-university engineering education at the same time. They criticise the fixation on the term of working, unclear guiding categories, a missing superordinate referring discipline and an insufficient positioning of technology (Schmayl, 2010, p. 138).

The Multi Perspective Approach

The multi perspective approach adopts a technological-scientific, a technological and a pedagogic perspective (Sachs, 1999). It aims to put technological sciences, technology and pedagogics in the right proportion (Schmayl, 2010, p. 122). As here technology is explicitly understood as a part of culture, technics becomes a cultural subject which aims to convey central contents of technology (ibid., p. 123).

It appears to be problematic that such respective sciences – cultural theory of technology – does not exist yet. By differentiating between technology as a natural social and a human dimension there are different assigned perspectives of perception, to wit different scientific disciplines (Ropohl, 1979). Agents describe the approach as “a widely succinct concept, based on an extensive term of technology” (Schmayl & Wilkening, 1995) which is the problematic point about it. Due to the extent of the term of technology there are many respective sciences possible. The special feature of technology, not only being the subject of different sciences but also developed into a whole field of science with engineering technology, remained mostly unappreciated in pedagogic discourses on the multi perspective approach. It did not lead to any pedagogic consequences and the term of culture which is used as a basis of the approach does not seem to define science as a part of culture and does seemingly not want to draw the connection between the two. It also appears problematic to blend out the connections to engineering technology, mathematics and natural sciences which have a high significance in technical development.

Due to a missing respective discipline the approach does not hold an assured table of contents (Schlagenhauf, 2000/2001). Hence, a scheme of categories, containing problem areas and areas of acting, in order to indicate parts of reality and assign contents (cf. Sachs, 2001): (1) work and production, (2) building and built environment, (3) supply and disposal, (4) transport and traffic and (5) information and communication which have been complemented by more categories: household and spare time as well as protecting and securing. However, these fields have never been deduced theoretically until this day, they have gaps and are not free from overlapping. The risen claim to contribute to personality development and world comprehension (Schmayl, 2010) also has to apply for other approaches and is not a feature with an island position.

The Polytechnic Approach

The polytechnic approach represents an integratively applied conception which aims to connect the subject-specific, the socially oriented and conditionally also the multi prospective model (Meier, 1999). This approach was assigned to the polytechnic classes in the GDR. It focuses on the significance of the production process for society and the role of work. Classes put the technical problem solving, the “development of creating” and the “work education” into focus. Polytechnics were understood as a principle, also in its rank in the subjects’ arrangement (cooperating class combination). The closeness, the solid setting and the scientific foundation are said to be ground-breaking. The “overemphasis on the collective face to face with the individual” as well as the “insufficient reference to learners’ reality of life” (cf. Meier, 1999) is criticised.

The Process Oriented Approach

The process oriented approach is traced back to Theuerkauf (2013). It is based on an integral description of technology whereat processes themselves are said to be fundamental. Theuerkauf argues especially from the view of an engineer, upon examining the question which pedagogic approach the modern era needs to connect to. Technological changes with its effects on humans, nature and society, the rising complicity and complexity of technological processes and especially the meaning of digitisation need to experience a reflection in education. His thesis on the matter is: living and working environment are characterised by networked processes so that they form a guideline for a pedagogic approach on technology together with the process orientation.

On the one hand Theuerkauf connects conservatively to the technological processes on material changes, changes in energy and changes in information, on the other hand he introduces innovative transdisciplinary and hybrid approaches and understand technological systems in a new way. Thus, Theuerkauf differs between structurally engineered, technical and interdisciplinary technological systems. In connection to this he discusses methods for process and system shaping and puts emphasis on product lifecycle management. The approach of process oriented education is without a doubt based on an engineer’s mind whereas engineering technologies are demanded to be the leading discipline in technology-specific pedagogy.

An even clearer pedagogic frame working of the approach by product lifecycle management would grant the approach even more conciseness and especially grant it an evident pedagogic-methodical orientation. This wholly on process orientation based view can lead the current discourse on pre-university engineering education in a new direction. By this the headstone of a discussion on integration of pre-university engineering education in natural sciences, demanding more interdisciplinary than ever, is laid. Especially within the examination of interdisciplinarity lies the special and prescinded quality of this approach. The approach can be understood as an appeal to initiate an interdisciplinary process in which different subject-specific pedagogy, the general pedagogy and educational theory contribute to engineering technologies.

The Systemic Approach

Graube (2009) tries to find an integrative approach by introducing the systemic model of technology. It focuses on the creation and the use of technology by presenting three connected levels. The focal point are the technological product in the different phases of acting within its maintenance history. One level beneath there are systems and processes linked to the different phases of acting. The upper level contains social systems and their communication processes. This means every phase of a product's maintenance history holds typical technological systems which are assigned to thinking and acting (e.g. CAD systems in their construct, engineering offices, informational and communicational systems) while typical social systems are assigned to their form of communication (e.g. development teams, project groups).

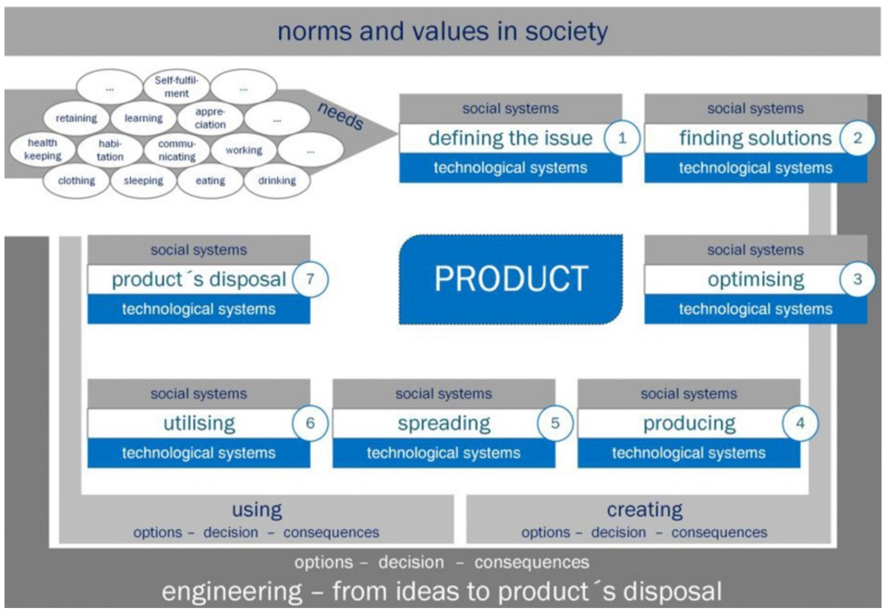

Figure 1. Systemic model of technology (cf. Graube, 2009)

Based on this extended maintenance history of products one can form different views on technology in means of its formation, use and deposition in dependence on Ulrich and Probst (1988). This perspective on technology is – in contrast to a multiperspectivity according to Wilkening (1977/1994) – equitable to different perspective of findings (e.g. the historical perspective of findings, the perspective of findings on product genesis amongst others). By a therewith involved change of view relationships, effects and interdependencies within and in between two levels and their systems can appear which allows a systemic view on technology. It further allows to experience technology and its development more extensively and understand it better. From this level model a pedagogic model on technology is deduced in due consideration of a moderate constructionist attitude.

These traditional approaches on technical general education each have their own weaknesses but cannot build a proper basis for pre-university engineering education only by a continuation of their convention. They do not fulfil the demand for connecting economy with technology and cannot link up general premises on technology. The systemic approach of technical teaching can be understood as an integrative framework which includes different approaches or their elements, expands or accents them differently and arranges them newly. Thereby the approach offers the points to already existing approaches.

VISTA

It has to be noted that within the conflict area of people, nature, technology and society different approaches on pre-university engineering education have been developed. According to the authors, this highly controversially held discussion on the claim on validity and the reach of the individual approaches have not contributed in the further development of subject-specific pedagogy but rather led to an inconsistent presentation to the outside world.

As pedagogic approaches are based on world views and therewith connected views of technology they differ, have strengths and weaknesses and also have to develop with regard to the social change. All in all, pre-university engineering education depicts a non-consistent, permanently changing section which consists of many facets and is hardly represented and fixed in schools. In this situation demands for the subject-specific pedagogy become apparent: Rossouw et al. (2010) and Renn et al. (2012) for instance ask to pass on to a new subject, geared to engineering and technology instead of keeping a traditional orientation on crafting due to the subject's development. A well-founded conception with close interdigitation of mathematics, natural sciences and engineering could do justice to this demand. This would correspond to the intentions of MINT subject combination which, however, does currently not experience an adequate implementation in the framework of a pedagogy conception.

According to the authors such a claim on interdisciplinary can only be turned into a common subject if the following basic assumptions are fulfilled:

- A constructivist understanding of learning and teaching processes.
- Learning settings orientated on solving problems.
- Taking conduct into consideration that is implied by disciplines. For instance natural sciences are herewith based on research whereas engineering is primarily based on development (Graube & Mammes, 2013). Thus, technology would incorporate a figure of integration, connecting research and development.

The consideration of all three basic assumptions can serve as a framework of an integrative, pedagogic conception. A sole examination of individual disciplines is abrogated, instead a teaching and learning process on research and development of technological solutions takes place.

In doing so, the focus should never be on displacing the perspectives of individual subjects from school. They should rather be complemented by a new, forward-looking perspective. Thereby, learners should gather knowledge that makes them capable of acting in handling the challenges of our future society.

REFERENCES

acatech/VDI. (2009). *Ergebnisbericht Nachwuchsbarometer Technikwissenschaften*. München/Düsseldorf: acatech und VDI.

Banse, G. (2013). Erkennen und Gestalten – oder: über Wissenschaften und Machenschaften. In W. Bienhaus & W. Schlagenhauf (Eds.), *Technische Bildung im Verhältnis zur naturwissenschaftlichen Bildung* (pp. 21–49). Offenbach am Main: BE.ER-Konzept.

Baumert, J. (2007). *Schule zwischen Bildungsauftrag und pädagogischen Realismus. Der Bildungsbegriff im Wandel* (pp. 18–21). Berlin: Friedrich-Ebert-Stiftung.

BMWi. (2014, February 19). *Technologieaufgeschlossenheit und Bildung*. Verfügbar unter http://www.bmwi.de/BMWi/Redaktion/PDF/W/workshop-technologieaufgeschlossenheit-und-bildung,property=pdf,bereich=bmwi2012,sprache=de,rwb=true.pdf [4.05.2015].

Buhr, R., & Hartmann, E. A. (2008). *Technische Bildung für Alle. Ein vernachlässigtes Schlüsselelement der Innovationspolitik*. Berlin: Institut für Innovation und Technik.

Dohmen, G. (1989). Bildung und Technik. In L. Boehm & C. Schönbeck (Eds.), *Technik und Bildung* (pp. 37–55). Düsseldorf: VDI-Verlag.

Euler, M. (2008). Situation und Maßnahmen zur Förderung technischer Bildung in der Schule. In R. Buhr & E. A. Hartmann (Eds.), *Technische Bildung für alle. Ein vernachlässigtes Schlüsselelement der Innovationspolitik* (pp. 67–104). Berlin: VDI/VDE Innovation und Technik.

Graube, G. (2009). *Technik und Kommunikation – ein systemischer Ansatz technischer Bildung.* Göttingen: Cuvillier Verlag.

Graube, G. (2013). *Technoscience und Technoscience Education. Zum Paradigmenwechsel didaktischer Bezugsgrößen*. Verfügbar unter http://www.digibib.tu-bs.de/?docid=00048892, http://sunny.biblio.etc.tu-bs.de:8080/DB=1/LNG=DU/und http://gso.gbv.de/LNG=DU/DB=2.1/ [4.05.2015].

Graube, G. (2014). Wissenschaft und Technik. Zur Reflektion von Technoscience und Interdisziplinarität in der Allgemeinbildung. *Journal of Technical Education (JOTED), 1*, 129–148.

Graube, G., & Mammes, I. (2013). *Didaktisches Konzeption eines interdisziplinären Ansatzes „Natur und Technik" für die Gymnasialklassen fünf und sechs*. Verfügbar unter http://www.digibib.tu-bs.de/?docid=00054672 [4.05.2015]

Graube, G., & Mammes, I. (2015). *Gesellschaft im Wandel – Interdisziplinäres Denken im natur- und technikwissenschaftlichen Unterricht*. Vorbereitung: Klinkhardt.

Graube, G., & Theuerkauf, W. E. (2002). *Technische Bildung. Ansätze und Perspektiven.* Frankfurt am Main: Peter Lang Verlag.

Graube, G., Theuerkauf, W. E., & Dyrenfurth, M. J. (2003). *Technology education. International concepts and perspectives*. Frankfurt am Main: Peter Lang Verlag.

Hartmann, E., Kussmann, M., & Scherweit, S. (2008). *Technik und Bildung in Deutschland. Technik in den Lehrplänen allgemeinbildender Schulen. Eine Dokumentation und Analyse.* Düsseldorf: VDI.

Heydorn, H.-J. (1980). *Ungleichheit für alle: zur Neufassung des Bildungsbegriffes*. Frankfurt am Main: Bildungstheoretische Schriften.

Huck, J., & de Haan, G. (2013). *Kurzbericht: MINT-Bildung@Zukunft 2030*. Von Institut Futur, Freie Universität Berlin. Verfügbar unter www.institutfutur.de/sites/default/files/Kurzbericht%20MINT-Bildung@Zukunft2030.pdf [4.05.2015].

Hurrelmann, K. (2006). *Einführung in die Sozialisationstheorie* (9th ed.). Weinheim und Basel: Beltz Verlag.

ITEA, International Technology and Engineering Education Association. (1996, 2007). *Standards for Technological Literacy: Content for the study of Technology* (3rd ed.). Virginia, VA: Author. Retrieved May 4, 2015, from http://www.iteea.org/TAA/PDFs/xstnd.pdf

Jörissen, B., & Marotzki, W. (2009). *Medienbildung – Eine Einführung. Theorien – Methoden – Analysen*. Bad Heilbrunn: Verlag Julius Klinkhardt.

KMK – Kultusministerkonferenz. (2009). *Empfehlungen der Kultusministerkonferenz zur Stärkung der mathematisch-naturwissenschaftlich-technischen Bildung*. Verfügbar unter http://www.kmk.org/fileadmin/veroeffentlichungen_beschluesse/2009/2009_05_07-Empf-MINT.pdf [4.05.2015].

Klafki, W. (1985). Zur Unterrichtsplanung im Sinne kritisch-konstruktiver Didaktik. In W. Klafki (Eds.), *Neue Studien zur Bildungstheorie und Didaktik* (pp. 194–227). Basel: Beltz Weinheim.

Lindemann, H. (2006). *Konstruktivismus und Pädagogik*. München: Ernst Reinhard Verlag.

Mammes, I. (2014). *Technische Bildung von Anfang an – nationale und internationale Perspektiven*. Hohengehren: Schneiderverlag.

Mammes, I., & Schäffer, K. (2014). Anschlussperspektiven? Technische Bildung in der Grundschule und ihrem Übergang zum Gymnasium. In A. Liegmann, I. Mammes, & K. Racherbäumer (Eds.), *Facetten von Übergängen im Bildungssystem. Nationale und internationale Ergebnisse empirischer Forschung* (pp. 79–94). Münster: Waxmann.

Mammes, I., & Tuncsoy, M. (2013). Zur Bedeutung technischer Bildung für die Selbstbildung. In I. Mammes (Eds.), *Technische Bildung von Anfang an - nationale und internationale Perspektiven* (pp. 8–21). Hohengehren: Schneiderverlag.

Meier, B. (1999). Grundstrukturen der Ausbildung von Lehrkräften für den Technikunterricht. In E. Hartmann, C. Hein, C. Schulte, K. Uździcki, & H. Wolffgramm (Eds.), *Technikdidaktik – Entwicklungsstand – Theorien – Aufgaben* (pp. 121–123). Zielona Gora: Fässler.

OECD. (2001). *Knowledge and skills for life: First results from PISA 2000*. Paris: OECD.

OECD. (2003). *The PISA 2003 assessment framework - mathematics, reading, science and problem solving knowledge and skills*. Paris: OECD.

OECD. (2010). *PISA 2012 field trail problem solving framework*. Paris: OECD.

Pongratz, L. A., & Bünger, C. (2008). Bildung. In H. Faulstich-Wieland & P. Faulstich (Eds.), *Erziehungswissenschaft. Ein Grundkurs* (pp. 110–129). Reinbek: Rowohlt.

Ralle, B. (2012). *MINT-Fachdidaktiken in Deutschland. Eine Experteneinschätzung zur aktuellen Situation*. Bonn: Deutsche Telekom Stiftung.

Renn, O., Duddeck, H., Menzel, R., Holtfrerich, C.-L., Lucas, K., Fischer, W., & Pfenning, U. (2012). *Stellungnahmen und Empfehlungen zur MINT-Bildung in Deutschland auf der Basis einer europäischen Vergleichsstudie*. Berlin: Berlin-Brandenburgische Akademie der Wissenschaften.

Ropohl, G. (1979). *Systemtheorie der Technik*. München, Wien: Zur Grundlegung der Allgemeinen Technologie.

Ropohl, G. (1999). *Allgemeine Technologie. Eine Systemtheorie der Technik* (2nd ed.). München, Wien: Hanser.

Rossouw, A., de Vries, M. J., & Hacker, M. (2010). *Concepts and contexts in engineering and technology education: An international and interdisciplinary Delphi study*. Verfügbar unter http://www.springerlink.com/content/4u32551r6h44kx42/ [4.05.2015].

Roth, H. (1965). *Technik als Bildungsaufgabe der Schulen*. Hannover: Hermann Schroedel Verlag.

Sachs, B. (1999). *Zum Stand der Technikdidaktik in Deutschland*. In E. Hartmann, C. Hein, C. Schulte, K. Uździcki, & H. Wolffgramm (Eds.), *Technikdidaktik. Entwicklungsstand – Theorien – Aufgaben* (pp. 29–45). Zielona Gora: Fässler.

Sachs, B. (2001). Technikunterricht – Bedingungen und Perspektiven. *tu – Zeitschrift für Technik im Unterricht*, *26*, 5–12.

Schlagenhauf, W. (2000/2001). Technikdidaktik und Technikwissenschaft – Überlegungen zu einer fachlichen Bezugswissenschaft der Technikdidaktik. *tu – Zeitschrift für Technik im Unterricht, 98–99*, 16,20 und 5–11.

Schmayl, W. (1992). Richtungen der Technikdidaktik. *tu – Zeitschrift für Technik im Unterricht, 65*, 5–15.

Schmayl, W. (2003). Ansätze allgemeinbildenden Technikunterrichts. In B. Bonz & B. Ott (Eds.), Allgemeine Technikdidaktik – Theorieansätze und Praxisbezüge (pp. 131–147). Baltmannsweiler : Schneider.

Schmayl, W. (2010). *Didaktik allgemeinbildenden Technikunterrichts*. Baltmannsweiler: Schneider Verlag Hohengehren.

Schmayl, W., & Wilkening, F. (1995). *Technikunterricht*. Bad Heinbrunn: Klinkhardt.

Tenorth, H.-E. (1994). *„Alle alles zu lehren“. Möglichkeiten und Perspektiven allgemeiner Bildung*. Darmstadt: Wissenschaftliche Buchgesellschaft.

Theuerkauf, W. E. (2013). *Prozessorientierte Technische Bildung*. Frankfurt am Main inter alia: Peter Lang publisher.

Ulrich, H., & Probst, G. (1988). *Anleitung zum ganzheitlichen Denken und Handeln. Ein Brevier für Führungskräfte*. Bern: Verlag Paul Haupt.

Urban, K. K. (2004). *Kreativität. Herausforderungen für Schule, Wissenschaft und Gesellschaft*. Münster: Lit Verlag.

Uździcki, K., Wolffgramm, H. (1999). *Technikdidakitk. Entwicklungsstand – Theorien – Aufgaben*. Zielona Gora: Fässler.

von Hentig, H. (2003). *Die Schule neu denken*. Weinheim: Beltz.

Weber, M. (1921/1972). *Wirtschaft und Gesellschaft*. Tübingen: Mohr Siebeck.

Wilkening, F. (1977/1994). *Unterrichtsverfahren im Lernbereich Arbeit und Technik*. Villingen-Schwenningen: Neckar-Verlag.

Wolffgramm, H. (1978). *Allgemeine Technologie. Elemente, Strukturen und Gesetzmäßigkeiten technologischer Systeme*. Leipzig: VEB Fachbuchverlag.

Wolffgramm, H. (1994). *Allgemeine Technologie*. Hildesheim: Franzbecker.

Wolffgramm, H. (2006). *Allgemeine Techniklehre. Elemente, Strukturen und Gesetzmäßigkeiten*. Frankfurt/Oder: Eigenverlag.

Gabriele Graube
Institute for Educational Sciences
Technische Universität Braunschweig
Germany

Ingelore Mammes
Institute for Education
Universität Duisburg-Essen
Germany

GREG PEARSON

5. CHARACTERISTICS OF PRE-COLLEGE ENGINEERING EDUCATION IN THE UNITED STATES

Any cross-national discussion of education benefits by taking account of the unique factors that shape a particular country's education system. From the point of view of educational change, these factors often constrain what can and cannot be done; how quickly change occurs; and how likely it is that change, once begun, will endure. Thus this chapter begins with a brief description of key facets of the pre-college education system in the United States. This context will help readers calibrate their own experiences in education with what occurs in the United States.

THE U.S PRE-COLLEGE EDUCATION SYSTEM

Pre-college education in the United States spans the earliest introduction of formal schooling, typically kindergarten, age 5, (though some children have even earlier, "pre-kindergarten," experiences), through primary schooling (also called "elementary" and ending at either grade 5 or grade 6 (age 10 or 11), depending on the school), culminating with "secondary" education, ending at grade 12 (age 18). Secondary schooling comprises "middle" and "high" school components, the former beginning at either grade 6 or 7. Pre-college education is the United States is frequently referred to as K-12 education.

In contrast to the situation in many other nations, in the United States the federal government plays a relatively minor role in funding pre-college education. Under the U.S. Constitution, responsibility for K-12 education rests with the 50 states. Only about 12 percent of funding for public K-12 education flows from the federal government, with the remainder coming from localities and states (New America, 2015).

Also in contrast to other parts of the world, in the United States the federal government has relatively little control over what is taught in classrooms. Development of curriculum—the scope and sequence of the subject matter delivered by teachers to their students—is determined by a combination of the states, individual school districts (of which there are more than 14,000), and leadership in individual schools. Most policies governing what curricula are used, how teachers are trained and credentialed, and what is considered acceptable academic performance by students are determined by a combination of state law and elected or appointed advisory boards. The independence of the states with respect to setting the education agenda

M. J. de Vries et al. (Eds.), Pre-university Engineering Education, 65–79.

is highly valued by many but is also responsible for considerable lack of coherence and significant variations in the quality of K-12 education across the country.

One recent exception to a federal role in U.S. K-12 education is the so-called No Child Left Behind Law (NCLB), enacted in 2001 during the administration of President George W. Bush. As a condition for receiving federal education funding, the law required states to test student progress toward ambitious achievement goals in mathematics and English language arts in multiple grades, and it mandated that teachers have documented proficiency in the school subjects for which they are responsible. The law was intended to encourage low-performing schools and states to improve. However, the law has had limited positive impact, in part because not all states used the same rigor in developing and measuring achievement of student learning goals. In addition, nearly all states have been given federal waivers allowing them to miss key elements of NCLB without penalty. A major rewrite of the program, dubbed the "Every Student Succeeds Act," was signed into law by President Obama in December 2015. The new program gives states the lead in deciding how to deal with low-performing schools, and it eliminates the federal role in teacher evaluation.

A second defining feature of the U.S. education system is its reliance on education standards and student assessments. Standards documents spell out the specific knowledge and skills students are expected to acquire at various points in their educational careers. The emphasis on standards as a tool for educational improvement began in earnest in the mid-1980s. A key impetus was the 1983 report, A Nation At Risk (USDOE), which pointed out the relatively low achievement of US precollege students in comparison with their international peers. Standards now exist in some form for nearly every school subject taught in K-12, though the extent of their influence varies considerably. In many subjects, such English language arts, mathematics, and science, standards are designed by groups of subject-matter experts and teachers, often with public input. The resulting document is typically seen to represent a national-level consensus (though not, importantly, a federal mandate). These national documents are often adopted or adapted in some form by individual states, though this is not required. Recently, a new model of standards development has emerged that gives states a more prominent role in the design process. In the case of science, this has resulted in standards that include a substantial engineering component. These standards, the *Next Generation Science Standards* (*NGSS*; Achieve, 2013) will be described in greater detail later in the chapter.

State assessments are used to gauge the performance of individual students, teachers, and schools in a particular state. These tests, administered by the states to comply with NCLB, are considered "high stakes," because there are potentially serious consequences for teachers and schools for sub-par performance. In contrast, the U.S. Department of Education conducts periodic matrix-sample-based national assessments in many K-12 school subjects as part of the National Assessment of Educational Progress (NAEP). These assessments (like the international comparative assessments, Trends in International Mathematics and Sciences Study [TIMSS] and the Program for International Student Assessment [PISA]) do not report scores for individuals. They allow the performance of one state to be compared with another. The US Department of Education tries to coordinate NAEP results in science and mathematics with those from TIMSS and PISA, so states can compare their performance to that of other nations.

Because there is no way to directly connect NAEP results to a specific student (or his or her teacher), these assessments are often referred to as “low stakes.” In 2014, for the first time ever, the NAEP fielded an assessment of “engineering and technology literacy” among a sample of U.S. 8th grade students. The assessment was in three parts, addressing technology and society, design and systems, and information and communications technology. The framework (NAGB, 2013) used to develop the assessment relied on various existing documents and input from experts for its treatment of engineering concepts. Because engineering is not part of the formal curriculum in the United States and because there are no previous results that can be used as a baseline, interpretation of the results, expected to be released in spring 2016, may be difficult.

ENGINEERING IN U.S. K-12 EDUCATION

Though the situation is slowly changing, engineering historically has not been part of the formal K-12 curriculum in the United States. This can be explained in part by Americans’ limited awareness of what engineering is and what engineers do (e.g., Cunningham & Knight, 2004; Cunningham et al., 2006; NAE, 2008). If children and their parents and teachers are largely unaware of engineering or have somewhat negative views of the field, it is not hard to see why public interest in pre-college engineering education has been slow to emerge. Until relatively recently, even the professional engineering community, when advocating for the value of pre-college education, has tended to push for more or higher-quality mathematics and science education, not engineering education per se.

That engineering has been largely outside the mainstream of K-12 education can also be explained by the difficulty of inserting new content into an already packed school curriculum. If engineering is added, one argument holds, something will have to be cut from the existing program to make room. This zero-sum view has some basis in reality, because in many cases there is not much flexibility to shift, combine, let alone drop, pieces of the curriculum. This is especially true in mathematics and English language arts, subjects where teachers are under pressure to spend time preparing students to take mandated state assessments, driven by NCLB requirements. Time spent preparing for the tests leaves less time for other school subjects. In some states, parent objections to these tests have resulted in significant numbers of students opting out of the assessments. For example, in 2015, 20 percent of eligible students declined to take the tests in New York (Harris, 2015).

An additional limiting factor in the uptake of engineering education at the K-12 level is the lack of professional pathways for teachers in this domain. Currently, there are very few university-based teacher-preparation programs that provide engineering coursework to prospective classroom educators. And there is no certification process, as there is for other school subjects like mathematics and science, that assures a basic level of competency for teachers of engineering. Not surprisingly, very few science teachers, less than 10 percent, express confidence in their ability to teach about engineering (Horizon Research, 2013). Certification is available to technology education teachers, and some of these educators are introducing engineering to their students. But this cohort of teachers is quite small compared to those in science and mathematics, and certification for technology educators does not yet address engineering in any meaningful way.

The Role of Standards

Because of the central role that standards have come to play in U.S. education, a final constraint on the inclusion of engineering in U.S. K-12 education has been the relative absence of engineering in these documents, which shape curriculum as well as other aspects of the education system, including teacher education and student assessment.

One of the earliest and best cases for exposing students to engineering ideas was presented in *Science for All Americans*, a 1989 publication of the American Association for the Advancement of Science (AAAS). An elegant argument for the value of science literacy, not standards, the book devoted separate chapters to the nature of technology and to the designed world, effectively defining "science" to include technology, engineering, and mathematics. The document laid the groundwork for the first K-12 science education standards in the United States, also developed by AAAS, *Benchmarks for Science Literacy* (1993). *Benchmarks* presents many concepts often associated with engineering, such as design, feedback, trade-offs, constraints, systems, and failure, but it does so mostly in the context of technology. It also devotes substantial attention to the important ethical and social dimensions arising from the relationship between humans and the technological world.

Benchmarks was soon followed by publication of the *National Science Education Standards* (*NSES*; NRC, 1996), which recommended learning goals for K-12 students in the life, physical, and earth and spaces that were very similar to *Benchmarks'*. But *NCES* was organized differently, placed greater emphasis on the doing of science ("science inquiry"), and included high-level guidance for effective teaching, professional development, and assessment. Like *Benchmarks*, *NSES* made almost no reference to engineering, but it did suggest students develop abilities of "technological design" and understand a number of related concepts. Technological design was portrayed as the identification of particular human needs or problems and developing, testing, and evaluating solutions to them. Concepts deemed important for student understanding included criteria, constraints (e.g., costs, time, materials), and trade-offs. Overall, however, technological design activities were expected to play a relatively minor role in the science classroom:

Because the study of technology occurs within science courses, the number of these activities must be limited. Details specified in this standard are criteria to ensure quality and balance in a small number of tasks and are not meant to require a large number of such activities. Many abilities and understandings of this standard can be developed as part of activities designed for other content standards (NRC, 1993, p. 192).

In the late 1990s, the International Technology Education Association (now, the International Technology and Engineering Educators Association, ITEEA), began work on its own standards, the first for the field. Technology education, with roots in manual training and industrial arts (Herschbach, 2009), is a small segment of U.S. K-12 education, but it is an especially important one because of its historical focus on constructivist learning strategies. As part of the process of developing the standards, ITEEA asked the National Academy of Engineering (NAE) to review an early draft of the document for quality and appropriate coverage of technical topics. The NAE review, and a subsequent review by a committee of the National Research Council (NRC, 1999), precipitated major changes in the draft, including the addition of content related to engineering. Compared with the earlier science standards, *Standards for Technological Literacy: Content for the Study of Technology* (ITEEA, 2000) went into greater detail on the conceptual underpinnings of engineering and technology, and it provided more emphasis on application of the design process (Table 1).

Emerging Consensus on the Big Ideas in K-12 Engineering Education

Since publication of *Standards for Technological Literacy,* educators, education researchers, and others have continued to wrestle with how best to characterize the concepts, skills, and dispositions of engineering appropriate for K-12 education. Eight such efforts (ASEE CMC, 2008; Childress & Rhodes, 2008; Childress & Sanders, 2007; Custer et al., 2009; Hacker et al., 2011; Koehler et al., 2005; NAE & NRC, 2009; Sneider, 2006), using methodologies such as Delphi study, literature reviews, focus groups, and an expert consensus process, identified 30 characteristics of engineering felt to be relevant to K-12 education. Eight of the 30 were cited by four or more of the eight assessments (Table 2).

Throughout the 2000s in the United States, there was a surge in development of K-12 engineering curricula, funded by the National Science Foundation, a government agency, as well as by industry and philanthropic organizations. As more and more of these projects emerged, it became possible for education researchers and others to explore how the theoretical framing of engineering presented in standards and other documents was represented in instructional materials. One such effort, led by the NAE in collaboration with the NRC (2009), collected materials from over 30 K-12 engineering curriculum projects, analysing 15 of them in depth. One result of this study was a "beads and threads" model (Figure 1) intended to help explain how engineering was being presented in the curricula.[1]

Table 1. Engineering-related topics in standards 2, 8, 9, 10, 11 of Standards for Technological Literacy
(Copyright © 2007 International Technology and Engineering Educators Association. Reprinted with permission)

	Standards	*Benchmark topics Grades K-2*	*Benchmark topics Grades 3–5*	*Benchmark topics Grades 6–8*	*Benchmark topics Grades 9–12*
2	The Core Concepts of Technology	• Systems • Resources • Processes	• Systems • Resources • Requirements • Processes	• Systems • Resources • Requirements • Trade-offs • Processes	• Systems • Resources • Requirements • Optimization and Trade-offs • Processes
8	The Attributes of Design	• Everyone can design • Design is a creative process	• Definitions of design • Requirements of design	• Design leads to useful products and systems • There is no perfect design • Requirements	• The design process • Design problems are usually not clear • Designs need to be refined • Requirements
9	The Attributes of Design	• Engineering design process • Expressing design ideas to others	• Engineering design • process • Creativity and considering • all ideas • Models	• Iterative • Brainstorming • Modeling, testing, • evaluating, and modifying	• Design principles • Influence of personal characteristics • Prototypes • Factors in engineering design

10	The Role of Troubleshooting, Research and Development, Invention and Innovation, and Experimentation in Problem Solving	• Asking questions and making observations • All products need to be maintained	• Troubleshooting • Invention and innovation • Experimentation	• Troubleshooting • Invention and innovation • Experimentation	• Research and development • Researching technological • problems • Not all problems are technological or can be solved • Multidisciplinary approach
11	Apply the Design Process	• Solve problems through design • Build something • Investigate how things are made	• Collect information • Visualize a solution • Test and evaluate solutions • Improve a design	• Apply design process • Identify criteria and constraints • Model a solution to a problem • Test and evaluate • Make a product or system	• Identify a design problem • Identify criteria and constraints • Refine the design • Evaluate the design • Develop a product or system using quality control • Reevaluate final solution(s)

Table 2. Core engineering concepts, skills, and dispositions, selected sources

Source	*Method*	*Design*[1]	*Connections to science, technology, and mathematics*	*Engineering and society*	*Constraints*	*Communication*[2]	*Modeling*	*Optimization*	*Analysis*
Hacker et al. (2009)	International Delphi Study	✓		✓			✓	✓	
Custer et al. (2009)	Literature review, focus groups, "reaction panel"	✓			✓		✓	✓	✓
NAE & NRC,[3] 2009	Consensus study	✓	✓			✓	✓		✓
ASEE CMC (2008)	Meetings of experts	✓	✓	✓		✓			
Childress & Sanders (2007)	Literature review	✓	✓		✓	✓			
Childress & Rhodes[4] (2008)	Focus groups and modified Delphi study	✓	✓	✓	✓	✓	✓	✓	✓
Sneider (2006)	Literature review, experience with curriculum development	✓	✓	✓	✓				
Koehler et al. (2005)	Not specified	✓	✓	✓	✓	✓		✓	✓

[1] *Includes both understanding and doing design.*
[2] *Communication includes use of computer and computer-based tools.*
[3] *The core concepts, skills, and dispositions from the study were taken from the three principles outlined in Chapter 6.*
[4] *Participants in the Childress and Rhodes Delphi study achieved consensus on 43 "outcome items" for high school students hoping to purse engineering in college. Only those who ranked 3.5 or higher (on a 5-point Likert scale) are included in the table.*

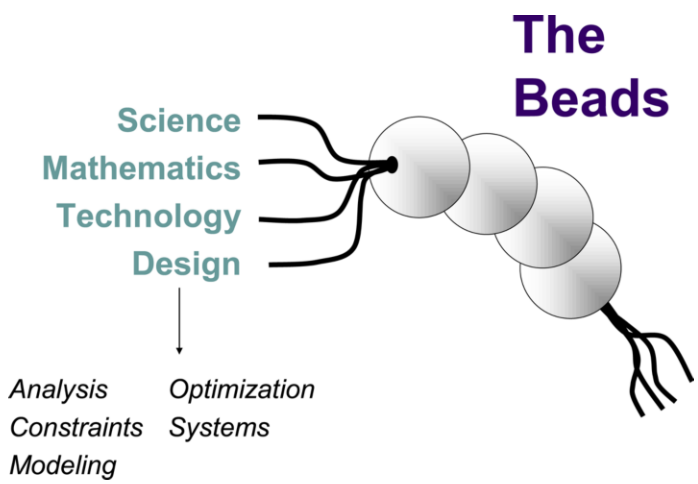

Figure 1. Beads-and-threads model of K–12 engineering curricula

In the model, the beads represent the "packaging" in which the engineering content of the curriculum is delivered to students. Most of the curricular materials used interesting technologies, such as the Internet and cell phones, digital video and movie special effects, and electronic music, to package content into manageable chunks. Other developers organized materials around hands-on learning activities familiar to and popular with many students and teachers, like making and testing CO2-powered dragsters, magnetic-levitation vehicles, water-bottle rockets, model rockets, and Rube Goldberg devices. The content of several curricula was organized around the design process itself, with lessons and learning activities for identifying problems, gathering information, brainstorming solutions, drawing plans, making models, building prototypes, and making presentations. Sometimes, prominent local or regional industries were used as examples in interdisciplinary thematic units. The material in one curriculum was organized around traditional fields of engineering (e.g., civil, environmental, electrical, agricultural, and mechanical engineering).

The threads, which run through the beads, represent the core concepts and basic skills a curriculum is designed to impart, independent of the particular packaging. Three threads, mathematics, science, and technology, represent domain knowledge in these subjects that is used in engineering design. A fourth thread represents the engineering design process. The design thread incorporates a number of specific attributes of engineering design, such as analysis, constraints, modeling, optimization, and systems. Design and its attributes were defined by the expert committee that oversaw the study as follows:

Design—a purposeful, iterative process with an explicit goal governed by specifications and constraints.

Analysis—a systematic, detailed examination intended to (1) define or clarify problems, (2) inform design decisions, (3) predict or assess performance, (4) determine economic feasibility, (5) evaluate alternatives, or (6) investigate failures.

Constraints—the physical, economical, legal, political, social, ethical, aesthetic, and time limitations inherent to or imposed upon the design of a solution to a technical problem.

Modeling—any graphical, physical, or mathematical representation of the essential features of a system or process that facilitates engineering design.

Optimization—the pursuit of the best possible solution to a technical problem in which trade-offs are necessary to balance competing or conflicting constraints.

Trade-offs—decisions made to relinquish or reduce one attribute of a design in order to maximize another attribute.

System—any organized collection of discrete elements (e.g., parts, processes, people) designed to work together in interdependent ways to fulfill one or more functions.

The expert committee found that most curricula emphasized select threads of the beads-and-thread model, such as science or mathematics concepts. In many cases, multiple elements of the model were either missing or presented in ways the committee deemed to be incomplete or incorrect. This was especially true for how the design process was portrayed. Even so, the model and the curriculum analysis suggested several high-level principles (Box 1) that the committee said should guide K-12 engineering education in the United States moving forward.

Box 1. General Principles for K-12 Engineering Education

Principle 1: K-12 engineering education should emphasize engineering design.

Principle 2: K-12 engineering education should incorporate important and developmentally appropriate mathematics, science, and technology knowledge and skills.

Principle 3: K-12 engineering education should promote engineering habits of mind. Habits of mind include (1) systems thinking, (2) creativity, (3) optimism, (4) collaboration, (5) communication, and (6) attention to ethical considerations.

SOURCE: Adapted from NAE and NRC, 2009

Centrality of Engineering Design and the Challenge of STEM Integration

As K-12 engineering education continues to evolve in the United States, engineering design is emerging as the foundation upon which both pedagogy and student learning are being built. While a variety of models of engineering design have been proposed, nearly all of them share the qualities of being systematic and iterative. Design is a non-linear process that includes steps that can be repeated, although not always in the same order. The steps typically include research, brainstorming, planning, prototyping, testing, and improving the design. Engineering design is purposeful, always beginning with an explicit goal. If it were a journey, it would be one with a specific destination, not a random sightseeing trip. Engineering design is also a social, collaborative enterprise. It is often done in small teams that include people with different kinds of knowledge and experience. Designers are continuously communicating with clients, team members, and others. And, done well, engineering design provides application opportunities for concepts and practices in other subjects, including not only science and mathematics, but also history, literature, and art.

While engineering has much to offer students and their teachers, implementing engineering in the classroom in ways that are authentic, age appropriate, and that connect with other parts of the curriculum in meaningful ways is challenging. Most teachers in the United States stilll know little about engineering or how to teach it. Findings from the cognitive sciences and education research (NAE & NRC, 2014, Chapters 3 and 4) suggests learning in integrated ways often requires more time, additional student supports, and more flexible school structures that allow teachers opportunity to plan and collaborate.

LOOKING TO THE FUTURE

NGSS was developed by a consortium of 26 states, and, as of this writing, 15 states and the District of Columbia have officially adopted the standards. More states are expected to join them. Adoption is merely the first step in a years-long process of implementation, which will require development of new curriculum materials, assessments, and teacher professional development. More than any previous version of national standards, *NGSS* creates opportunity for introducing a large number of U.S. students to engineering, many for the first time. The standards present a new model called "3-D learning," in which core ideas, crosscutting concepts, and practices in science and engineering are blended in student performance expectations. Engineering design is integrated into selected performance expectations in in the three disciplinary areas of life, physical, and earth and space sciences, and it is also included as a separate standard in each of the four grade bands, K-2, 3–5, 6–8, and 9–12. A more detailed explanation of engineering and how it should be understood in the context of K-12 science education is contained in *A Framework for K-12 Science*

Education: Practices, Cross-Cutting Concepts, and Core Ideas (NRC, 2012), which guided development of NGSS.

Relative to other models of engineering design, the version in *NGSS* is relatively simple, comprising concepts in three areas: defining a problem, developing solutions, and optimizing the solution. Embedded in this three-part model are many of the ideas others have identified as important: criteria, constraints, research, testing, and iteration. For K-12 engineering education, the significance of the standards lies less in the specifics of how engineering design is portrayed and more in the large size of the science teacher corps in the United States. At over 210,000 in 2012 (NCES, 2014), it is nearly an order of magnitude larger than the cohort of technology educators. At this relatively early stage of implementation, however, the focus of the states and of teachers seems to be mostly on the challenge of understanding the document's call for 3-D learning, not on the engineering component.

NGSS presents the *possibility* of a new era of more integrated science and engineering education, but the fate of pre-college engineering education in the United States does not hinge solely on what happens with the new standards. For one thing, there are a number of well-established curriculum projects that show no sign of going away (Box 2). In addition, the College Board, a non-profit organization that develops a variety of college-entry exams and courses for advanced high school study, is considering developing a new Advanced Placement course in engineering. And, as noted, the federal government is expected to release results from an assessment of student engineering and technology literacy early next year. Both developments may bring added attention to K-12 engineering education.

Box 2. Examples of Established K-12 Engineering Curricula

Project Lead the Way

Project Lead the Way (PLTW; www.pltw.org) was started in the late 1980s by a New York high school technology education teacher. In the late 1990s, with support from a private foundation, PLTW created a high school curriculum that was adopted by a number of New York high schools. PLTW offers engineering-focused coursework at the high school and middle school levels, and recently launched a new elementary program. PLTW teachers take part in a two-week summer training program to be certified to deliver the curriculum. PLTW claims a a presence in more than 6,000 schools across all 50 states.

Engineering is Elementary®

Engineering is Elementary® (EiE; www.eie.org) is a 10-year-old project of the National Center for Technological Literacy® at the Museum of Science, Boston. EiE consists of 20 units, each of which has a hands-on engineering design challenge combined with a thematic storybook, teacher guide, and a materials kit. The EiE project conducts workshops and other teacher professional development activities to support use of the curriculum, As of November 2014, EiE says more than 72,000 teachers and 6.6 million students across the country have used EiE in all 50 states plus Washington, DC.

Engineering by Design™

Engineering byDesign™ (EbD; www.iteea.org/ebd) is a K-12 curriculum project developed by ITEEA. The units address topics across the spectrum of technology and engineering, and they are used primarily by technology education programs in a 20-state consortium. Through its STEM Center for Teaching and Learning, ITEEA provides professional development for teachers planning to use the EbD curriculum.

There is also a small but vibrant group of learning scientists and education researchers who continue to push our understanding of how important ideas and practices in engineering education are best taught and learned, and when and how connections to other subjects will be most effective (e.g., Purzer et al., 2014).

In summary, in the United States, after almost two decades of experience, there is general agreement on the characteristics of engineering important to the education of K-12 students. From the standpoint of implementation, much more work, by practitioners and researchers, is needed to identify and refine successful approaches to more integrated forms of STEM education. Teachers—whether in science, technology, mathematics, or other subjects—will need to know more, not only about engineering but also about other disciplines. And they will need to be given greater opportunity to work collaboratively with their peers and, potentially, with others, such as STEM professionals. From a policy perspective, the current lack of viable pathways for development of engineering literate K-12 educators is perhaps the most important looming challenge.

NOTE

[1] This study examined the intended curriculum, looking only at the written documentation and other instructional materials provided by the curriculum developers. The study did not consider the enacted curriculum, what teachers actually do in the classroom. Education research has documented significant inconsistencies between intended and enacted curriculum.

REFERENCES

AAAS (American Association for the Advancement of Science). (1989). *Science for All Americans. Project 2061. AAAS*. New York, NY: Oxford University Press.

AAAS. (1993). *Benchmarks for science literacy. Project 2016. AAAS*. New York, NY: Oxford University Press.

Achieve, Inc. (2013). *Next generation science standards: For states, by states*. Washington, DC: The National Academies Press.
ASEE CMC (American Society for Engineering Education Corporate Member Council). (2008). *K-12 STEM guidelines for all Americans*. Retrieved October 15, 2015, from https://www.asee.org/member-resources/councils-and-chapters/corporate-member-council/special-interest-group/cmc-k12-stem-guidelines-for-all-americans-rationale.pdf
Childress, V., & Rhodes, C. (2008). Engineering student outcomes for grades 9–12. *The Technology Teacher, 67*(7), 5–12.
Childress, V., & Sanders, M. (2007, February 11–13). *Core engineering concepts foundational for the study of technology in grades 6–12*. Paper presented the National Symposium to Explore Effective Practices for the Professional Development of K-12 Engineering and Technology Education Teachers, Dallas/Ft. Worth, TX.
Cunningham, C., & Knight, M. (2004, June 20–23). *Draw an engineer test: Development of a tool to investigate students' ideas about engineers and engineering*. Proceedings of the 2004 American Society for Engineering Education Annual Conference and Exposition, Salt Lake City, UT.
Cunningham, C., C. Lachapelle, & Lindgren-Streicher, A. (2006, June 18–21). *Elementary teachers' understandings of engineering and technology*. Proceedings of the 2006 American Society for Engineering Education Annual Conference and Exposition. Chicago, IL. (Washington, DC: ASEE.)
Custer, R.L., Daugherty, J. L., & Meyer, J. P. (2009, July 8–9). *Formulating the conceptual base for secondary level engineering education—A review and synthesis*. Paper presented at the NAE Workshop on Standards for K-12 Engineering, Washington, DC.
Hacker, M., DeVries, M., & Rossouw, A. (2011). Concepts and contexts in engineering and technology education: An international and interdisciplinary Delphi study. *International Journal of Technology and Design Education, 21*(4), 409–424.
Harris, E.A. (2015, August 12). *20% of New York State students opted out of standardized tests this year*. Retrieved October 12, 2015, from http://www.nytimes.com/2015/08/13/nyregion/new-york-state-students-standardized-tests.html?_r=0
Herschbach, D. R. (2009). *Technology education—Foundations and perspectives*. Homewood, IL: American Technical Publishers.
Horizon Research. (2013). *Report of the national survey of science and mathematics education*. Retrieved October 15, 2015, from www.horizon-research.com/2012nssme/wp-content/uploads/2013/02/2012-NSSME-Full-Report1.pdf
Koehler, C., Faraclas, E., Sanchez, S., Latif, S. K., & Kazerounian, K. (2005). *Engineering frameworks for a high school setting: Guidelines for technical literacy for high school students*. Proceedings of the 2005 American Society for Engineering Education Conference. Retrieved from http://soa.asee.org/paper/conference/paper-view.cfm?id=21254
NAE (National Academy of Engineering). (2008). Changing the conversation: Messages for improving public understanding of engineering. In *Committee on public understanding of engineering messages*. Washington, DC: National Academies Press.
NAE and NRC (National Academy of Engineering and National Research Council). (2009). Engineering in K-12 education: Understanding the status and improving the prospects. In L. Katehi, G. Pearson, & M. Feder (Eds.), *Committee on K-12 engineering education*. Washington, DC: National Academies Press.
NAE and NRC. (2014). *STEM integration in K-12 education: Status prospects, and an agenda for research* (M. Honey, G. Pearson, & H. Schweingruber, Eds.). Washington, DC: National Academies Press.
NAGB (National Assessment Governing Board). (2013). *Technology and engineering literacy framework for the 2014 national assessment of educational progress*. Retrieved October 16, 2015, from https://www.nagb.org/content/nagb/assets/documents/publications/frameworks/technology/2014-technology-framework.pdf
NCES (National Center for Education Statistics). (2014). *Institute of education sciences. Digest of Education Statistics. Table 209.10, Number and percentage distribution of teachers in public and*

private elementary and secondary schools, by selected teacher characteristics: Selected years, 1987–88 through 2011–12. Retrieved October 16, 2015, from http://nces.ed.gov/programs/digest/d14/tables/dt14_209.10.asp

New America. (2015, June 19). *Federal, state, and local K-12 school finance overview* (Updated). Retrieved January 22, 2016, from http://atlas.newamerica.org/school-finance

NRC (National Research Council). (1999). *Final letter report of the international technology education association standards review committee*. Washington, DC: National Academies Press.

NRC. (1996). *National science education standards*. Washington, DC: National Academy Press.

NRC. (2012). *A framework for K-12 science education: Practices, cross-cutting concepts, and core ideas.* Committee on Conceptual Framework for New K-12 Science Education Standards. Retrieved January 22, 2016, from http://www.nap.edu/catalog/13165/a-framework-for-k-12-science-education-practices-crosscutting-concepts

Purzer, S., Strobel, J., & Cardella, M. E. (2014). *Engineering in pre-college settings: Synthesizing research, policy, and practices*. West Lafayette, IN: Purdue University Press.

Sneider, C. (2006, November 12). Draft learning progressions for engineering design. *Boston Museum of Science*. (Unpublished).

USDOE (US Department of Education). (1983, April). *A nation at risk: The imperative for educational reform*. Retrieved January 22, 2016, from http://www2.ed.gov/pubs/NatAtRisk/index.html

Greg Pearson
U.S. National Academy of Engineering
Washington, D.C.
USA

CHRISTINE M. CUNNINGHAM

6. ENGINEERING EDUCATION FOR ELEMENTARY STUDENTS

INTRODUCTION

In the last two decades educators have begun advocate for the inclusion of engineering at the pre-university level. Before this time, efforts were focused on students at the secondary level – a goal was to recruit and prepare students for engineering majors in college. More recently, attention has turned to involving younger children – elementary children – in engineering activities. For a dozen years, my team and I have been leading the effort in the United States to introduce engineering concepts and practices to elementary-aged children in both school and out-of-school (afterschool and summer camp) educational settings. This chapter summarizes what we have learned from the literature, our close work with classroom teachers, and the testing of our curricular materials in thousands of classes and programs nationwide. The chapter begins by articulating some of the reasons why educators should consider introducing young students to engineering. It then explores some of the goals that should underlie engineering activity. Finally, it concludes with a few features of engineering lessons that should be considered.

WHY SHOULD YOUNG CHILDREN ENGINEER?

Time is precious in classrooms; why should educators include another new discipline – engineering? Engineering has the potential to engage students with their hands and minds as they learn how to tackle problems in a structured, yet creative way. Early exposure to engineering activities helps children develop skills that are important for success in school and life such as making decisions based on data, working in teams, and persisting through failure. There are a number of reasons why it's important to introduce young children to engineering; these include:

Engineering Fosters Children's Natural Dispositions as Engineers and Problem-Solvers

Watch young children at play and you'll see them engage in problem solving and engineering behaviors. They build bridges, forts, towers, and contraptions. They watch them topple, take them apart, modify, and improve them. Children often imagine, draw, and construct fantastical solutions for new devices or technologies.

M. J. de Vries et al. (Eds.), Pre-university Engineering Education, 81–99.

We need to nurture and build upon such natural inclinations by engaging kids in engineering activities from young ages.

Engineering Helps Children Understand Their World

We spend over 98% of our time interacting with the human-made (or engineered) world around us. The clothes we wear, the forks we use to eat, the bicycles we pedal, the bandages we apply, and the smartphones we rely on are all products of engineering. To understand the world in which they live, children should recognize that engineered products surround them and should develop a basic understanding of how such technologies are created.

Engineering Can Bolster Children's Motivation and Engagement

Children enjoy the challenges of engineering. Asking children to engage with relevant, engineering design projects can motivate, engage, and interest them more than traditional curricula (Barron et al., 1998; Lachapelle et al., 2011; Moffett, Weis, & Banilower, 2011). Engineering design projects often foster children's sense of agency and encourage them to take responsibility for their learning (Fortus, Dershimer, Krajcik, Marx, & Mamlok-Naaman, 2004; Kolodner et al., 2003; Silk, Schunn, & Cary, 2009). Participation in engineering activities can also help children (re)consider their own capabilities and foster their affiliation with or identity as an engineer.

Engineering Offers Potential to Increase Science and Mathematics Learning

Engineering projects can encourage children to apply science or mathematics concepts and as they address relevant, interesting contexts and problems. Students who manipulate science knowledge as they engage in engineering projects improve their understanding (Fortus et al., 2004; Kolodner et al., 2003; Lachapelle et al., 2011; Sadler, Coyle, & Schwartz, 2000; Wendell, Connolly, Wright, Jarvin, & Rogers, 2010). Because students are also using mathematics as they engineer, they may also increase mathematical achievement (Diaz & King, 2007).

Engineering Develops Practices That Are Important for Success in School and Life

As they grapple with engineering challenges, particularly those that are problem-based (Krajick & Blumenfeld, 2006), open-ended, and hands-on, children engage in epistemic practices (Kelly, 2008). As they engineer, children develop facility collaborating in teams, brainstorming multiple solutions, problem-solving, iterating, making data-driven decisions, communicating designs and results, and persisting in the face of failure. Identifying, modeling, and scaffolding such practices with children provides them with accurate ideas about the kind of work engineers do. And it develops foundational habits they can use and build upon in later school grades and life (Cunningham & Carlen, 2014).

ELEMENTARY ENGINEERING RESOURCES

Engineering began to make its way into elementary classrooms as a distinct, named discipline about a dozen years ago. (Prior to this engineering activities were occurring in some classrooms but were part of/subsumed in "technology" or "design" education.) As engineering came into its own, curriculum developers, engineers, and educators have started to develop materials to help teachers include it in their lessons. Current elementary engineering resources for educators include curricula and such as:

Engineering Is Elementary (www.eie.org)

The Engineering is Elementary (EiE) project has produced a school-based curriculum for children ages 6–12. EiE's 20 units each focus on a field of engineering and integrate with a science topic children study in elementary school. Each four-lesson unit begins with an illustrated storybook to set the context and culminates with children using a five-step engineering design process to design and create a technology. EiE units also make significant connections to math, social studies, and literacy learning. EiE has also created an elementary engineering curriculum for out-of-school-time (afterschool and summer camp) programs called Engineering Adventures.

Hands-On Standards® STEM in Action (www.hand2mind.com/brands/hands-onstandards)

Hands-On Standards has been designed curriculum for children ages 5–13. Similarly to EiE, the Hands-On Standards curriculum integrates math and science with engineering. These units, however, are designed to be particularly easy to implement, with shorter lessons and simpler activities, streamlined objectives, and the inclusion of some direct instruction.

Novel Engineering (http://www.novelengineering.org)

The Novel Engineering project focuses on integrating literature and engineering with children ages 5–14. After reading books or other literature, students identify an engineering problem the characters face and then engages in the engineering design process to design solution to the challenge. The project primarily reaches its goals through professional development work with teachers, and does not prescribe any particular curriculum of books, challenges, or a design process in order to allow students to explore their own ideas. The project is currently engaged in creating curricular materials.

ENGINEER (www.engineer-project.eu)

The ENGINEER project drew heavily upon the EiE framework to develop curricular units for use European schools with children from ages 9–12. A collaborative of European educators developed 10 units, each with a focus on a field of engineering. Each unit contains four lessons and is grounded in the same engineering design process used by EiE.

PLTW Launch (https://www.pltw.org/pltw-launch)

Project Lead the Way has developed the Launch curriculum from children ages 5–12. According to the website, four modules are identified for each grade. The curriculum can only be accessed by members.

Other Resources

In addition to curriculum, a couple of online collections of lessons and hands-on activities feature an array of elementary engineering activities. These include:

> *Teach Engineering (www.teachengineering.org) and TryEngineering (www.tryengineering.org).*

IMPORTANT GOALS OF ELEMENTARY ENGINEERING ACTIVITIES

What should engineering look like in elementary school? How can engineering lessons interest and engage *all* students, particularly those who have traditionally been underrepresented or underserved in engineering and science fields? These are questions I set out to explore when I started the *Engineering is Elementary* project. Over the past dozen years, my team and I have written hundreds of elementary engineering lessons, working closely with hundreds of teachers as well as afterschool and summer camp educators. We've spent approximately 2000 hours observing children doing the activities and collected over 100,000 elementary student engineering journals and assessments. The educational research literature, our experiences, and our research have helped us outline some important principles for elementary engineering.

Overall we believe that children need to learn to engineer by *doing* engineering – by doing the kinds of activities engineers do and using the practices that engineers use. As they work through age-appropriate engineering problems, children develop engineering understandings and practices, and ways of seeing and thinking about the world (Kelly, 2014). As with all disciplines, the design of engineering activities for elementary students needs to begin by considering where the children are developmentally – what are the physical, cognitive, and social abilities of children?

Our years of research have helped us identify several critical components of effective elementary engineering curricula. Including these components helps assure that children will build understanding of both the content knowledge and the practices of engineering. This section describes seven features (or design parameters) of engineering activities and challenges that we believe should be present in elementary engineering. These design parameters are the result of a review of the literature, our work developing curricula, field testing lessons in elementary schools, and conducting research about children's learning.

Develop Understandings of Engineering and Technology

Children come to school with well-formed ideas about the world around them. They already have some (mis)conceptions of what "engineering" and "technology" are. Introducing engineering instruction with activities that help children to develop clear, accurate, and complete understandings of these foundational concepts is critical.

Children, like many adults, have limited or incorrect understandings of what engineering is. Children often describe engineers as train drivers, auto mechanics, construction workers, and people who use large machines (Capobianco, Diefes-Dux, Mena, & Weller, 2011; Cunningham, Lachapelle & Lindgren-Streicher, 2005; Fralick, Kearn, Thompson, & Lyons, 2009; Karatas, Micklos, & Bodner 2010, Knight & Cunningham, 2004). Children focus on constructing structures, especially buildings and bridges, and also indicate that they believe engineers fix or repair items such as engines, motors, or cars (Lachapelle, Shams, Hertel, & Cunningham, in review). The *object* of work (structure, electronics, motors) is often what children focus on rather than or in addition to the *type* of work (designing, improving) that is being accomplished (Lachapelle et al., in review).

Children's understandings of technology are similarly inaccurate or incomplete. In countries around the world, elementary children consistently associate technologies with items that are "high tech" and use electricity, such as cell phones, computers, and televisions (Burns, 1992; de Vries, 1996; Jarvice & Rennie, 1996, 1998; Jocz & Lachapelle, 2012; Solomonidou & Tassios, 2007). Research demonstrates that children generally understand that natural items, such as trees, flowers, or animals are not technologies. However, children often do not recognize that simple human-made items – such as shoes, a basket, or a broom – or mechanical technologies – such as a piano, bicycle, or roller blades – are also technologies (Lachapelle, Oh, Shams, Hertel & Cunningham, in review).

A critical goal of pre-university engineering education is that children (and their teachers) develop robust understandings of what engineering and technology are… and are not. We use the following age-appropriate definitions of each:

> Technology: Any human-made object, system, or process that is used to solve a problem or fulfill a desire.
>
> Engineering: The process by which humans solve problems through the design or analysis of a technology.

We understand that, historically, “technology” has often been considered to subsume engineering—after all, engineering can be considered to itself be a set of human-derived, technological processes. However, like many others (Clark & Andrews, 2010; ITEA, 2000; NGSS, 2013) we find it helpful to teachers, students, and parents to highlight engineering as a discipline with its own culture (and subcultures) and collections of disciplinary practices. Engineering is more than the technological processes and products that comprise it; it is also a human endeavour practiced by both professionals and amateurs, evolving and growing with each new generation of practitioners.

How can we help young children generate understandings of engineering and technology through classroom activities and instruction? We begin all of our engineering instruction with two lessons – one designed to help children construct an understanding of technologies as human-made for a purpose, and one that connects the problem-solving process that humans naturally engage in with engineering. Here I briefly describe two exemplar activities; we have now developed a number of such lessons, all of which aim to develop similar ideas.

What is technology?/Technology in a bag. We launch classroom engineering with an activity designed to help learners understand the range of things (technologies) that engineers create. We begin by asking children, “What comes to mind when you hear the word “technology?” Children brainstorm ideas and their thoughts are recorded by the teacher.

Then, every pair of children is given a small brown paper bag. Inside the bag is a technology. These can include a wide variety of small items – a plastic spoon, a binder clip, a glue stick, a barrette, a hotel key card, a ping pong ball, a train schedule, and a recipe are some examples that we have used. We try to include examples of technologies that are objects, systems, and, for older students and adults, processes. The children open the bag and reveal their technology. Then they discuss with their partner the following questions:

- What is the technology?
- What does your technology do? What problem does it solve?
- How else could you use it?
- What material(s) is it made of?
- What other materials could it be made of?

After the pairs have explored their technology, each group introduces their technology to the class by answering these questions. After the class has seen the range of items that are all considered technologies, students are challenged to generate a definition of the word “technology.”

For many students (and teachers) the activity prompts them to construct a new definition of technology. Because most of the examples are low-tech, students need to adjust their understandings to include these more common items in their definitions.

What is engineering? Tower power. Also foundational to engineering is an understanding of the problem solving process that engineers use to design technologies. Following their explorations of technology, we engage children in an activity that develops their awareness of engineering as a process. Children are introduced to a problem they are asked to solve. Every student group is given a pack of index cards and 12 inches (30 cm) of tape, and is asked to design a structure that will display a small stuffed animal. As they ask questions to clarify the problem, they learn that the structure must be above a specific height and that their structure must support the animal for 10 seconds. Children work in small groups for 40 minutes using the materials to design a tower that meets all of the criteria. When the time is up, the groups present their designs to the class, test them with the stuffed animal, and discuss possible improvements.

After all groups have shared and tested, the class reflects on the design process. Using verbs, students describe the different things they did, and from their responses, the teacher outlines a simple engineering design process. This activity illustrates how instinctive it is for humans to identify and use the engineering design process.

From these two introductory activities, children construct an understanding of the pervasiveness of technology in our world. They also recognize that they naturally use a process to try to solve problems which can be codified as an engineering design process. A grasp of these two foundational concepts is a critical part of engineering education.

Expose Students to a Range of Types of Engineering and Technologies

Another goal of engineering education should be to expose students to a range of types of engineering and technologies. Helping children construct a robust understanding of the impact of engineers or engineering on society is another parameter for selecting or design engineering activities: activities should expose children to a variety of fields of engineering and a diversity of technologies. Children come with narrow views of the types of work that engineers do. Some may have a notion of civil engineering, computer engineering, and perhaps mechanical engineering. They are much less likely to understand that engineering also encompasses the work of biomedical, industrial, green, environmental, or chemical engineers. To help children develop a comprehensive view of the types of work in which engineers engage, it is important to introduce them to more than the "standard" fields. Broadening students' view of engineering is beneficial because some of the less-stereotypical fields are also those that tend to be more attractive to and populated by women (Yoder, 2014).

Children should have the opportunity to design a variety of technologies that represent a range of engineering fields. However, especially at the elementary level this can be challenging. Many of the engineering activities that are currently available, particularly for young children, focus on structures (civil engineering) or vehicles (mechanical engineering). It is rare to find challenges that invite children to act as biomedical or chemical engineers. This is understandable – appropriate challenges of this sort are much more difficult to develop for young children. In part this is because the objects that such engineers manipulate are often less accessible or understandable, for instance, they might be microscopic. Curriculum developers must think carefully and creatively about how to convey impressions of the kinds of work engineers in these fields might do while also respecting the limited knowledge that children can draw upon to address a challenge. However, to accurately represent engineering and to attract a range of types of students, educators should select or develop engineering challenges that help children construct an understanding of the diverse types of products that engineers design. Instead of the standard suite of cars, rockets, bridges, robots, buildings, catapults, and egg drops, children should try their hand at engineering bandages, playdough, or a prosthetic limb. They should also design processes such as those used to clean up an oil spill or make ice cream.

Provide a Context That Highlights How Engineers Help People

Exposing children to the diverse range of technologies that engineers design also helps us achieve another important goal. Engineering activities should provide a context that highlights how engineers help people. Children learn better when they engage in meaningful, purposeful, and relevant activity (Brophy, Klein, Portsmore, & Rogers; 2008). Helping children to understand the relevance and purpose for what they are doing can help motivate and engage them, particularly girls (Burke; 2007). Setting design challenges in a larger context can help children to see why they might engage in the activity, realize there are natural constraints and criteria they need to consider, and see the relevance of what they are studying in the larger world.

The context-setting should also stress how engineers help people, animals, society, or the environment (Cunningham & Lachapelle, 2014). These type of connections can be particularly important to girls and underrepresented minorities; research has shown that girls are more interested in "helping" careers (Jones, Howe, & Rua; 2000; Miller, Blessing, & Schwartz, 2006). A study by the United State National Academy of Engineering (National Academy of Engineering, 2008) found that messages that connected engineering to its impact on the world and how it helps people resonated most strongly with youth. They recommended four messages:

- Engineers make a world of difference
- Engineers are creative problem solvers
- Engineers help shape the future
- Engineering is essential to our health, happiness, and safety.

Thinking carefully about the context of design activity, particularly how it can highlight how engineers are helping others or shaping their world, is something educators can add even when such information is not endemic to the activity. A rich context can go a long way in shaping children's perceptions of or affiliations with a challenge. For example, instead of engaging children in a context-free egg drop that relates little to the real-life, the activity might be recast so children are thinking about how to protect food, water, and clothing that need to be air-dropped into disaster-hit areas. A task that asks children to program a robotic vehicle to successfully follow a line might be enriched by a context detailing the need to send robots to look for victims in remote areas hit by an earthquake that are still too dangerous or inaccessible to humans.

There is more than one way to set a rich context for engineering challenges. Our three engineering curriculum development projects each use a different medium to establish an age-appropriate narrative and set a context for the activities.

Our *Engineering is Elementary* curriculum is a school-based elementary engineering curriculum. It uses an illustrated child's storybook to set a context for each unit. The book relates the story of a protagonist living in a country somewhere around the globe who encounters a challenge that s/he solves with the help of an engineer. The children in the class then address the same problem. For example, in one unit, children hear from Teyha, a Native American who experiences an oil spill on her beloved river. Working with an environmental engineer she reflects upon the damage this could have on the local ecosystem and considers methods and processes that are used to clean oil spills from water.

The *Engineering Adventures* curriculum is designed for elementary out-of-school (summer camp and afterschool) programs. It features a brother-sister duo, India and Jacob, who travel the world encountering engineering challenges. As they do, they send emails back to the children asking for their help solving various challenges. These messages are available to the students in print or in audio form. For example, in one green engineering unit set in Senegal, India and Jacob solicit children's help to design toy "racers" (vehicles) made entirely from recycled materials as toys often are in African countries.

The *Engineering Everywhere* curriculum designed for middle school children in out-of-school programs uses a ten-minute documentary-style video to set the context for the challenge the kids will pursue. For example, one video focuses on the design of safety helmets and how these can protect the heads of athletes such as those who compete in roller derby.

In each of these cases, the context motivates students to design a solution that people, society, pets or other animals have encountered. Every engineering challenge should begin with an activity that communicates the role of engineering in shaping the world in which we live.

Engage Children in Hands-On Challenges That Use Materials

Children make sense of the world around them by actively exploring it so engineering should engage children in hands-on challenges that use materials. At the elementary level it is critically important that children are engaged with physical materials. In engineering challenges, the opportunity to externalize complex concepts or principles onto physical components, break systems into smaller parts to investigate, and receive sensorimotor feedback may reduce the cognitive load and enable children to engage in challenges that are fairly complex (Levy, 2013; Roth, 1996). As children manipulate objects, tools, and materials they come to construct understandings about the possibilities that the materials can afford and also their limitations – they begin to develop an understanding of the properties of materials.

One fundamental engineering principle that should be cultivated in children during elementary school is that materials have properties and these properties govern which materials might work best for a given task. An activity might begin by exploring what a properties of a material are. Materials often have many properties and having students generate lists of these helps them to think about them as they also expand their vocabulary – "strong" and "soft" might be familiar words but "translucent" or "malleable" might be a new word and a critical descriptor. Helping children assemble a rich library of properties they can assess prepares them for engineering work. As they engineer, children also need to learn to focus on the features that are relevant to the challenge at hand. What attributes do you want a bridge to have? What about a hand pollinator? Children, especially young children, may need a scaffolding to select materials that are strong (bridge) or that are fluffy (hand pollinator), instead of focusing on those they like for aesthetic reasons (e.g., they are pink or shiny) or that bear a surface resemblance to common examples of a technology (e.g., children choose heavy white felt to make a sail for a model boat because of its color).

Once children articulate or understand what their technology is supposed to do, they can think about the attributes it needs to have. Then they can reflect on which individual materials might have properties that will be relevant. With practice, children will come to realize that understanding the properties of individual materials is a vitally important part of engineering.

Children need to develop their familiarity with how materials behave. A seven-year-old often will not be able to predict which materials – eraser, marbles, aluminum foil, tape, pompoms, or pipe cleaners – would transport "pollen" (baking soda) well as part of a hand pollinator design. To help children construct this knowledge, during each of our engineering activities we allot time for children to engage in materials exploration. After the challenge is introduced but before they begin to brainstorm solutions, children engage in an activity to help them focus on and learn more about the available materials and their properties. The children are given a small sample of each material that they will be able to use. For example, in the hand pollinator challenge children are provided with the materials listed above (eraser, marble etc.). They are encourage to touch and manipulate them. As a class, the children generate a list of the properties of those materials.

They make predictions about which material might work best for the stated challenge, in this case to pick up and drop off pollen. They think about *why* certain materials might work. Then they test each material individually and create a class data table to display their results. After considering the results of the testing, the class describes which materials worked best to pick up and drop off pollen,

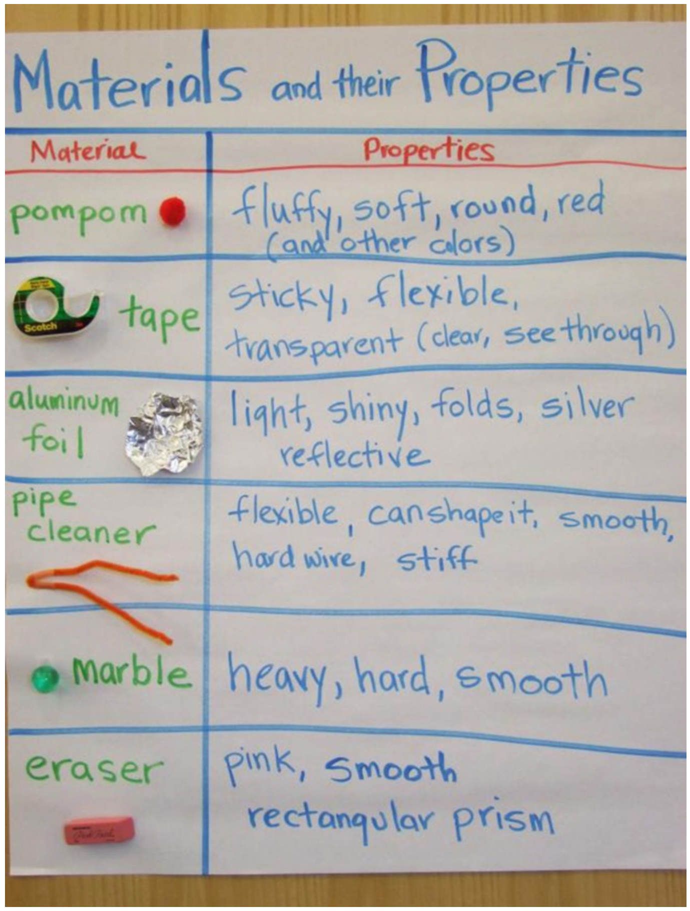

Figure 1. Materials and their properties table

evaluates their prediction, and identifies which properties of the materials seemed to be important.

Developing this knowledge of properties of materials should be a central part of elementary engineering. Children need opportunities to predict, test, and reflect about materials and their properties as they are engaged in meaningful challenges. They also need practice thinking about which properties matter to the challenge they are addressing.

The exploration of materials helps position the students so they can approach their challenge from a position of knowledge. As they begin to brainstorm possible solutions, the students can draw upon their understandings and data to inform their designs.

Provide Open-Ended Challenges with Multiple Solutions

After gaining experience with a variety of different materials, students begin to realize that in the world of engineering, challenges rarely have one and only one solution – much depends on the context, the trade-offs, and the client's preferences. Early engineering experiences should provide open-ended challenges with multiple solutions. Engineering solutions are never "final"; human ingenuity, preferences, and scientific advances push toward improvements or modifications in the technologies. Classroom engineering challenges should model this open-ended nature of engineering and invite students to think creatively instead of funneling them toward a single, correct answer.

This does not mean all solutions are viable or equally as good. Instead, as in the real world, a series of criteria and constraints should govern children's work. If students evaluate their solutions against these criteria they can assess how well their design meets the stated goals or determine whether modifications to an original design improved or detracted from it. It follows that, as they establish design specifications for a classroom engineering challenge, educators should check that they will allow a range of solutions.

In addition to supporting creative and innovative ideas, opening the problem space can also serve to pique children's interest and participation. Teachers regularly report that children in their classes who had been turned off by standard activities that drive toward a singular answer are re-engaged by open-ended engineering challenges in which multiple diverse solutions are allowed and celebrated.

Foster Groupwork and Sharing

A great way to generate lots of idea and consider multiple solutions is to work in groups. Elementary engineering lessons should foster groupwork and sharing. Most adult engineers work in teams and learning to attend to, work with, and negotiate with others is also an important elementary school skill.

In engineering classrooms, investigating and designing work is usually best done in small groups (2–4 children) but whole class sessions also play an important role. Students can learn a lot if they are given the opportunity to look across a range of solutions and reflect upon what seems to work well as well as what does not. Periodically throughout an engineering challenge, teachers may pause, reconvene the whole class and ask each group to report out on specific questions or aspects of their designs. As children describe their work and findings they practice valuable communication, observation, and listening skills. Pointing out the benefits of utilizing the ideas of all students and groups in the classroom can model for children how a class can generate knowledge and how designs can be enhanced by seeking input or ideas from outside the team. By working in pairs or small groups as they engineer, children need to communicate their ideas, explain their thinking, consider the perspectives of others, develop a plan, and negotiate when ideas differ.

Present Engineering as a Cyclical, Iterative, Problem-Solving Process

As students work together, revise plans, test and re-test solutions, they come to recognize engineering as a cyclical, iterative problem-solving process. Perhaps the central message of engineering at the elementary level is that engineers solve problems in a principled matter which can be described as a process – the engineering design process. Engineering design processes used in industry or college often include a dozen or more steps. Elementary children, as novices, have difficulty grasping this number so we created an age-appropriate engineering design process with five steps – Ask, Imagine, Plan, Create, and Improve.

Figure 2. The engineering is elementary engineering design process

Of course, in the real world adherence to a rigid set of steps does not occur, nor should it in the classroom. Instead, the articulation of steps or phases of the process should be used as a way to help structure children's work and thinking. The process thus serves as a heuristic to support activities around problem solving, design, and analysis. As they become more experienced and more fluent engineers, the students will naturally move back and forth between the various steps as they employ skills that they need for the task they are addressing. An important feature of engineering design is that it is iterative; thinking about how to improve a design launches another cycle of the process.

When confronted with a problem to solve, many children want to jump right in and start constructing something. One role an articulated process can play is to help children (and adults) reduce impulsivity, consider problems more systematically, and draw upon what they already know. They are invited to Ask questions, Imagine a variety of possibilities, and make a Plan. By calling out these types of background work, children Create more thoughtful designs that are successful within the context of the problem. Of course, most children immediately want to

Improve what they have designed, and approach this by Asking what they can make better.

OTHER CONSIDERATIONS FOR ELEMENTARY ENGINEERING LESSONS

Constraints and Criteria

The purpose of engineering is to create a technology that meets a set of goals articulated by a client. In classrooms, the audience for students' work is often the teacher. To move away from this artificial client, engineering in schools can set problems in contexts with expected clients. Designing effective solutions to a problem requires children to understand what they are aiming to do and how their solutions will be evaluated. What features matter and how much? Engineering solutions are bounded by constraints and criteria. Children need to develop an understanding of the types of constraints that are common in engineering – limited materials, resources, money, and time. They also need to know the specifications or criteria that their solution will need to meet to be considered successful. Articulating criteria and constraints clearly to children and explaining how they will assess their solutions should be part of the introduction to the engineering challenge. We usually provide and review the rubrics that children will use to judge their designs as part of the problem specification.

For example, one EiE design challenge asks children to develop a process for cleaning a model oil spill. Students are told that their solutions will be judged on three criteria: (a) a cost score, which reports how much their technology will cost based on the price of the materials it uses, (b) a shore score, which reports whether any oil from the spill remains on the model riverbank after clean up, and (c) an ecosystem impact score which evaluates how much oil is left on the water. Students rank each of these on a rubric and then total the number of points. These three criteria are articulated as they begin to explore their work so all students are aware of what they need to consider and optimize.

Brainstorming and Creativity

Once children understand the expectations and requirements for their work, they can start to undertake it thoughtfully. A key element of engineering is innovation; it aims to generate new, creative ideas and solutions. Thus, classroom engineering challenges should also require and reward children's creativity. Students should brainstorm to generate a diversity of possible solution paths. Teachers should encourage pupils to generate and try original, risky ideas and celebrate out-of-the-box thinking. This may represent a change for children from their regular school day expectations, but one that many embrace. Fostering children's creativity and unique approaches to problems can help cultivate the habits of mind that lead to innovative ideas and solutions.

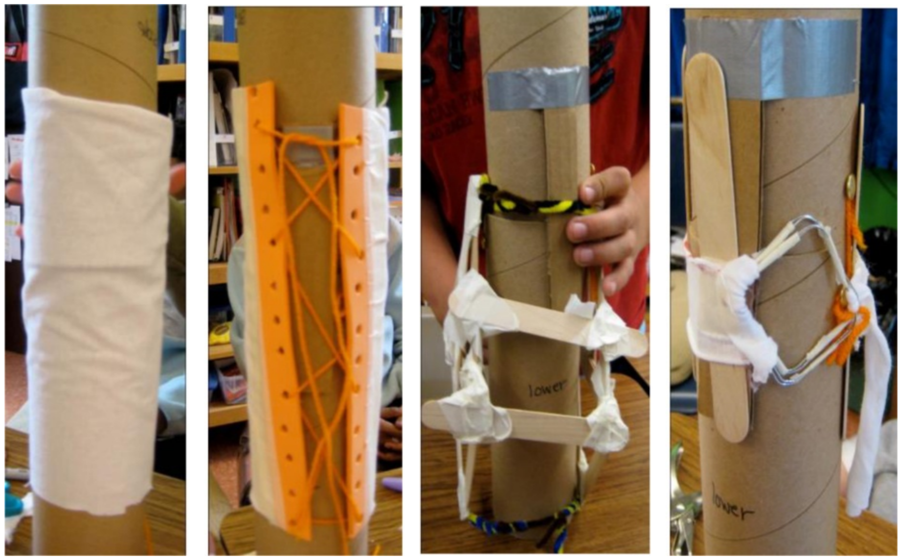

Figure 3. Four student designs for a knee brace

To help organize elementary children's brainstorming and to encourage quiet children or those who might need more time to reflect to share ideas, our curricular materials ask children to work individually to draw two to four different ideas for how they might approach any given problem. After they document these, children share their ideas with their partner or small group. The teacher stresses the value of surfacing multiple ideas and instructs the children to think about which elements from all the various designs they might want to choose as parts for their first concrete plan. As a group, the children can discuss which ideas they will include in their group plan.

Collecting and Using Data

Helping children to think as engineers also means nurturing their abilities to make and justify decisions based in data. Throughout the engineering design process, children should be drawing from information and collecting, analyzing, and using data. We strive to have children record quantitative metrics that they can analyze. One of the challenges in developing engineering challenges is figuring out which data children might collect that can inform their decisions. Like most adults, children become attached to their favorite idea and may not recognize its weaknesses or consider other equally or more viable alternatives. Asking students to collect numerical data, or rank feature of their design on a rubric, can help provide an "objective" measure of their designs' performance. These tasks often involve pooling data across different teams' results, allowing each student team to learn from the others. Such data can be especially useful as a team compares the various design solutions they generated. As they engineer, students should be asked what data supports the decisions that they make.

For example, in the oil spill challenge, students collect data to determine which cleanup process worked best. As mentioned previously, children knew their designs would be evaluated in three areas – cost, oil on the shore, and oil on the water. Cost is readily calculated based on the pricelist of the materials and then converted into a score (1–6). The impact of the oil spill on the riverbank is determined by laying a piece of brown butcher paper across the shoreline to detect whether oil is still present in the soil (+5 points) or not present (0 points). (A low score is better on the rubric.) Finally children lay a paper grid across the surface of the water, circle any oil spots the paper detected, and convert their data to a third score. All these factors are combined to produce a "total score," which teams use to compare their designs. More importantly, students complete a worksheet asking them to reflect upon their data to determine which parts of the process they would change during two subsequent improvements.

Failing and Improving

Taking risks or trying something new means that you often don't get it "right" immediately. Part of the engineering design process is failing. In fact, engineers must "fail often to succeed sooner." (Nightline, 1999). Children's designs rarely work well on the first attempt, so a central pedagogical concern when designing elementary engineering activities should be helping children to persist through and learn from failure. Teachers need to help students understand that failure is a natural part of the design process. For some students (those who are used to striving for a single, correct answer) this might initially be unsettling. But for others, often those who have not been that successful in traditional school classrooms, the freedom to take risks, without the usual negative consequences if something does not work the first time, is liberating.

All children need to understand that the important part of failing is the learning that takes place. Including a critical "Improve" step in the engineering design process communicates to children that encountering failure is an expected part of what they will do. However, curricular materials and instructional strategies an also help children to productively manage their failed or less-than-functional attempts. For example, in our unit on agricultural engineering, after children create their hand pollinator technology, they test it and collect data about its performance pollinating a model flower. Inevitably, some of the group's initial designs do not work well or at all. Most children are naturally highly motivated to continue to redesign. But helping to focus their efforts can be valuable. Thus, as part of the Improve step, students are asked to reflect upon which features of their design worked well and which did not. All students, regardless of how well their technology performed, complete this worksheet. Not only does it help them attend to the strengths and weakness of their designs but it also communicates the message that technologies can always be improved!

Improving on existing technologies is the primary way new technologies are engineered. Solutions are never really "final"; human ingenuity, preferences, and scientific advances push toward modifications and advances in technology. The smartphone we carry today was preceded by flip phones, cordless home phones, and rotary phones. To reflect this, some engineering challenges could start by asking how they might improve an existing or a mal-functioning technology.

Access, Affiliation, and Agency

A last set of considerations when developing engineering activities focuses on developing children's access, affiliation, and agency (Brown, Reveles, & Kelly, 2004). As we develop engineering abilities in children, we should carefully consider how we might develop materials so they attract and include *all* students, not just those types of people who are currently represented in engineering and science fields (Cunningham & Lachapelle, 2014).

Effective elementary engineering activities do not require access to expensive or specialized materials. General principles of engineering remain constant whether computers and high-tech gadgets are used or whether children are designing with paper, tape, and recycled materials. Developing affordable challenges increases the likelihood that underserved children can participate. Furthermore, designing with simple materials allows children to continue to improve their technologies at home. A number of teachers have reported that interested students continued engineering outside of school and were able to do so because they could easily find the components. All children, especially those low-income schools and homes, should have access to high-quality engineering lessons.

Helping children to see themselves as capable engineers is something both curriculum and instruction should foster. Valuing children's ideas and solutions, helping them to understand that the work they are engaged is engineering, referring to them as "engineers," all can help children develop an affiliation with engineering or an identity as an engineer. Connecting the work that students to do the work that is done by "real" engineers can also help children understand that they are capable of and might consider jobs as engineers. Regardless of their future career plans, all children should gain an appreciation for their abilities as problem solvers from their engineering work.

REFERENCES

Barron, B. J. S., Schwartz, D. L., Vye, N. J., Moore, A., Petrosino, A. Zech, L., Bransford, J. D., & The Cognition and Technology Group at Vanderbilt. (1998). Doing with understanding: Lessons from research on problem-and project-based learning. *Journal of the Learning Sciences*, *7*(3/4), 271–311.

Brophy, S., Klein, S., Portsmore, M., & Rogers, C. (2008). Advancing engineering education in P-12 classrooms. *Journal of Engineering Education*, *97*(3), 369–387.

Brown, B. A., Reveles, J. M., & Kelly, G. J. (2005). Scientific literacy and discursive identity: A theoretical framework for understanding science learning. *Science Education*, *89*, 779–802.

Burke, R. J. (2007). Women and minorities in STEM: A primer. In R. J. Burke & M. C. Mattis (Eds.), *Women and minorities in science, technology, engineering and mathematics* (pp. 3–27). Northampton, MA: Edward Elgar Publishing.

Burns, J. (1992). Student perceptions of technology and implications for an empowering curriculum. *Research in Science Education*, *22*(1), 72–80.

Capobianco, B. M., Diefes-Dux, H. A., Mena, I., & Weller, J. (2011). What is an engineer? Implications of elementary school student conceptions for engineering education. *Journal of Engineering Education*, *100*(2), 304–328.

Clark, R., & Andrews, J. (2010). Researching primary engineering education: UK perspectives, an exploratory study. *European Journal of Engineering Education, 35*(5), 585–595.

Cunningham, C. M., & Carlsen, W. S. (2014). Precollege engineering education. In N. Lederman (Ed.), *Handbook of research on science education* (pp. 747–758). Mahweh, NJ: Lawrence Erlbaum Associates, Publishers.

Cunningham, C. M., & Lachapelle, C. P. (2014). Designing engineering experiences to engage *all* students. In S. Purzer, J. Strobel, & M. Cardella (Eds.), *Engineering in pre-college settings: Synthesizing research, policy, and practices* (pp. 117–142). Lafayette, IN: Purdue University Press.

Cunningham, C. M., Lachapelle, C. P., & Lindgren-Streicher, A. (2005). *Assessing elementary school students' conceptions of engineering and technology.* Proceedings of the American Society for Engineering Education Annual Conference and Exposition, Portland, OR.

de Vries, M. J. (1996). Technology education: Beyond the "technology is applied science" paradigm. *Journal of Technology Education*, *8*(1), 7–15.

Diaz, D., & King, P. (2007, June 24–27). *Adapting a post-secondary STEM instructional model to K-5 mathematics instruction.* Proceedings of the American Society for Engineering Education Annual Conference and Exposition, Honolulu, HI.

Fortus, D., Dershimer, R. C., Krajcik, J. S., Marx, R. W., & Mamlok- Naaman, R. (2004). Design-based science and student learning. *Journal of Research in Science Teaching, 41*(10), 1081–1110.

Fralick, B., Kearn, J., Thompson, S., & Lyons, J. (2009). How middle schoolers draw engineers and scientists. *Journal of Science Education and Technology*, *18*(1), 60–73.

International Technology Education Association [ITEA]. (2000). *Standards for technological literacy: Content for the study of technology*. Reston, VA: Author.

Jarvis, T., & Rennie, L. J. (1996). Understanding technology: The development of a concept. *International Journal of Science Education*, *18*(8), 977–992.

Jarvis, T., & Rennie, L. J. (1998). Factors that influence children's developing perceptions of technology. *International Journal of Technology and Design Education*, *8*(3), 261–279.

Jocz, J., & Lachapelle, C. (2012). *The Impact of Engineering is Elementary (EiE) on students' conceptions of technology*. Boston, MA: Museum of Science.

Jones, M. G., Howe, A., & Rua, M. J. (2000). Gender differences in students' experiences, interests, and attitudes toward science and scientists. *Science Education*, *84*(2), 180–192.

Karatas, F. O., Micklos, A., & Bodner, G. M. (2011). Sixth-grade students' views of the nature of engineering and images of engineers. *Journal of Science Education and Technology, 20*(2), 123–135.

Kelly, G. J. (2014). Discourse practices in science learning and teaching. In N. G. Lederman & S. K. Abell (Eds.), *Handbook of research on science education* (Vol, 2, pp. 321–336). Mahwah, NJ: Lawrence Erlbaum Associates.

Knight, M., & Cunningham, C. M. (2004). *Draw an Engineer Test (DAET): Development of a tool to investigate students' ideas about engineers and engineering.* Proceedings of the American Society for Engineering Education Annual Conference and Exposition, Salt Lake City, UT.

Kolodner, J. L., Camp, P. J., Crismond, D., Fasse, B., Gray, J., Holbrook, J., Puntambekar, S., & Ryan, M. (2003). Problem-based learning meets case-based reasoning in the middle-school science classroom: Putting Learning by Design into practice. *Journal of the Learning Sciences, 12*(4), 495–547.

Krajcik, J., & Blumenfeld, P. (2006). Project-based learning. In R. K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (pp. 317–334). New York, NY: Cambridge University Press.

Lachapelle, C. P., & Cunningham, C. M. (2007). Engineering is elementary: Children's changing understandings of science and engineering. In *ASEE Annual Conference & Exposition* (p. 33). Honolulu, HI: American Society for Engineering Education.

Lachapelle, C. P., Cunningham, C. M., Jocz, J., Kay, A. E., Phadnis, P., Wertheimer, J., & Arteaga, R. (2011). *Engineering is elementary: An evaluation of years 4 through 6 field testing*. Boston, MA: Museum of Science.

Lachapelle, C. P., Oh, Y., Shams, M. F., Hertel, J. D., & Cunningham, C. M. (in review). What is technology?: A simple instrument for measuring children's conceptions. *Journal of Engineering Education.*

Lachapelle, C. P., Shams, M. F., Hertel, J. D., & Cunningham, C. M. (in review). Measuring elementary school children's conceptions of engineers. *Journal of Engineering Education.*

Levy, S. T. (2013). Young children's learning of water physics by constructing working systems. *International Journal of Technology and Design Education*, *23*, 537–566.

Miller, P. H., Blessing, J. S., & Schwartz, S. (2006). Gender differences in high-school students' views about science. *International Journal of Science Education*, *28*(4), 363–381.

Moffett, G. E., Weis, A. M., & Banilower, E. (2011). *Engineering is elementary: Impacts on students historically underrepresented in STEM fields*. Chapel Hill, NC: Horizon Research Inc.

National Academy of Engineering. (2008). *Changing the conversation: Messages for improving public understanding of engineering*. Washington, DC: National Academies Press.

NGSS Lead States. (2013). *Next generation science standards: For states, by states*. Washington, DC: The National Academies Press.

Nightline (Writer). (1999). The deep dive: Five days at IDEO. Nightline with Ted Koppel. *ABC News.*

Roth, W.-M. (1996). Art and artifact of children's designing: A situated cognition perspective. *Journal of the Learning Sciences, 5*(2), 129–166.

Sadler, P. M., Coyle, H. P., & Schwartz, M. (2000). Engineering competitions in the middle school classroom: Key elements in developing effective design challenges. *Journal of the Learning Sciences*, *9*(3), 299–327.

Silk, E. M., Schunn, C. D., & Cary, M. S. (2009). The impact of an engineering design curriculum on science reasoning in an urban setting. *Journal of Science Education and Technology, 18*(3), 209–223.

Solomonidou, C., & Tassios, A. (2007). A phenomenographic study of Greek primary school students' representations concerning technology in daily life. *International Journal of Technology and Design Education*, *17*(2), 113–133.

Wendell, K. B., Connolly, K. G., Wright, C. G., Jarvin, L., & Rogers, C. (2010). *Children learning science through engineering: an investigation of four engineering-design-based curriculum modules*. Proceedings of the International Conference of the Learning Sciences, Chicago, IL.

Yoder, B. L. (2014). *Engineering by the numbers*. Retrieved from American Society for Engineering Education web site: https://www.asee.org/papers-and-publications/publications/14_11-47.pdf

Christine M. Cunningham
Engineering is Elementary
Museum of Science, Boston
USA

PETER THOMPSON

7. PRE-UNIVERSITY ENGINEERING EDUCATION IN NEW SOUTH WALES

INTRODUCTION

Schools in New South Wales, Australia have had specific engineering education as a senior high school subject since 1965. This is the result of teachers of the suite of Industrial Arts subjects at the time seeing the need to offer a subject to students destined to what would now be called STEM careers. Industrial Arts (Engineering Science) and Industrial Arts (Technology) were unique in the world at the time and have influenced the direction of technology curriculum in the state since. The subject has evolved to Engineering Studies and remains a high level integration of physics, chemistry, materials science, mathematical analysis and graphical understanding. In 2000 the specific engineering curriculum was extended into junior high school with Industrial Technology (Engineering). Modules of study in structures, mechanisms, control technology and alternative energy are available to schools.

This has recently been extended for junior high school with a curriculum authority endorsed course in integrative STEM involving higher level mathematics and advanced manufacturing.

THE AUSTRALIAN EDUCATIONAL CONTEXT

In Australia school education is the jurisdiction of the states and territories. There are 6 states and 2 territories. New South Wales (NSW) on the east coast is the country's largest jurisdiction with over 2900 schools teaching a common curriculum managed by the Board of Studies, Teaching and Educational Standards (BOSTES). Victoria has 2118 schools and curriculum is managed by the Victorian Curriculum and Assessment Authority (VCAA), other states and territories are significantly smaller, and the state legislation for education varies to meet the needs of the state. The Australian population distribution is in the South East of the continent. Schooling is mandatory for all citizens up to the age of 17 in most states, this age does not coincide with the completion of high school which is normally 18 years so some students exit high school prior to receiving the high school accreditation. Over 90% complete their high school education. The Australian constitution gives states the responsibility to manage their school curriculum. Recent agreement between state ministers for education has resulted in an attempt to create a standard curriculum across the country in all areas of learning. Implementation of the Australian

M. J. de Vries et al. (Eds.), Pre-university Engineering Education, 101–120.

Curriculum commenced in 2012 and implementation time lines vary due to the jurisdictional rights of states.

The states have separate legislation governing what occurs in their schools. A major difference is the level of mandate. In some, a syllabus or curriculum is 'approved for use' where in others a statement about the minimum study for all students is legislated. Some states publish a framework for study with overall guidelines for schools to develop their teaching documents, others publish a syllabus with fine detail about what has to be taught and what students will know and can do at the completion of the course. Public examinations are conducted in some states for the award of a high school credential. Additionally, the various states have their own university admissions centre who aid in the calculation of a national ranking of students for university entry. The Australian Tertiary Entrance Rank (ATAR) is calculated by each state's University Admissions Centre (UAC, SATAC, VTAC, QTAC, TISC, and UTAS).

There are three types of school systems in Australia;

- Government schools are those managed by the state or territory government.
- Catholic Schools, managed by the Catholic Education Commission.
- Independent schools which are managed by various groups of either religious denomination, cultural type or are totally independent.

Depending on the state legislation, all schools will follow a common curriculum or may develop school based syllabuses based upon a state determined framework.

A DEFINITION OF ENGINEERING

Engineering may be defined in this context as the use of a process of design to develop solutions which meet human needs and aid humans in the advancement of society. In the Australian Curriculum, endorsed for use by all states and territory ministers in September 2015, the learning area 'Technologies' has developed two subjects. Design and Technologies and Digital Technologies. The definition of Engineering from this work is

> the practical application of scientific and mathematical understanding and principles as part of the process of developing and maintaining solutions for an identified need or opportunity. (Australian Government, 2012)

This matches very closely the definition of design used in technology curriculum in the various states and territories of Australia, historically. For example, NSW have a subject called Industrial Technology where

> The core modules of each focus area include the design, production and evaluation of practical projects. (Government of New South Wales, 2016)

Or in that state's subject also called Design and Technology, where a student,

> applies and justifies an appropriate process of design when developing design ideas and solutions. (Board of Studies, Teaching and Educational Standards, 2016)

In this way virtually all of the courses offered in the Technology, Design and Technology, Technology and Enterprise curriculum areas of each state could be determined to be "Engineering courses". If engineering is a human endeavour to meet human needs, and is the application of scientific and mathematical content to design and produce solutions, be they products, systems, digital products or systems then all technology curriculum in Australia shows evidence of this. However, for the purpose of this paper a focus will be taken on New South Wales (NSW) specific engineering curriculum where the content of the course reflects a pathway to an engineering career.

TECHNICAL TRAINING

Australia also has a system of Technical and Further Education (TAFE) colleges, who provide education to diploma level in many engineering fields and to degree level in some domains where approved by the Higher Education Accreditation Committee. During 2015 the delivery of these "skills" training courses was made available to private providers to compete with the TAFE offerings. TAFE is funded by the federal government with state organisations managing the business in their state. TAFE has consistency of delivery nationally. There are 58 Institutes of TAFE with over 1000 campuses.

Though TAFE courses are typically studied as a post school option, some high school students in Australia have the opportunity to study one or more TAFE courses while still attending high school. These are commonly viewed as a transition to the workforce with trade training being common in industries such as Construction, Metal and Engineering, Electro-technology, Automotive, Primary Industries and the like.

Where schools have staff qualified to teach the TAFE course in a Vocational Education and Training (VET) mode, they can offer the TAFE course structure within the school.

The Australian Qualifications Framework (AQF) sets standards for all courses of tertiary education.

> The AQF is the national policy for regulated qualifications in the Australian education and training system. It incorporates the quality assured qualifications from each education and training sector into a single comprehensive national qualifications framework.
>
> The AQF was first introduced in 1995 to underpin the national system of qualifications in Australia encompassing higher education, vocational education and training and schools. (Department of Education and Training, 2016)

Vocational courses are popular in schools, for example in 2015, 11303 students out of 73,000 studied a Vocational course while at school in NSW.

> The national report on schooling from 2012 can provide background information. (Australian Government, 2016)

COMPUTING

In all states and territories the use of Information and Communication Technologies (ICT) is seen as a "cross-curricula capability". Given the different state's legislation, the level of prescription varies and the level of implementation varies. ICT is used in all subjects to enhance learning as learning technologies and as a tool for research by students and teachers. In the sense of engineering, states and territories have specific curriculum or syllabuses that focus more on the aspects of systems engineering or in some, the use of coding or computer programming to create solutions.

It is also valuable to note that in recent years, faculties of engineering in the university sector and faculties of computing or information sciences have been combined. At the time of writing (2016) there are only 8 separate faculties of Information Technologies with the vast majority, over 30 others, being amalgamated as faculties of Engineering and IT (Australian Education Network, 2016).

Thus the digital world is being more integrated with engineering. The tools to develop digital solutions and to simulate and develop all types of engineering solutions relies on understanding the digital world. If engineering is seen as the creative problem solving to meet specific needs then the courses in computing, digital technology, systems design and so on offered by the states and territories school curriculum authorities could also be seen as engineering. However, for the purposes of this discussion, those aspects of engineering that are more traditional such as mechanical, civil and so on have been considered only.

ENGINEERING EDUCATION IN NSW

The New South Wales (NSW) legislation defines learning areas to be studied in schools. The current New South Wales curriculum for Primary (Elementary) schools is organised into 6 Key Learning Areas (KLAs).

- English,
- Mathematics,
- *Science and Technology,*
- Human Society and its Environment,
- Creative and Practical Arts,
- Personal Development, Health and Physical Education.

Within the Science and Technology subject, students learn basic engineering principles such as machines, push and pull, cause and effect. The syllabus document focusses on the processes of working scientifically and working technologically. The NSW Education Act 1990 specifies that courses of study in each learning area must be provided to students in each year of primary school and that the course must be "based on and in accordance with a syllabus developed or endorsed by the Board and approved by the Minister." (Government of New South Wales, 2016) The Board refers to the Board of Studies Teaching and Educational Standards (BOSTES) see www.BOSTES.nsw.edu.au. NSW BOSTES and the state legislation specifies that syllabus documents are produced for the state and are structured with broad objectives and outcomes that should be achievable by students by the end of a stage of learning. Progression is age based with no minimum standard applied to allow progression.

In primary education, there is what can be called pre-engineering education, but this is not much different from what happens in much of primary school technology education elsewhere. Therefore we will not describe it in detail and concentrate on those educational levels where the NSW situation does show some unique features.

ENGINEERING IN THE NSW CURRICULUM YEARS 7 TO 12

In secondary education the technology learning area is named, in the Education Act as the Technological and Applied Studies Key Learning Area (TASKLA). It is one of eight areas of study for the award of a Record of School Achievement (RoSA). This is the certification awarded to those who leave school prior to the Higher School Certificate. The Key Learning Areas of the NSW secondary curriculum are:

English,
Mathematics,
Science,
Human Society and its Environment,
Languages other than English,
Technological and Applied Studies,
Creative Arts,
Personal Development, Health and Physical Education. (Government of New South Wales, 2016)

The TASKLA is a broad curriculum that has at its core the development of solutions to meet needs using specific technologies or a mix of appropriate technologies.

The subjects available as Board approved courses are as follows.

From year 7 to year 10 student ages from 13 to 16.
7–10 Technology (Mandatory)
This course is studied by all students in the state for 200 hours usually in years 7 and 8.

In years 9 and 10 of high school students can elect to study from the following:

7–10 Agricultural Technology
7–10 Design and Technology
7–10 Food Technology
7–10 Graphics Technology
7–10 Industrial Technology
7–10 Information and Software Technology
7–10 Marine and Aquaculture Technology (Content Endorsed Course)
7–10 Textiles Technology. (Government of New South Wales, 2016)

Post year 10, students in NSW must study English as the only mandatory course for the award of the state's Higher School Certificate (HSC). The HSC is the high school exit credential typically for students ages 18 to 19. These students have the following courses to select from if offered by their school. All students must remain at school until they reach 17 years of age or are progressing to further study or full time paid employment.

Technology Subjects are:
Agriculture
Design and Technology
Engineering Studies
Food Technology
Industrial Technology
Information Processes and Technology
Software Design and Development
Textiles and Design. (Government of New South Wales, 2016)

BACKGROUND TO THE NSW SECONDARY TECHNOLOGY AND ENGINEERING CURRICULUM

Technology and Engineering curriculum in New South Wales (NSW) has its roots in the American Industrial Arts movement. The Education Act of 1990 and a significant review preceding this known as Excellence and Equity (1988) developed the Key learning areas referred to above. Industrial Arts educators are grouped with the other subjects under the banner of Technological and Applied Studies (TAS). A recent survey of 'Industrial Arts' faculty heads at a conference showed that 90% saw themselves as Technology and Engineering Educators (Thompson, Survey of IA/TAS Head Teachers, 2008).

The Industrial Arts heritage resulted from an active educator who visited USA schools and universities on a scholarship in the 1950's. A subject similar to the UK Design and Technology curriculum is also taught in NSW, this follows an industrial design model of delivery and, as with all courses in the TASKLA is based upon developing solutions to meet needs. An indication of popularity in schools can be seen in the following table from 2015 enrolments.

In the suite of NSW secondary school subjects those which can be identified as technology and engineering include;

- Technology (mandatory), a subject studied by all students for at least 200 hours in every school.
- Graphics Technology, an elective subject for technical graphics and architecture.
- Industrial Technology which includes focus areas of various technologies such as automotive, electronics, timber, metal, engineering, multimedia, polymers etc. Students may study two of these focus areas up to year 10 (15–16 years old) and only one in year 11 and 12 (17–18 years old).
- Information and Software Technology, a computing course deeper than Information and Communications Technology for students up to year 10 (16 years old).
- Information Processes and Technologies, a senior high school course around systems engineering, communication protocols and options of control technology and Computer Integrated Manufacture (CIM).
- Software Design and Development, a senior high school course devoted completely to computer programming.
- Engineering Studies, an engineering course for senior high school focussed completely on engineering principles and the scope of the engineering profession.

In addition there are a range of vocationally focussed courses in Metal and Engineering, Electro-technology, Automotive and the like which lead to trade qualifications at the lowest levels.

In recent years a federal government initiative established trade training centres across the country. These were attached to schools so that vocational education could be conducted on site. Many technology and engineering teachers extended their training to also be able to offer these courses. Employment needs dictated the recruitment and degree course acceleration for tradesmen and women to become technology teachers. This discussion does not include analysis of the vocational engineering courses.

The subject, Industrial Technology years 7 to 10 is typically offered by schools in years 9 and 10 and has within it a broad range of focus areas:

- Automotive
- Building and Construction
- Ceramics
- Electronics
- *Engineering*
- Farm Maintenance
- Leather

- Metal
- Multimedia/Photography
- Polymers
- Timber

Students are to engage in practical activity for more than 50% of the course time. Flexibility of study applies to this subject, schools can deliver 100 hours or 200 hours of study enabling schools to tailor offerings to their clientele and local community needs. Industrial Technology is also offered for years 11 and 12. Of these focus areas Engineering is of primary interest.

In 2015 over 3500 students were enrolled. Student numbers in Industrial Technology – Engineering are accelerating from its first availability in 2000. The course structure is in 4 modules.

- Structures
- Mechanisms
- Control Technology and
- Alternative Energy

The study of Industrial Technology Years 7 to 10 provides students with opportunities to engage in a diverse range of creative and practical experiences using a variety of technologies widely available in industrial and domestic settings. Through the study of Industrial Technology Years 7 to 10 (though typically this subject would be offered by schools in years 9 and 10 where students are 15 to 16 years of age) students develop knowledge relating to current and emerging technologies in industrial and domestic settings. Students study the interrelationship of technologies, equipment and materials used in a variety of settings and develop skills through hands-on interaction with these in the design, planning and production of practical projects.

The aim of the Industrial Technology Years 7 to 10 Syllabus is to develop in students' knowledge, understanding, skills and values related to a range of technologies through the safe interaction with materials, tools and processes in the planning, development and construction of quality practical projects. The syllabus aims to develop in students an understanding of the interrelationships between technology, the individual, society and the environment, and to develop their ability to think creatively to devise solutions to practical problems (Government of New South Wales, 2016).

In the Engineering focus area as with the others, the practice is to engage in practical hands on design and production for the vast majority of time. The state's approach to theoretical content is to embed that within the practical hands on activity and not see it as an adjunct or secondary. Good practice is to embed the theoretical content with the practical hands on, project based learning.

Content of the Engineering focus area:

> Structures, an understanding of stable structures including…
>
> Some work with materials science, hardness, ductility, compressive and tensile strength, elastic and plastic behaviour of materials, composite materials and the

corrosion of steels. Structures can include bridges, columns, towers, chairs and the like. Study of force, mass and acceleration also form part of the analytical work.

Students are expected to use elementary engineering principles to design and produce simple structures. Typical practice is for students to design and build scale model bridges or towers and test them for stiffness as a non-destructive test and then test for maximum load in a destructive test.

The use of design tools such as the Bridge Design contest software or other simulations including 3D modelling CAD packages are used to develop the structures. Teachers challenge their students with a design specification around a valley width or hypothetical distance to span.

All modules include drawing, from sketching to technical communication to Australian Standards, including Orthographics and Isometrics. CAD is now common place with the PTC Academic program having the most penetration at this time (2016) but also with Autodesk products and Solid Edge academic programs being used extensively. Google SketchUp is also used for design development. Some schools still purchase CAD software such as SolidWorks. Students are expected to use software to generate reports of their work ranging from design portfolios showing the history of development of their design for a structure, a mechanism, a control technology or an alternative energy device. Work Health and Safety is also a theme throughout these courses as the hands on activities will require the use of machines, tools, processes and techniques. A proprietary product is commonly used to manage this in OnGuard Safety training. The practical application of this theoretical knowledge is encouraged. Towers supporting the largest mass are also a popular project. Using timber sticks or spaghetti and epoxy resin as the joining method. This not only enables introductory structural analysis with for example, redundant members typically being discussed. The relevance of materials understanding is commonly studies here with the assessment task including some fundamental understanding of the materials being used. Better teacher practitioners will allow students to choose from a range of similar materials and place an evaluation criteria that aims for lowest mass or least members. This allows students the flexibility to redesign and iterate solutions to the challenge, either theoretically, by simulation or by experimentation. Testing is often recorded. Videos of some testing can be found on YouTube.

Another typical project approach is to allow students to design a functional item, such as a DVD storage medium but design it around a known structure such as a Pratt or Whitney Truss, the product often being constructed from members of sheet metal, bent to form ‘mini purlins’ and spot welded together. The use of real materials appeals to students and provides opportunity for testing of materials they see in the world around them. These structures are often designed to meet a specification that can lead to a challenge such as the “stiffest structure” or the lightest. Typically a quantitative measure is used that forms part of the assessment. The remainder of the assessment in this subject will be around a design portfolio for the project and then a formal examination of some sort. The existing syllabus structure with its delineation of what students learn about and what students learn to do makes it clear for teachers as to what they need to assess and report on. The second 50 hours of study is Mechanisms and includes further materials understanding, toughness, malleability, corrosion resistance, torsional and shear strength, classification of materials, metals, polymers and ceramics, heat treatment and the chemical properties of materials used in mechanisms. Levers, pulleys, gears and cams are mandated study which typically lead to classic Rube Goldberg machines, 'mousetrap' powered vehicles, trebuchets, and other ancient machines. The opportunity to integrate learning from history and other subjects is not lost on the teachers of 'junior engineering'.

Some schools take this further and include electric motors, steppers and servos can be used to meet the syllabus requirement of "methods to drive mechanisms". Theoretical study is deeper than other areas where mechanical advantage, velocity ratio, efficiency and friction are part of this module. Design a machine to place a coin in a box, design a machine to fold a paper plane, design a device to open a bottle, and similar. A "marble run" or "mouse trap" game is also a common project as is the design and manufacture of spring or inertia powered vehicles. In essence again the product is the focus for a project that will engage students in the need to learn about the syllabus topics of gears, mechanisms, velocity ratio, efficiency and friction. There are a growing range of suppliers for the gears, pulleys and other 'parts' necessary. However, with the increasing use of 3D printers and laser cutters in schools these are also often produced on site by students or in lesson preparation by teachers. Kits are also used to develop understanding of the engineering principles here. Examples are the Soccer Bot or the Ant from Scorpio Technologies. These are generally used as a starting point for a project where students will be challenged to extend the design by remodelling the structure or re-purposing the parts of the kit for a more sophisticated design solution. The assembly of kits alone would not meet the syllabus requirement of providing students an opportunity to apply their knowledge in new situations. In assessment, the highest level of application is defined as:

Grade A

A student at this grade typically:

- demonstrates extensive knowledge of traditional, current, new and emerging technologies in their field of study, and evaluates the social, cultural and environmental impacts of these technologies.
- displays advanced technical skills in identifying and using appropriate materials and hand and machine tools to produce practical projects of excellent quality, independently assessing and managing risks and consistently applying safe work practices.

- evaluates the suitability of materials for specific applications and the functional, aesthetic, environmental and economic aspects of projects and commercial products.
- independently selects and uses a range of media to illustrate practical projects, and confidently uses technical terminology to discuss production processes with a range of audiences.
- independently and consistently applies skills and design principles to the development and production of new projects (Government of New South Wales, 2016).

Teachers are asked to assess how well students understand and apply, designing, communicating, evaluating and producing quality projects, Work Health and Safety and risk management, properties and applications of materials and their impact on society. Electronics supply companies such as Jaycar in Australia, also provide a range of resources often used in this module. Building a simple electric motor, using a motor as a generator and designing a water turbine provides students with preliminary knowledge for the following modules of Industrial Technology – Engineering. The preceding, introductory modules of Structures and Mechanisms are the core modules for schools who study this subject for 100 hours. The third module of Industrial Technology Engineering is control systems. This is a specialised module, referring to the optional nature of this extension for those studying this course for 200 hours.

The need for computer coding knowledge provides a challenge for teachers who may not be trained in this area, so the use of on-line learning from the suppliers of control technology devices such as LEGO Mindstorms, Arduino, PicAXE, Raspberry Pi and the like are popular. Projects therefore revolve around the standard tutorials with only some exemplary teachers leading with projects that are more engaging and individualised for students. At this time (2015) the cost of sophisticated control technology such as Arduino prohibits the ability to have a student design and build a project and take it home to keep and to experiment further. Smaller projects can be constructed but these have less appeal for students. The painful cry of “We spent 5 lessons and we made some lights blink” does not foster engaging technology and engineering education.

Some schools will take a broader meaning to control technology and use the “Rube Goldberg” machine or similar from the previous module and mechanise the feed with a stepper or servo. The mechanisation of a simple device is an entry level project for this module but is most commonly presented at this time. It is also possible to use pneumatics and hydraulics simulations using many off the shelf products such as the Festo Didactic pneumatics control technology or Lego Systems. The syllabus does not mandate the use of electronic or digital control, but teachers are aware that this is the industrial practice. Professional development of teachers is required in this area.

With the development of the Internet of Things and such applications as PTC’s Thingworx academic program there are many more opportunities for this module in the future. Teacher professional associations are providing professional learning in this area and courses are typically oversubscribed. The final module of Industrial Technology – Engineering is Alternative Energy. This includes content such as:

Engineering Principles and Processes:
the nature and purpose of alternative energy systems
various types of alternative energy systems such as wind, solar, wave, human, geothermal
advantages and disadvantages of alternative energy systems
electrical units and values of voltage, power, current and energy in relation to alternative energy systems

Students learn to:

plan and construct or simulate a working model, prototype or full-scale alternative energy system
examine the components of an alternative energy system
use an alternative energy system to power a device
compare the advantages and disadvantages of alternative energy systems (Government of New South Wales, 2016).

Given the overarching requirements of the subject, students are again challenged to design and produce alternative energy solutions. Solar powered vehicles, hydrogen fuel cell vehicles, wind farms and turbines are designed and produced. The use of water as a propulsion method is very popular with water rockets being used to demonstrate principles. Many schools also incorporate the Formula 1 in schools' initiative within this module. A more legitimate study of alternative energy generating forms is expected by the syllabus document. Contemporary CAD modelling and the availability of computational fluid dynamic solutions have improved the accessibility for schools.

School developed courses. Schools in NSW also have the opportunity to develop a course for their own students that better meets the needs of the local community and does not overlap with existing curricula. These courses can be submitted to the Board of Studies, Teaching and Educational Standards and be 'endorsed' by the Board. These Board Endorsed courses then have the same status as the other elective courses and will appear on the student's testamur. These courses are often seen as potential future state wide Board courses.

In 2012 Maitland Grossman High School developed an integrated Skills, Technology, Engineering and Mechanics course they called iSTEM. This is an integrated engineering program for years 9 and 10.

The course was and is supported by a federal government regional development Australia (RDA) initiative. The school is located in a regional area. RDA Hunter, the School of Engineering in Newcastle and the Faculty of Engineering and Information

Sciences at the University of Wollongong have promoted the subject and schools across NSW have embraced it. Over 80 schools currently (2015) teach the course with materials hosted on the ME program web site. http://meprogram.com.au/

The course integrates high level physics, mathematics and advanced manufacturing into a design and produce project based program inclusive of inquiry learning. Delivery is around a range of modules which include, aerodynamics, mechatronics, surveying, motion, statistics, and a 50 hour self-directed STEM project, amongst others.

ENGINEERING IN THE NSW CURRICULUM YEARS 11 AND 12

At the highest level, the subject called Engineering Studies is a pre degree level study of engineering. It is taught in faculties known across the state as either, Technology and Engineering, Technological and Applied Studies (TAS), Industrial Arts, Technology or in some instances faculties of Science. It deserves special analysis due to its long history and its successful record of students graduating from it into a STEM career and specifically into degree level engineering study. An informal survey conducted with 1200 teachers in 2014 revealed that more than 65% of students graduating from Engineering Studies went on to study a University engineering degree level program.

HISTORY OF THE SENIOR ENGINEERING SUBJECTS IN NSW

Industrial Arts 1967

The subject Industrial Arts was first introduced to senior high school by a group of teachers in 1963, it was first examined at the matriculation examination in 1967 (Government of New South Wales, 2014).

During the 1970’s senior high school students in NSW, up to 18 years of age had access to 2 courses under the Industrial Arts subject. Engineering Science and Technology. Named, officially as Industrial Arts (Engineering Science) and Industrial Arts (Technology). This resulted from of a group of Industrial Arts teachers wishing to bring study of this type into senior high school. The opportunity was presented by the extension of one year of school study being available to all. Prior to this the culmination of the study of these subjects was Metalwork, Woodwork and Descriptive Geometry and Drawing up to the Leaving Certificate (Holden, former Engineering Science teacher, 2015; Rochford, Engineering Studies teacher and publisher, 2016; Ecclestone, 2016).

Industrial Arts (Engineering Science) 1966 to 1987

The subject was predominantly theoretical and required a high level of mathematics understanding, including calculus. Topics included:

Mechanics.
including statics and dynamics, force analysis, centrifugal motion, stress and strain.
Materials Science.
including testing, dislocation and its impact on materials properties, bonding and classification, miller indices and the like.
Drawing.
including orthographic, auxiliary projection, pictorial views and graphical problem solving using technical drawing equipment.
The History of Technology.
Including the great British engineers, Telford, Watt, I.K. Brunel and their achievements.

The subject grew to be popular and provided engineering degree entry level material that ensured students who studied it at school could easily progress to a technology or engineering degree at University. Students completed a public examination of 3 hours duration which covered a sampling of the topics studied throughout the course.

Integrated learning in Engineering Science. In the period 1988 to 2000 the engineering science curriculum development lead to an approach where the content knowledge was learnt then applied to specific objects or systems so that students could see the direct application and the integration of knowledge of materials, mechanical analysis, graphics and the historical aspects. The "integrated topics" were then also part of the formal public examination structure. The following topics were mandated by the Board developed curriculum:

- Lawn mowers
- Push bikes
- Cranes
- Motor Vehicle brakes and
- Bridges

These provided opportunities for teachers and others to produce a range of resources useful in the delivery of the course. Texts, posters and interactive software by Metcalfe Resources and Workbooks and study materials by KJS Publications. In 1990, 3902 students studied Engineering Science. In comparison, 4033 studied Industrial Technology and 4767 studied Computing Studies at the senior high school (Government of New South Wales, 2016).

Industrial Arts (Technology) 1963 to 1985

In the same era a syllabus was developed alongside Industrial Arts (Engineering Science). The course was very broad and students needed to complete 4 different modules in the examination.

The areas of study were

- Graphics
- Materials
- Testing-Strength of Materials
- Modified and Composite Materials
- Shaping and Fabrication of Metals
- Machines
- Heat Engines
- Building Construction.
- Electricity
- Electronics
- Plastics
- Wood

Engineering Science 1988

Industrial Arts (Technology) Industrial Arts (Engineering Science) were revised in 1985/86 and became known as simply Engineering Science, examined for the first time in 1988. The Industrial Arts (Technology) course was replaced 2 years prior to this by the subject called Industrial Technology. Though it could be argued that Industrial Technology is an engineering course, the focus of this paper is those subjects that are inarguably engineering. Significantly, however Industrial Technology (years 11 and 12) was developed by many of the same individuals who were involved in the early adoption of the senior high school engineering course. They were also successful in introducing this new subject as a study of industry, it structure, management and role in society. Industrial Technology commenced as a study of industry, how it functions, work related matters, communications and the project management aspects of a large and complex project which students complete as part of the formal examination.

Industrial Technology in the senior school is a course of study focussed on the technologies of specific industries. These are referred to as focus areas and include:

- Automotive Technologies
- Building and Construction Technologies
- Electronics Technologies
- Graphics Technologies
- Metal and Engineering Technologies
- Multimedia Technologies
- Plastics Technologies
- Timber Products and Furniture Technologies.

Both the Preliminary (year 11) and HSC (year 12) courses are organised around four sections:

- Industry study
- Design and management
- Workplace communication
- Industry-specific content and production.

Though this subject involves students in the design and production of a major project to meet a specification, it is not dealt with in depth here. Further information can be obtained at the syllabus web page for this subject at http://www.boardofstudies.nsw.edu.au/syllabus_hsc/industrial-technology.html. Industrial Technology being separate from Engineering Science provided the opportunity for the latter to more explicitly apply concepts of physics and chemistry, materials science and graphics and take a more analytical approach.

Engineering Science also established a more integrated approach to study, where themes of products were used to integrate the Mechanics, Materials and Drawing aspects. The history of technology was used as an introductory unit to each module. The Preamble to this syllabus document stated that continual improvements in materials and processes make it highly desirable to keep abreast of these developments and to prepare for life in an age of rapid technological change and expansion. The content was offered as 3 separate but interrelated units of study in:

Graphics, Analysis and Applications
Graphics, which included Descriptive Geometry, Orthogonal Drawing and Graphical Mechanics.
Analysis included, classification of materials, forces and statics, basic machines, dynamics, testing and strength of materials, metals, single and multiphase materials, polymers, ceramics and composites.
Applications invited teachers to analyse an engineering device, or have the students design and construct one so a full analysis in terms of mechanics and materials could be conducted.

In 2000 Engineering Science was reviewed once more and became Engineering Studies with a greater focus on communication and the 'scope of the profession', this was a result of consultation with the engineering profession and the academic engineering community.

The long history of Engineering education in NSW schools, from Industrial Arts 1967 (Engineering Science and Technology), Engineering Science and Industrial Technology from 1988 and 1985 respectively, and now Engineering Studies and Industrial Technology from 2000 has provided a broad range of engineering education for senior high school students.

Engineering Studies 2000

The redevelopment of the senior engineering course involved engineering academics and the national professional engineer's association, then called the Institution of

Engineers, Australia and now known as Engineers Australia. This lead to a greater focus on communication skills, engineering reports, verbal and oral communication and the scope of the profession. 2 modules of the course, one third of the time, is dedicated to what engineers do and what engineering careers exist. The impact of engineers on society and their role as a team member.

Controversially the review of the subject content included new fields of digital logic, aeronautical engineering and telecommunications engineering. These were seen as engaging for students but were new to teachers. The local professional teacher association continues to run professional learning courses for practising teachers of Engineering Studies (Institute of Industrial Arts Technology Education, 2014).

Engineering Studies is viewed as a rigorous course by students, teachers and the profession. Enrolment continues to grow slowly though schools now find it difficult to find suitably qualified teachers.

CONCLUSION

It is difficult to separate engineering education from technology education in Australia, if the latter has underlying principles of designing and producing to meet needs, it matches contemporary definitions of engineering. In that sense, most curricula in the Technology/Design and Technology/Technological and Applied Studies in Australia meets the engineering measure. Specific senior high school (17–18 years of age students) courses including deeper engineering content have existed in several states of Australia for some decades, but some are not well subscribed due to their challenging nature. NSW has success in years 9 to 12. Recent developments of STEM courses and Engineering courses in junior high school are proving to be very popular. Initial indications from the iSTEM program is that it is having an effect on numbers of students pursuing engineering career options.

The development of the Australian Curriculum content in engineering will increase the understanding of engineering as a process and a career for both school communities, teachers and students. This will require significant professional learning for teachers, especially in K–6 education. This has been recognised. The vocational courses in engineering skills make a significant contribution to technician and technologist levels. These ‘trade’ courses are in great demand and form a major part of the STEM career shortage solution. In times of technological acceleration, importantly in digital technologies, these courses are having difficulty keeping pace with change.

The early introduction of engineering as a subject of rigour and demonstrating a clear path to tertiary study has influenced the stature of Industrial Arts and Technology Education in the state of New South Wales. Syllabus development in the breadth of courses offered reflects the influence of engineering design processes and understanding of materials and manufacturing processes. The training of teachers to be able to teach the high level engineering studies courses in schools gave them a depth of understanding and intellectual rigour that they could then apply to other courses. When, in 1990, the Technological and Applied Studies Key Learning Area (TASKLA) was developed as a model of educational structure for the state, it was challenging for teachers of the Industrial Arts to explain their pedagogical approaches to the Home Economics teachers who they were teamed up with to teach technology courses. It was also difficult to explain concepts of engineering to those who had not experienced it, this included educational administrators with a background in other areas of learning. Some challenging times ensued. The TASKLA also includes teachers of computing, agriculture and aqua culture.

The 21st century recognition and promotion of STEM disciplines has reinvigorated the interest and understanding of engineering education. Those trained to teach the high school engineering curriculum are well placed to deliver STEM as an integrated subject. The recognition afforded by the professional engineer's body and their willingness then to be involved with the development of the Australian Curriculum has resulted in engineering becoming one of 4 focus areas of Design and Technologies to be taught nationally from Kindergarten to year 10 in the near future.

The greatest challenge to these developments is the lack of depth of teacher training in engineering education in more recent years. Most of the teacher training institutions no longer train teachers in the depth required to teach Engineering Studies. Training is available as a graduate certificate course and is often sponsored by the state education department. In some cases practising engineers find teaching to be a rewarding alternative to their engineering career and pursue a master's level education degree. Teacher training courses currently endeavour to prepare teachers to teach every subject in the TASKLA in addition to a vocational subject such as hospitality or metal and engineering or construction. The integration of physics, chemistry and materials science is no longer evident in teacher training. This situation is the greatest threat to the longer term implementation of both senior school and junior school engineering courses.

The experience of having teachers trained in deep engineering knowledge, with good materials and manufacturing knowledge and not insignificantly, a good understanding of engineering design, technological design and industrial design and the influence that they have had on curriculum development has been beneficial to the state. The consequential depth of delivery in all courses in the technology learning area and the influence on syllabus development over the years since the 1970s cannot be underestimated.

REFERENCES

Australian Bureau of Statistics. (2016, January 26). *4221.0 Schools, Australia 2014*. Retrieved January 26, 2016, from Australian Bureau of Statistics: http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/4221.02014

Australian Education Network. (2016, January 26). *Study engineering courses in Australia*. Retrieved March 27, 2016, from Australian Education Network: http://www.australianuniversities.com.au/courses/australia/study/engineering/campus/c/d/all-engineering/

Australian Government. (2012, August 26). *Shape of the Australian curriculum, technologies*. Retrieved January 26, 2016, from Australian Curriculum and Assessment Authority: http://www.acara.edu.au/verve/_resources/Shape_of_the_Australian_Curriculum_-_Technologies_-_August_2012.pdf

Australian Government. (2016, January 26). *National report on schooling*. Retrieved January 26, 2016, from ACARA: http://www.acara.edu.au/verve/_resources/20151210_ANR_2012_Parts_1-6_8_and_10.pdf

Board of Studies, Teaching and Educational Standards. (2016, January 26). *Board of studies, teaching and educational standards*. Retrieved January 26, 2016, from Design and Technology: http://www.boardofstudies.nsw.edu.au/syllabus_sc/design-technology.html

Board of Studies Teaching and Educational Standards. (n.d.). *Board of studies statistics archive*. Retrieved February 29, 2016, from Board of Studies: http://www.boardofstudies.nsw.edu.au/bos_stats/hsc71_78stats.html

Board of Studies Teaching and Educational Standards NSW, Australia. (n.d.). *Board of studies teaching and educational standards syllabuses* (K. Siquera, Ed.). Retrieved February 29, 2016, from Board of Studies Teaching and Educational Standards: http://www.boardofstudies.nsw.edu.au/syllabuses/

Department of Education and Training. (2016, January 26). *What is the AQF*. Retrieved January 26, 2016, from About: http://www.aqf.edu.au/aqf/about/what-is-the-aqf/

Ecclestone, M. (2016, March 7). *Former Industrial Arts Teacher*. (P. Thompson, Interviewer)

Government of New South Wales. (2014, December 12). *Department of education*. Retrieved March 28, 2016, from Government schools: http://www.governmentschools.det.nsw.edu.au/index.shtm

Government of New South Wales. (2016, January 1). *Statistics archive*. Retrieved from Board of Studies, Teaching and Educational Standards: http://www.boardofstudies.nsw.edu.au/bos_stats/

Government of New South Wales. (2016, January 26). *Industrial technology*. Retrieved January 26, 2016, from Board of Studies, Teaching and Educational Standards: http://www.boardofstudies.nsw.edu.au/syllabus_sc/industrial-technology.html

Government of New South Wales. (2016, January 26). *NEW NSW syllabuses*. Retrieved January 26, 2016, from Board of Studies, Teaching and Educational Standards: http://syllabus.bostes.nsw.edu.au/science/science-k10/outcomes-k10/

Government of New South Wales. (2016, January 26). *NSW consolidated acts*. Retrieved March 27, 2016, from NSW Consolidated Acts: http://www.austlii.edu.au/au/legis/nsw/consol_act/ea1990104/s8.html

Government of New South Wales. (2016, January 26). *NSW syllabuses*. Retrieved January 26, 2016, from Science K-10: http://syllabus.bostes.nsw.edu.au/science/science-k10/outcomes/

Government of New South Wales. (2016, January 26). *Syllabus industrial technology.* Retrieved January 26, 2016, from Board of Studies, Teaching and Educational Standards: http://www.boardofstudies.nsw.edu.au/syllabus_sc/pdf_doc/indust_tech_710_syllabus.pdf

Government of New South Wales. (2016, January 26). *Years 7–10 syllabuses*. Retrieved January 26, 2016, from Board of Studies, Teaching and Educational Standards: http://www.boardofstudies.nsw.edu.au/syllabus_sc/

Government of New South Wales. (2016, January 26). *Years 11 and 12 Syllabuses*. Retrieved January 26, 2016, from Board of Studies, Teaching and Educational Standards: http://www.boardofstudies.nsw.edu.au/syllabus_hsc/

Holden, R. (2015, December 18). *Former engineering science teacher* (P. Thompson, Interviewer).

Institute of Industrial Arts Technology Education. (2014, December 1). *Events*. Retrieved from Institute of Industrial Arts Technology Education: www.iiate.asn.au

Metcalfe, R. (2014, December 25). *Engineering posters*. Casula, New South Wales, Australia.

New South Wales Department of Education. (n.d.). *Reform movement*. Retrieved February 29, 2016, from NSW Government schools story: http://www.governmentschools.det.nsw.edu.au/story/reform_movement.shtm

Queensland Government. (2010, January 1). *Engineering technology*. Retrieved March 12, 2016, from Queensland Curriculum and Assessment Authority: https://www.qcaa.qld.edu.au/senior/subjects/ict-design/engineering-technology-2010

Rochford, J. (2014, December 23). *Engineering studies workbook.* Tumbi Umbi, NSW, Australia. Retrieved from http://www.kjspublications.com.au/

Rochford, J. (2016, January 10). *Engineering studies teacher and publisher* (P. Thompson, Interviewer).

Scorpio Technology. (2016, January 26). *Intermediate kits.* Retrieved from Scorpio Technology: http://www.scorpiotechnology.com.au/intermediate-kits

Thompson, P. (2008, November 18). *Survey of IA/ TAS Head Teachers*. Unpublished research, Rooty Hill, NSW, Australia.

Peter Thompson
Technology Education
Board of Studies, Teaching and Educational Standards NSW
Australia

LARS BO HENRIKSEN[1]

8. "ARE THEY READY?"

The Technical High School as a Preparation for Engineering Studies

INTRODUCTION – THE TECHNICAL HIGH SCHOOL – HTX

The Confederation of Danish Industry (DI) has warned, time and time again, that in the near future Danish companies will have severe difficulties hiring enough qualified engineers. The main reason is that most young people, as they transition from second level schools, simply do not want to pursue a career in engineering, science and technology. A European Commission (2011) survey and the so-called ROSE project (Jenkins & Pell, 2006) both provide evidence for this hypothesis; namely, that awareness of and interest in science and technology is absent from most youngsters' minds. There has been, therefore, an increased interest in attracting more students to engineering studies. The Danish technical high school HTX (Higher Technical Examination Program) was established in the 1980s partly to increase participation in such studies, and partly to provide an admissions track into engineering studies for apprentices from the technical colleges. The HTX is now well established within the Danish educational system, and it provides an alternative to the traditional high school. For admission to Danish universities students must have graduated from one of the high school education streams (general upper secondary school) or from similar educational institutions. The majority of Danish university students have a background in the ordinary high school – STX. STX offers a broad general education in classical fields such as modern languages, math, physics, etc. In 2013, 27,000 students were enrolled in STX schools. In addition to STX, the Danish educational system also includes the business high school – HHX which had 10,000 students enrolled in 2014, and the technical high school HTX, introduced above, which had 5,000 students enrolled in 2014.

The key research question addressed in this chapter is: does the HTX technical high school prepare Danish students for a future as engineering, science or technology students? Does it equip the students with the study competences necessary for such studies?

Using direct participant observation and other sources, I explore its original purpose, analyse its curricular content, highlight some prominent issues, and basically critically explore the ability and potential of the HTX technical high school to equip its students with the requisite study competences.

M. J. de Vries et al. (Eds.), Pre-university Engineering Education, 121–140.

The empirical basis for this chapter draws on the following: it is partly based on ministerial orders and guidelines, curricula and other written materials related to the study program; interviews with teachers and students from four HTX schools in the Jutland area of Denmark; interviews with engineering students at Aalborg University with a background in HTX; teaching observation, observation of exams and the students' written work.[2] The study does not include all schools or all students and not even a representative sample of schools; it can, therefore, only provide a snapshot of what is possible. The question is, therefore, not whether all students in all schools achieve the required study competences, but whether it is possible, within the current framework, to implement a form of education that allows students to achieve the required study competences. The purpose of this study is to explore whether it is possible to achieve the required study skills – not that all students, in all cases achieve them. The study program provides opportunities, but other issues can get in the way of the desired results or outcomes. These are not included in this study – the intent is only to look at what is possible.

The purpose of all high school education in Denmark is to equip its students with study competences and with a general formation of character (Bildung) (ministerial order §1). In this chapter study competences will be described as students 'knowledge of the tradition', that is, knowledge of the discipline, theories and methods, and the students' formation (Bildung), that is, how students change through meeting with the school's challenges and the students' ability to produce new knowledge, that is, students' ability to apply theories and methods in practice. This means that the requirement for study skills or study competences require both Bildung and the ability to solve problems using the theories and methods learned at the school. In the process which equips students with the necessary study competences, different forms of knowledge are included. These forms of knowledge can be summarized as *episteme*, *techne* and *phronesis*: roughly translated these correspond to theoretical, practical and social knowledge, all of which are necessary for students' study competences (Gallagher, 1992; Henriksen, 2013, p. 49). The following sections examine whether this is the case in the Danish HTX program.

THE HTX PROGRAM – BACKGROUND

The technical high school was inaugurated in 1982, first as an experiment, and later from 1995 as a permanent addition to high school education at the same level as the ordinary high school. This started out as a supplement to the technical colleges' apprenticeship programs. The initial idea was to have a high school education stream explicitly directed at science and engineering as well as combining theory and practice in an innovative way. The study program was very much influenced by the Problem Based Learning (PBL) principles of the new Danish universities – Aalborg and Roskilde – and was, therefore, interdisciplinary with project work included as part of the curriculum right from the very beginning. In HTX there is a special emphasis placed on what are known as 'profile subjects'. Profile subjects are subjects offered only by this specific program. In the case of HTX the profile subjects are 'technology' and 'technical science'. In addition to the profile subjects, the 'study area' (called SO) and the 'study direction project' (called SRP) are also described. The study area is an interdisciplinary collaboration between the subjects and is here described separately, partly because the profile subjects are included in the study area activities, partly because the study area in its foundation is interdisciplinary and problem-oriented and therefore central to the development of students' study competences. The SRP project is a large report drawing on two different subject areas written by HTX students.

THE HTX – CONTENT

In the ministerial order for the HTX program, the objectives are stated as follows:

> §1. The program for higher technical examination is a three-year secondary education, which is targeted at young people interested in knowledge, depth, perspective and abstract thought. The program represents a whole and concludes with an examination following the national standard.

If we look at the ministerial order in the light of the study competences described above – tradition, Bildung and the ability to produce new knowledge, it is clear the ministerial order is asking for precisely that. The preamble describes the purpose of obtaining the 'study competences', that is, 'to prepare students for higher education' (§1.2); they need to prepare students for further education at universities or engineering schools. This is to be achieved by introducing students to the tradition: 'Knowledge' and 'breadth and depth' (§1.2), develop professional insight (§1.3) and 'professional and educational progression' (§1.3).

The education received should 'form' the students (Bildung): 'general education' (§1.2), 'professional and educational progression' (§1.3), 'The program must have an educational perspective with emphasis on students' development of personal authority' (§1.4). The educational and school culture as a whole should prepare students for active participation, joint responsibility, rights and duties in a society with freedom and democracy (§1.5). Finally, the programs should enable students to produce new knowledge: 'Competencies' (§1 para. 2). They should become familiar with the use of various forms of work and have the ability to function in a study environment which demands independence, cooperation and pursuit of knowledge; the training should also develop students' creative and innovative skills and critical thinking (§1 section 4).

Overall, the ministerial order is fully consistent with the description of the study competences above – tradition, Bildung, and production of new knowledge. This is supported further by the order's descriptions of the program's scope and duration (Chapter 2), structure and content (Chapter 3), and especially in the description of the 'study areas' identity and purpose (discussed below). The ministerial order fully supports the idea of developing study competences as described above. Of course, one could say that this is basically the whole purpose of any high school education; however, the ministerial order quite explicitly mentions knowledge of the tradition, Bildung, and the ability to produce new knowledge as the purpose here. In what follows, I will examine the subjects 'technology' and 'technical science' as these subjects are the so-called 'profile subjects' which mark the difference between HTX and other secondary education programs. I also examine the 'study area' (SO) and 'study project' (SRP), as these activities are specially targeted at the formation of study competences.

HTX has a basic course and a study direction. The basic course lasts for six months and is common to all students – the first half of the first year. The basic program consists of compulsory courses and the study area (SO). Compulsory courses include Danish A, English B, Mathematics B, Physics B, Chemistry B, Technology B, Communications and IT C, Civics C and Biology C. A is a three year course, B a two year course and C a one year course. After the basic course, the students choose one of the offered 'study directions'. Study directions are combinations of subjects which continue over the program's remaining two and a half years. The ministerial order states that:

> Study directions consist of compulsory subjects, and continued teaching in the study area, subjects, electives and a study direction project. (§13)

Each study direction must include three electives; in practice this means that the HTX school offers different packages that ensure interaction between electives (§14). Individual schools offer their own core modules and use these to profile specific interests and efforts. In HTX examples could include core modules in biotechnology, chemistry of nature, the world of physics, and so on. An example of one such module could be the world of physics (Aalborg HTX). The package includes profile subjects (Physics A, Mathematics A, History of Ideas B), compulsory subjects (Technology B, Danish A, English B, Chemistry B, Communication/It C, Civics C, Biology C), Technical Science A, where there is a choice between three directions; design and manufacturing, construction and energy, and process, food and health. In addition, an elective in this package can be selected, for example Innovation C, German C and B, Information technology B, Psychology C. There are a number of constraints on the composition of core modules, precisely to ensure coherence between subjects and the possibility of SRP interdisciplinary study projects.

HTX PROFILE SUBJECTS: TECHNOLOGY AND TECHNICAL SCIENCE

The profile subjects in HTX schools are technology and technical science. These profile subjects distinguish HTX from other upper secondary education. These courses are only offered at the HTX or offered only marginally at others – e.g. technology in the ordinary high school. The engineering, science and technology focus is central and explicit.

Technology

The subject 'technology' is concerned with the relationship between technology and society in its broadest sense. The subject's goal formulations are all characterized by a socio-technical concept of technology (Trist & Bamforth, 1951; Müller et al., 1984), i.e., technology conceived of as composed of knowledge, organization, technology and product. The subject thus takes its starting point in social issues and analyses technology development, community development and the interplay between technology, knowledge, organization and product. In this form of analysis, social scientific, technical and scientific knowledge are combined with workshop oriented practical work. Students are provided with technological Bildung, e.g., they acquire an understanding of the interplay between technology and society. From the outset, the Technology profile subject is interdisciplinary and problem-oriented.

This course in technology should provide students with an understanding of the relationships between science, technology and society; a critical approach to technological development and social conditions; knowledge and understanding of technology as a solution to problems; knowledge and understanding of technology which creates problems; knowledge and understanding of the need to involve various stakeholders in technology development; experience working with the connection between scientific theory and practical training in workshops and laboratories; knowledge of, and experience with, a selection of production processes; knowledge of various technologies used in business; knowledge of the development of ideas and innovative and creative processes important in product development. Finally, it is an objective that students gain experience with PBL (problem based learning) in larger projects, both individually and in cooperation with others, as well as the study and work methods that are relevant in higher education.

The technology course contains a number of specific topics, including materials and machining processes, technology and environmental assessment, product development, production, and marketing. The course also aims at developing the students' understanding of project work and their skills in documentation and presentation. Note that Technology A also includes the company perspective and the manufacturing process; i.e., a three year program with subjects like quality and environmental management, strategy, marketing, logistics, costing, etc.

It is clear that the objectives of the subject 'technology' are to achieve study competences, and this is an integral part of the course objectives. Technological literacy is explicitly mentioned and the students' own ability to create new knowledge through independent projects is also a central element in this. However, the subject's own tradition poses a particular challenge. Technology is a relatively new subject, only about 20 years old in a high school context and has not, in the same way as other upper secondary school subjects, many years of experience to build upon. The tradition must first be established and the content of the technology subject is so broad that it is open to numerous interpretations. The ministerial order and its supplements are all based on a socio-technical approach, a socio-technical technology concept, which in itself can be very sensible, because it is useful and manageable in a secondary school context. But, in principle, other approaches could be selected. Therefore, it may also be difficult to talk about 'tradition' in the subject technology, since it is open to interpretation to a degree that does not exist in exactly the same way in other upper secondary school subjects and programs. Yet, it appears that it has been possible for teachers in the subject technology to establish a tradition based on its project and problem orientation and in its above-mentioned socio-technical approach. A typical course in Technology includes classroom teaching, workshop courses, and group work; all are organised in a number of projects whereby various topics are processed.

A course might look like this: First year, basic course, the themes are project processes (how to work in projects), technology history, design of playground equipment (a practical design task), workshop courses, and working environment. The subject work is made in collaborations with the subjects Danish, Civics and Chemistry and the course is part of the study area (see below). In the study direction, still one year, the topics are project processes, workshop courses, as well as 'climate and environment' carried out in collaboration with the subject English and included in the study area. In the last project, processes with the topic 'a bike light'; this topic is carried out in collaboration with Physics and is also part of the study area.

Study programs continue in the second year, and here the topics are project processes, systematic product development, participation in science cup (Young Enterprise Competition), and technology assessment carried out in collaboration with Danish and English and included in the study area. Fourth course is 'science and technology' in collaboration with Chemistry, Physics and Mathematics, and the course is part of the study area. Fifth course is called 'technological development' and carried out in cooperation with the History of Ideas and is also part of the study area. Finally, the second year is completed with an examination. Those students who take Technology level B complete the course at the end of the second year.

Third year Technology is for students who have chosen technology at A level. The difference to B level is that A level students also include manufacturing processes and business in their analyses of technology. A typical third-year project course could look like this: Integrated product optimisation of waste of resources, re-design of existing products carried out in collaboration with design and the technical science subject, urban design again in collaboration with technical science and Design, Danish and an external company. The process is included in the study area and is part of a competition: 'From idea to business' in collaboration with the subjects Design, Chemistry, Technical Science, Mathematics, included in the study area. Integrated product development phase 4 – 'Design 3rd world' in collaboration with the subject Design; 'Concept Design', continuation of design for the 3rd world. Business Building in collaboration with an external company. CreaCamp in collaboration with an external company. 'Product development and manufacturing' is the final part of the student's One Year Project. At the end of the year the students complete a program where they gather all work done in the third year in an examination report. For each of these projects, teachers outline learning objectives, work methods, content and scope.

Teaching of the technology subject is most often organised as projects. The education, therefore, also has an emphasis on projects as the guiding principle and projects, group work, individual project work and teacher-led classroom training forms the basis of the activities in the subject 'technology'. This means that project work largely allows students to actively shape the content of the courses and even make suggestions on how projects should be approached. Students are very positive about the subject technology and consider their own ability to shape the projects as an advantage; as several of the students expressed to the author, they found that there was great freedom to 'do things' and even to control the process themselves. Several students noted that they viewed this freedom as a major reason for choosing the HTX. They had heard about the projects from friends or had heard about it from visits to HTX while still in primary school.

The lectures I observed in the subject technology can best be described as an organised creative chaos. The students sat in groups discussing loudly with each other, they visited other groups to ask for their solutions or they sat very concentrated and wrote or calculated on their PCs. Everything seemed very focused on the project itself. Even when two students returned to the group after passing their theory test for their driver licences, congratulations and high-fives lasted only about 5 minutes, after which the group work resumed. The teachers were highly engaged in discussing projects and guiding students when they had specific questions for their work.

Example 1. Conversation between a girl and her teacher. The group was engaged in a design task where they have to develop a product in relation to some external requirements.

> Girl: Why should we look at the requirements again – we have already looked at the requirements under the point X?
>
> Teacher: You should compare your product with the requirements – does your product meet the requirements?
>
> Girl: Well, I do not understand, we have been working on the requirements and we have not made our finished product yet. How can we see if we meet the requirements when we are not finished (with the product)?
>
> Teacher: Well, you can go back and look at the requirements and use them while you are designing your product.
>
> Girl: Oh, yes, of course, that's what we do, we can of course use the requirements, so we are sure that it is in line with the requirements.

Example 2. Four boys are working on a project on the filtering of rapeseed oil. They want to make an installation that a car owner, whose car runs on rapeseed oil, can have in his garage. They have made a sketch of a filtration plant, but are not happy because they think their plant is too tall to fit in a garage. They discuss whether there is something they can do. 'Think out of the box!' says the teacher. One of the boys asks whether the existing filters can fit into a PVC pipe. The teacher picks two filters that the boys can investigate. Another boy asks if the filter can lie horizontally, so they could make the system fit into the garage. They continue the discussion and try to make sketches on paper with a pencil.

Example 3. Two girls and two boys are working on a project on disability aids. They have made an experimental setup with an actuator. Unfortunately the actuator does not work and they turn to the teacher with the problem. The teacher picks a new actuator in the workshop and students can continue to study the actuator.

Generally, the students are very satisfied with the way the technology subject is organised. Comments included: 'The best thing is the way we work, the projects, it is all very relevant what we learn'. 'The practical part is good too – you can touch the things and many company visits, it has all been applicable what we have made'. 'This is not what is normally understood as a school such as writing essays – we got that freedom. Much of what we do, we can see the purpose of, rather than that we just have to fill in some student hours'.

Students also mentioned the group work. Comments included: 'For me it (the best thing) is group work – one hundred (per cent). We meet after school and on weekends, now in technology. We work well together socially, and then we sometimes do something else, it is sometimes … some long days, but there will also be some pleasant days … better than if you just sit and nerd it all day'. 'There are many things we must do alone – but we have helped each other – we are good at working together'. 'If someone does not do something then they get a earful'. 'So they get a kick in the behind!'. 'The teachers were good at this, in the first year, you have to work with many different (class mates) and those who are not doing anything are automatically excluded, they know it very well. Those who want to make something go along, those who make 'in between' go together so … it happens quite naturally'. 'In the large project (Third year technology project), we work together with those class mates we prefer to work with'. 'You learn something by being together … so at different levels, some are good at writing, some are good in the workshop … learning from each other, we pull each other up by being different'.

As noted, most work in the technology course is focused on student projects. In third year Technology A, the students carry out a major project where they, in groups or individually, work on a chosen project. In this project, students work with a technological problem, analyse the problem and construct a solution, a product and at the same time relate their solution to the technology's societal importance. The work is documented partly in a report, partly as a tangible product. The project work is the basis for that year's exam in the subject. Exams can be individual or in groups with individual assessment.

Examples of 3rd Year Technology Projects

Example 1. Two girls and a boy work with a project where they will find solutions to the problem that many cyclists are injured, or even killed, by trucks in right turn accidents. Through an analysis of the number of accidents they conclude that a problem still exists, despite the fact that there has been a reduction of the number in recent years. The solution will be to develop a sensor that can be placed on the bike and a receiver that the truck driver has in his cab. In the preparation for the project, the group has worked with a local Carlsberg depot, where the group has interviewed the drivers about the problem and their proposed solution. The report itself is structured as a business plan for a company that manufactures and sells sensors and receivers to avert right turn accidents. The report includes the following: problem analysis, line of business, business structure, market description, business strategy, mission, vision and goals, technology analysis of another product, production, product development and manufacturing and engineering drawings for the product. In addition to the report, the students made a sensor and a receiver and made a model showing that the product actually works. The final report is well composed and it demonstrates that students are able to handle project work and enable them to use the methods and techniques they have met in the technology course. At the same time they have contacted actors outside school in order to assist in solving their problem, thereby demonstrating a degree of maturity. Overall, the project shows, from idea to implementation, that these two girls and one boy have been able to handle project work by themselves and that they are able to plan, implement and document their work.

Example 2. Four boys have discovered that they have difficulties getting started with the technology project. They are, therefore, interested in work and working conditions and they decided to initiate a project on work organisation and motivation. The project report is structured as a description of the company 'Communication Matters', i.e., the boys have been working on a specific issue – organisation of work – and translated their solutions into a business concept. The report has the following content; problem and a problem statement, generating ideas, method, theories of work, business description, including vision, mission, goals and actions, and technology analysis of the planning tool the boys had developed. This project is very interesting as it shows a very high professional level, both in choice of subject, analyses, use of theories and methods, and finally in the chosen solution. Furthermore, the report is very well composed and very well written in a good and mature Danish language. But the boys have had to produce a physical product that actually had not been necessary. Technology project requires the preparation of a physical product (Ministerial Order, Section 28 paragraph 4.2). But in this case the students worked with a process and it had been smarter to make the physical product as a piece of computer software. The description of the physical product also seems somewhat overdone, something that just has to fit into the ministerial requirements and not something that is presented to make the project better. Working on work process improvement is a classic engineering discipline and should provide the basis for a technology project without it having been necessary to produce a 'physical' product – software is much more appropriate here.

In early 2014 representatives of four HTX schools, and the consultant from the ministry, gathered for a meeting in the city of Slagelse. Common to these four HTX schools was that their students scored significantly higher grades in the subject Technology than the national average of HTX schools. The purpose of the meeting was to discuss what is special about these schools, whether they are doing something different in Technology? The results of the discussions can be summarized as follows: The management of these four HTX schools take the subject seriously as a profile subject and have placed it on an equal footing with other subjects. Significantly, the course is led by a group of teachers who collaborate on the subject. When making schedules the subject is taken into account, so it can be placed in the study area and it can cooperate and be included with other subjects. This cooperation among the teachers is important. It is also important that different disciplines are represented in the teaching staff, and that the various disciplines are utilized and can complement each other. Emphasis was placed on the fact that teaching is based on ambitious goals, ensuring progression in the core substance and goals of the projects. Participation in competitions and business collaboration is very motivating and provides the students something tangible to aim at. School facilities must allow for workshop instruction, and there must be room for group work. Worth noting is that managers of all schools said that they work very consciously with the students' written work in connection to report writing.

The subject technology contributes significantly to the students' development of study competences and can help to prepare them for their future conduct in the education system – especially for those students who later choose natural sciences, health sciences, engineering or other technological studies. The subject aims especially at developing awareness of methods that develop students' understanding of and ability to work in a project-oriented and problem-oriented education system. Compared to study competences (understood here as tradition, Bildung and knowledge production) it is the emphasis on the production of knowledge that comes into focus and noted above in project examples provided. Technology is a relatively new discipline; as a tradition, it is still under development and not yet rooted similar to more established subjects in Danish upper secondary school. In order to achieve the Technology subject objectives, and for students to develop the requisite study competences, it is vital that the school management and the school teaching team work together to organise and implement the form of active teaching necessary.

This requires ambition, serious planning, management support, and a cooperative interdisciplinary teaching staff.

Technical Science

A level Technical Science is the other compulsory profile subject where students choose between three course options. (1) Design and Production, as the name implies, relates to design, materials, and manufacturing technology, and product design and development. (2) Construction and Energy, relates to the entire planning processes in construction from initial concept to finished design. Construction and energy related themes include planning, production and development of structures, materials, utility installations, and others. (3) Process, Food & Health, as the name implies, revolves around issues related to health, nutrition and the environment. Themes include physiology, genetics, disease and environmental sciences.

Technical science contains a number of mandatory key themes plus two themes of the student's own choice. Each school determines how to distribute the different subject areas. The course provides a final grade for the year and there is a mandatory project exam which is defended at an oral exam. The ministerial order describes Technical Science as follows:

> The course deals with the development and manufacture of products and related issues. The course consists of the relationship between technology, knowledge, organisation and product, with a focus on technical and scientific knowledge integrated into product development and manufacturing process and combined with practical work in workshops and laboratories.

The ministerial order's description of the subject's identity and purpose is virtually identical to that of the Technology subject discussed above. Again we see the socio-technical base – technology, knowledge, organisation and product. But in the technical science course, in the description of the subject, there is a *much greater emphasis on practical work in workshops* or as formulated in the notice: 'The course helps to make the HTX program realistic, contemporary and relevant' and 'The subject contains process and manufacturing of product at a level reflecting commercial professionalism within the chosen subject area'. Teaching is similar to the Technology subject; it is geared towards projects and problem orientation, but with an added emphasis on practical work in the workshops.

One example: A group of students and their teacher have contacted a company on cooperating on a project. The company has a problem with their packaging line. There are too many single operations and they would like the packaging of their products to be simplified, hence more effective. Through various analyses, and design suggestions, the students find out that four operations can be reduced to two and the company can save time and money. Problem defined and solution found.

This project looks very much like the projects that students in university engineering studies undertake in the first year at the engineering school. This HTX course, based on this evidence, is entirely up to the task of developing study competences relevant to university level engineering and science studies.

When asked directly, the students express enthusiasm for the Technical Science subject. 'That's where we can do something' with regard to the practical work in the workshop. 'That's where we can do something … they do not have anywhere else', with reference to the differences between HTX and the other secondary schools. Students see the possibility of working in the workshop as Technical Science's main contribution, as it differentiates their education from other secondary schools.

This, of course, does not mean that Technical Science is without its problems. First of all it seems that the subject is sort of 'left alone' among the other subjects; a bit of an outlier. According to the students it is a bit of a practical 'rock' or playtime that does not really have anything to do with the other subjects, but is a place where one does something practical and one can be active. These students like to 'do'. The idea of a socio-technical base does not appear to have reached the students I spoke with. It seems that Technical Science's level of cooperation with the other subjects does not work exactly as prescribed in the ministerial order. The students had a completely practical explanation for this apparent lack of cooperation. Three students in a Technology group that worked with their technology report, were asked why they had not included Technical Science in their work? The answer was simple. The three students had three different course options (noted above) in Technical Science and, therefore, they could not find a common topic. When I asked if they could choose to be with someone from the technical science class that had the same subjects in technical science, the answer was that it could not be possible – because they would not work with class mates from the technical science class, and therefore it was not possible to make an integration from their work on the subject technology and the subject technical science. Whether this can be the whole explanation is probably doubtful. Teachers can come up with a somewhat different explanation. What is clear is that there are issues related to integrating Technology Science with other subject areas.

As noted above, in early 2014 a group of HTX teachers, consisting of teachers in both Technical Science and Technology, along with a consultant from the ministry, wrote a report and provided some suggestions on how to achieve progression in student learning. This report included concept development, material selection, product requirements, and evaluation forms (Kaltoft et al., 2014). The group concluded that although the description of identity and purpose are very similar for the two disciplines (technical science and technology), there is to a high degree large difference between the subjects' descriptions of the academic and professional content. This difference is such that the difference in itself would have to cause problems when the two disciplines have to work together. That does not mean that it cannot be done (which plans for technical science also shows), but according to the report, it becomes necessary to develop cooperation in a way that will better secure progression in *both* subjects. They are interlinked; so why cannot they be interlinked in projects? One could begin by developing a set of uniform concepts for the two subjects, for example by developing a common 'engineering' concept, and ensure that it is clear that the Technical Science course builds on the Technology course, with the difference that technology is based on social issues, while the technical science subject has a more narrow technical/practical focus.

Perhaps it is here that the real difference between the two subjects lies. They work with each their own 'engineering' concept? Technology, throughout, is shown to be true to its socio-technical base and working on a technology concept in which social, organization and project management is an integral part of 'engineering'; on the other hand, it appears that Technical Science has chosen a very narrow product focus and thus departed from its socio-technical base. An example: from the goals of Technical Science class, design and production option, it is clear that it is the product that is in the centre and the primary focus and society, organization and project management play a minor role (Ministerial order, Annex 26, 2.1). That is, the engineering concepts behind the technology subject and the technical science subject are very different and this difference can be traced to a classical debate about the content of the engineering profession itself. Similar conflict between technique and technology can be found in debates about the engineering profession and engineering training (see e.g., Henriksen, 2014).

Based on a concept of study competence containing students 'understanding of the tradition, their formation (Bildung) and their own ability to produce new knowledge', it can be stated that both subjects, Technology and Technical Science, play an important role in developing the students' study competences. The courses are particularly important for the development of the ability to implement major projects and to work together in groups. The courses are also very popular with students and offer a great alternative for those students who prefer other forms of teaching than the traditional classroom and teacher centred teaching. Notwithstanding this positive evaluation, there are potentials in cooperation between the two subjects that are not fully utilized, partly due to the fact that schedules are difficult to arrange in a manner securing such cooperation; and partly because of uncertainty about the underlying ideas and key concepts of technology and engineering. The working group's proposal for the development of a common engineering concept seems, therefore, to be very well chosen.

THE PROFILE SUBJECTS IN THE STUDY AREA

In addition to the compulsory courses, the HTX program also includes a so-called 'study area'. The HTX study area represents collaboration between the subjects, the ministerial order states:

> The study area is a technical cooperation based on the technological and scientific fields of study and with the involvement of the humanities and social

> science disciplines. The study area deals with the interaction between theory and practical work, and includes experiments and workshop work individually and in combination'. […] 'The methodical element includes the subjects study techniques and work methods. The element of science and forms of knowledge includes knowledge production and scientific methods of subject areas as well as the underlying thoughts and theories'. […] 'Furthermore, the aim is that students gain insight into the relationship between natural sciences and choice of production processes through working with theory and practical workshops and laboratories. Innovation and entrepreneurship are part of one or more themes with the aim to develop students' creative abilities and give them insight into entrepreneurship.

Language and communication are central to the study area with the aim for students to develop their language, oral and written communication skills in order to acquire knowledge and disseminate results, attitudes and values (HTX, Appendix 2). The purpose of the study area is described very explicitly in the ministerial order. Its purpose is to develop students' study competences. The purpose is to transform primary school students to high school students in the basic course and transform high school students ready to begin a third level engineering and science education. This is accomplished through interdisciplinary projects. The ministerial order's instructions for HTX states that students must acquire knowledge and skills in the areas of learning, reading strategies, writing, planning, working (collective and individual), projects work, information retrieval, assessment methods, use of references, science and forms of knowledge (HTX, instructions).

The study area does not have separate lessons allocated; the learning objectives are to be achieved within the compulsory subjects, so that what is learned in one subject, for example project work, is used in other subjects. The study area at HTX is also part of the compulsory subjects and here it is also supposed that what is learned in one course is applied in other subject areas; hence, interdisciplinarity. Example: In the study area, in the second year, the students are working with the following topics: learning theory and learning processes, work methods, including project work, information retrieval, scientific methods, communication theory and evaluation theory. In practical terms, this takes place through a so-called SO-course (study area course) (Lund & Møller, 2009, p. 103). Here different subjects are combined in short courses where students work on projects that cut across the curriculum. The projects are most often finished with a written report that can then be included in the final sample folder. The sample folder collects all projects in a final report/portfolio that is used at the final exam. The final exam consists of a 30-minute individual oral examination on the basis of the sample folder. The sample folder consists of selected works from the whole process and must meet the academic goals in the study area. The sample folders content is selected on the basis of guidelines formulated by the teaching staff. In addition, the sample folder includes a short description of the selected works, as well as documentation of the student's academic and personal development. The oral examination consists of the student's presentation of the works, 15 minutes, and a conversation with the teacher and examiner, 10 minutes.

When students were asked about the "SO", as they call the study area, they responded mostly with some surprise: 'What do you mean? – oh, well, SO, yes, it's OK', without really taking a position either for or against. Just noticing that the SO exists and that, pretty much, is good enough. This may be due to the fact that the study area does not have its own lessons, but are collaborations between compulsory subjects. Therefore, the students might not even discover that they have the SO. Another student responded, 'Oh, well, SO, well, that's fine, because that is where we learn to use what we have already learned.' One might have added – 'precisely!'

The study area has, quite explicitly, the aim of preparing high school students to become university student – the purpose is to develop study competences. My conversations with HTX students about the study area showed an overall positive attitude towards the study area, although some students had not noticed that they also had SO, as they called it. This suggests that the study area's integration of the subjects is successful – to such an extent that the students do not even realise that they are engaged *in* the study area? Other students, however, were aware of the activities in the study area and when they say that 'the study area is where you learn to use what we have already learned', then it must be their way of saying that they have actually acquired some study competences, understood as the ability to independently produce new knowledge. It is evident from the written work included in my analysis that the objectives of project work and problem orientation are also certainly achieved.

STUDY DIRECTION – AND THE SRP PROJECT

Study Direction contains a major assignment called the study direction project (SRP project) which is described in an annex to the ministerial order (Appendix 5); the purpose of the study direction project in HTX is stated as follows:

> The purpose of the study direction project is that students work independently to explore and present an academic problem within a chosen area related to their field of study. By combining different disciplinary approaches and disciplines that enhances the academic work, students must demonstrate that they are able to independently select, integrate and use relevant background material, and that they are able to conduct a critical assessment of a professional and methodological basis. Through the work with the study direction project the students strengthen their study competences because they, through written presentation, must demonstrate that they are able to work on and present an academic and complex subject. (The Order Annex 5)

As seen in the formulation of the purpose it is once again independence, concentration, communication, interdisciplinarity, critical assessment, application of methods and, as they say in the formulation of the purpose, all to strengthen the students' study competences. This is also the case if the description of the objective is to develop study competencies described as tradition, Bildung and problem solving – it's all there. The study direction project becomes an exercise in implementing a major independent piece of work, that is, a foretaste of what awaits students in higher education; independent production of knowledge, based on tradition and thus study competence.

The study direction project has a scope of 30 hours, often an entire week, called project week, in the third year and must be prepared in two subjects, starting from a field of study subjects at A level and another subject of at least B level. The written report has to be approx. 8–12 pages. By October the subjects must be approved together with a preliminary assignment for the task. Annex 5 states:

> One mark is given, based on an overall assessment and based on an assessment of the extent to which the candidate's exam paper meets the objectives of the study project. If the task is written in only one subject, it is also included in the assessment, the extent to which the reply demonstrates the student's mastery of a specific academic subject'.

Example of SRP project: SRP, HTX, Social Studies B and Physics A. Title: Ship Stability. The report is app. 30 pages including annexes. It describes the importance of ship containers for globalisation and the problems dealt with are partly questions about globalisation (social studies) and partly how it is possible to use containers to carry large amounts of cargo on ships (Physics), which in turn is seen as a prerequisite for globalisation.

The idea of looking at the material conditions for globalization seems obvious. From physics the student finds theories about the centre of mass, buoyancy, etc. and this is assembled in the section, 'How is a force analysis of a container ship made?', where an analysis of the physical conditions for container traffic on ships is presented. From social studies the student finds theories of globalisation; 'realistic' and 'neo Marxist' theories. The discussion of globalisation is found in the chapter 'Denmark, the late modern society and globalisation'. Finally, it is concluded that even if a container is a simple box, it has been capable of changing the world economy completely. The project is very well organised and the whole idea is most interesting. The somewhat brutal materialism expressed in the conclusion is not problematised, for example in relation to the neo Marxist theories. But that would probably have been too much to ask at this level? The tasks are generally well laid out and one can see there has been a lot of work put into seeking information, organizing and writing the project report. This shows that students are actually able to formulate a project, find information, structure the information, and finally solve the problem statement with a plausibly presented solution. The students' own perception of the SRP (study direction project) varies widely. A boy said that 'it was wildly exciting, you can choose whatever you want, you know, the freedom, you can do what you want'; a girl had a more nuanced relationship with SRP:

> It's great! to help to solve a problem for a company with the theory we have learned. You become like seduced when you are in a business company, so it should just be done properly, it is not just nonsense. But the actual writing of the report … to put it bluntly, then it's a hell of a sit in … because you know it's going to count so much on one's diploma and it's hard for you, not to have a teacher who constantly sits and breathes down your neck. It is something you have to find out, even finding its conclusions. Well do I explain this properly? do I reach a point where I say what I want to say?

Similar to this independent minded girl, there were many students who found it difficult to write the report; on the other hand there were students who had already completed the study project, who were very proud to have been able to complete the study direction project, as it is a very large and demanding assignment. The study direction project, SRP, is the space where students' study competences really are going to be tested but also where they can be demonstrated. Of the projects observed, all are ready for the task, even though most students probably think that the project week had been very tough for them to get through it. But, they do.

CONCLUDING COMMENTS

HTX study competences have been described here as knowledge of a tradition; this is to be understood as the subject's tradition, and not only as canon or curriculum. Bildung is described as a process through which HTX students are 'Gebilded', changed, formed, hence becoming an able person. The final aim is to develop students' ability to participate, through interdisciplinary project work, in the production of new knowledge. This means that the students are in possession of the tools and methods necessary to be able to cooperatively formulate and solve problems. The question then posed was whether the HTX high school program is capable of achieving such goals?; are the students able to achieve the desired study competences? The answer, clearly, is that it can be done. This does not mean that all students in all schools also achieve the desired competencies, but just that it can be done within the limits of HTX school activities.

The ministerial order and its supplements constitute a useful framework to develop students' study competences. There is not much here that prevents such development. Looking at the profile subjects – Technology and Technical Science, it seems that it is possible to develop study competences within the current framework; but it is possible to develop these subjects even further. The profile subjects, technology and technical science do not, in the same way as other upper secondary school subjects, have a long tradition to build on. It seems that the underlying technology concept in both subjects remains open for further discussion. The socio-technical concept of technology may be sufficient in a high school context, but teachers should be aware that technology and technical science should not end up in a fixed form, but should provide a vehicle for debates on their content. Thereby, subjects can create the academic breadth necessary in order to achieve the desired goals. The technology concept, however, is problematic when Technical Science abandons the socio-technical technology concept in the description of its academic content with a focus only on a narrow product-technical technology concept. The working group (Kaltoft et al., 2014) has a valid point when they recommend the development of a common engineering concept as discussed above. There is certainly further potential in cooperation between these two subjects that are not presently fully exploited. It will, as the working group recommends, require in-depth discussions of the subjects' basis, content and methods to realise this potential.

The study methods – project work, problem orientation and group work – are important elements in developing study competences and also very popular among the students. Discussion of the profile subjects' basis could be supplemented by a similar discussion on future pedagogical development. Here, a discussion of cooperation between the subjects could be particularly helpful. That is, a discussion of the degree of problem orientation, project organisation, and student centeredness. HTX has the potential and has already come a long way in providing a valid alternative to teacher centred classroom training; that said, there seems to be room for taking development one step further within the current ministerial order and guidelines.

The Technology course is from its outset interdisciplinary and problem-oriented and it could provide the nucleus of a real PBL-based education. Discussions could focus on Technology's place in the curriculum and the other subjects' role in the entire program. Besides discussing the profile of the subjects' basis – a discussion of an 'engineering' concept – and a discussion of the degree of PBL, there are a number of more specific measures that could also be set in motion. The study of the best schools identified the following:

> It is important that the school management has a focus on the profile subjects. They should be placed at the centre of education and be, as profile subjects, taken seriously as just that. This means that the school management provides the necessary resources to the subjects and at the same time formulates some very ambitious goals. The Technology subject is problem-oriented and interdisciplinary and as a consequence, collaboration between teachers is an absolutely necessity. Therefore the technology subject needs a team of teachers who have the required professional breadth and in cooperation ensures problem-orientation and project organisation.

The individual teacher, however, cannot handle this job alone. Some further recommendations for HTX could look something like the following: (1) A discussion on the basis or foundation for the curriculum; the HTX' should consider the concepts 'engineering' and 'technology' and their role in the curriculum. (2) A discussion of the pedagogical basis where students' qualifications for working with interdisciplinarity and problem orientation are developed even further. (3) A management focus on the profile subjects so that these become the main focus of education. (4) Teacher collaboration in developing students' study competences is essential. (5) An increased focus on students writing reports for the various projects.

Report writing is a large part of the Technology subject. Students spoke with almost awe about the study direction project; understandably, since the study direction project (SRP) is viewed as one big challenge. It appears, however, that students are able to meet this challenge and are actually able to write projects at a high level, thus demonstrating that they possess, and have developed, the necessary study competences. The quality of projects shows clearly that the students will be ready to continue their studies at the university; this is also confirmed from my conversations with ex-HTX students at the university. The HTX education features many large written projects and it seems that this is a very good foundation to bring into the university; there is thus a fine progression from the HTX high school projects to the university's basic year. Study competences do not simply arrive by themselves. The ministerial order and its guidelines outline the framework, but these must be implemented. If schools exploit opportunities in the profile subjects – interdisciplinarity and problem orientation – there are good opportunities to further develop Danish students' study competences.

NOTES

[1] Professor, PhD, Department of Planning, Aalborg University, Denmark.

[2] Method: Interview with 8 teachers, 22 students at high schools, 10 students at the university, all with a background in the technical high school and two ministry officials. Shadowing of 2 teachers – 2 days each (Czarniawska, 2007). Participant observation of one exam, and of 8 lectures/classes/workshops. Reading of ministerial orders, study programs and of 25 student reports. Vital interviews were transcribed for further analyses.

REFERENCES

Czarniawska, B. (2007). *Shadowing and other techniques for doing fieldwork in modern societies*. Malmø: Liber.

Gallagher, S. (1992) *Hermeneutics and education*. New York, NY: State University of New York Press.

Henriksen, L. B. (Ed.). (2013). What did you learn in the real world today. Aalborg: Aalborg University Press.

Henriksen, L. B. (2014). Knowledge work and the problem of implementation: The case of engineering. In D. Jemielniak (Ed.), *The laws of the knowledge workplace*. Farnham, UK: Gower Publisher.

Jenkins, E. W., & Pell, R. G. (2006) *The Relevance of Science Education Project (ROSE) in England: A summary of findings*. Leeds: University of Leeds, Centre for Studies in Science and Mathematics Education.

Larsen, P., Hansen, B.R., Bertelsen, G.U., Funch, S., Linnane, W. & Kaltoft, P. (2014) *Progression fra teknologi til teknikfag* (Progression from technology to technique subjects). Rapport.

Lund, B. M., & Møller, D. B. (2009). *SO2 – Studieområdet Del 2 – HTX (The study area – Part 2 SO2 HTX)*. Viborg: Systime.

Muller, J., Remmen, A., Christensen, P. & Deleuran, C. (1984). *Samfundets teknologi – Teknologiens samfund (Society's technology – Technology's society)*. Herning: Systime.

The European Commission. (2011). *Science education in Europe: National policies, practices and research*.

The Ministry for Children, Education and Gender Equality. (2015). *The ministerial order: HTX*. Retrieved from http://eng.uvm.dk/Education/Upper-Secondary-Education/Four-Upper-Secondary-Education-Programmes-in-Denmark/The-Higher-Technical-Examination-Programme-(htx)

Trist, Eric, & Bamforth, K. (1951). Some social and psychological consequences of the longwall method of coal getting. *Human Relations, 4*, 3–38.

Lars Bo Henriksen
Department of Development and Planning
Aalborg University
Denmark

ANETTE KOLMOS

9. PBL IN THE SCHOOL SYSTEM

INTRODUCTION

> Young people need a wider range of competences than ever before to flourish, in a globalised economy and in increasingly diverse societies. Many will work in jobs that do not yet exist. Many will need advanced linguistic, intercultural and entrepreneurial capacities. Technology will continue to change the world in ways we cannot imagine. Challenges such as climate change will require radical adaptation. In this increasingly complex world, creativity and the ability to continue to learn and to innovate will count as much as, if not more than, specific areas of knowledge liable to become obsolete. (EU Commission, 2008)

The EU commission has emphasised lifelong learning, especially that young people learn skills and competencies broader than the knowledge perspective. In 2000, the Lisbon declaration was signed with the intention to reform the educational system. As the European Commission wrote in one document to the parliament, there is a need for new competencies. From the European policy level, there are definitely intentions to create a change in the entire educational system, from the school level to universities and continuing education. However, the policy given objectives might have more straitened circumstances when it comes to educational practice, especially the educational systems' facilitation of pupils' learning of skills and competencies. A study undertaken by the CASE network indicates that transformative skills need a more student-centred learning system (Jean Gordon et al., 2009; Jean Gordon, Rey, Siewiorek, Vivitsou, & von Reis Saari, 2012). There is a call for more student-centred learning throughout the system – also in the Science, Technology, Engineering, Mathematics (STEM) subjects at the school level.

Problem and project-based learning (PBL) is one of the answers to this societal request – both in terms of new competencies and in terms of deeper learning. Meta-analyses and single studies on PBL indicate that students' skill levels, retention of knowledge, learning environment, motivation and satisfaction among students and academic faculty are increasing, although not all studies point in the same direction (Bedard, Lison, Dalle, & Boutin, 2010; Dochy, Segers, Van den Bossche, & Gijbels, 2003; Galand, Raucent, & Frenay, 2010; Prince & Felder, 2006; Strobel & van Barneveld, 2009).

PBL has taken off in higher education and slowly moved into primary and secondary schools. In STEM, at the school level, trails of PBL pedagogy are found in very similar student-centred learning methods. Already in the 1980s, there were

M. J. de Vries et al. (Eds.), Pre-university Engineering Education, 141–153.

extensive experiments with new student-centred teaching and learning methods in STEM subjects at the school level. The GASAT movement (Gender and Science and Technology) held several conferences worldwide; the first was held in 1981 and the last in 2006 (Hodgson, Fears, Gender and Science and Technology Association, & GASAT Conference, 2008; Raat, Harding, & Mottier, 1981). The proceedings from these conferences witness extensive studies in the STEM area; however, many are no longer known due to the publishing methods at that time.

Today in STEM in Europe, educational practices very similar to PBL are found under other conceptual headlines, such as inquiry-based learning or active learning (Kearney, 2011; Prince & Felder, 2006; Rocard, 2007), or even as elements in existing pedagogies like Montessori schools that are built upon similar learning principles (Kolmos & de Graaff, 2014). In the US' STEM K–12 system, PBL is implemented in various ways.

This article will discuss developments in PBL and student-centred learning in higher engineering education, and will draw perspectives to STEM in primary and secondary school teaching – in terms of both present practice and future possibilities.

ORIGINS OF PBL

The origins of PBL go back to the 1960s and 70s when many new universities were established. Among these, there were five reform universities established as problem-based and project-based universities. Characteristic of all these universities was that they could develop a new curriculum concerning both the content and the teaching and learning methodologies.

McMaster University, Canada, was established in 1969, and started out by developing problem-based learning in medicine (Barrows & Tamblyn, 1980; Woods, 1994). In 1976, with a very similar PBL model, Maastricht University in the Netherlands was founded with problem-based learning where groups of students learned content knowledge by studying cases in study groups. At Maastricht, this PBL model was an institutional approach across subject areas (Barrows, 1996; de Graaff & Bouhuijs, 1993; Dolmans & Schmidt, 1996). Linkoping University in Sweden was also a new university established in 1975 (Dahlgren, 2002), and implemented the case-oriented, problem-based learning in medicine later during the 80s. Characteristic of these universities was that there was a case formulated by the academic staff, and the students normally followed a procedure for studying these cases. In this article, this is called case-based PBL.

At the same time, two Danish universities were established: Roskilde University in 1972 and Aalborg University in 1974, which used a slightly different model, called problem-oriented and project-organised learning (Illeris, 1974). For both Danish universities, this was an institutional approach across all faculties, and students worked on socially relevant problems as a starting point for projects. The students identified problems and completed projects in teams; for the two universities, the projects were substantial, normally running for an entire semester. As they were

Table 1. Comparison between the Maastricht PBL model and the Aalborg PBL model

	Maastricht	*Aalborg*
Problem	Cases defined by teachers – open and narrow	Problems defined by students or facilitators within a theme, which can be broad or narrow
Process	Seven jumps	Project management
Team aspect	Discussing together	Discussing and writing together
Assessment/Exam	Individual progress testing Individual exam	Formative group assessment or individual judgement in a team-based exam

new universities, it was possible to build the pedagogical ideas into the space, and both institutions had extensive numbers of small group rooms to facilitate students' learning. Studying was regarded as a collaborative work and the universities offered the physical environment as well as academic facilitation of these learning processes (Bitsch Olsen & Pedersen, 2005; Kolmos, Krogh, & Fink, 2004). In this article, this is called PBL.

The Danish models are different from the McMaster and Maastricht model in terms of both the organisation of the learning process and the learning product. Whereas the case-based PBL models at Maastricht and McMaster were much more centred on analysing teacher-prepared cases, the philosophy at the Danish universities, from the beginning, was that students should identify a societal problem that they could analyse and solve in their projects. In terms of teamwork, there were also substantial differences, as the case-based models applied a group-based approach and peer learning, and the Danish models were based on real teamwork where the students would submit a common product, most likely a written project report.

Internationally, the concept of project-based learning also exists and, actually, has a long, historic tradition (Prince & Felder, 2006). It is mostly defined by narrower problem formulations and is often limited to a subject. However, the practices are very diverse – no matter if it is problem-based learning or project-based learning, there might be well-defined and narrower problems on one side and more ill-defined and unstructured problems on the other. In Table 2, various PBL concepts are related to these two dimensions.

Table 2. Variations of the PBL concept

	Cases	*Projects*
Well-defined and narrow	Case-based PBL	Project-based PBL
Ill-defined and open-ended	Case-based PBL	PBL

PBL LEARNING PRINCIPLES

During the last 20 years, the development of the PBL implementation around the world indicates that institutions/programmes utilise elements of the two original models as they fit the learning outcomes. The literature clearly indicates that the original models are in phases of pragmatic merging and are applied in many different ways all over the world—they are mostly referred to as PBL (de Graaff & Kolmos, 2006; Kolmos & de Graaff, 2014).

However, the learning principles beyond the models are very similar; it is mostly at the concrete curriculum level that the differences are visible (Kolmos & de Graaff, 2014). There is not one learning theory that can explain the learning process in PBL. On the contrary, it takes a "patchwork of theories" to fully understand its complexity.

Some conceptualisations of learning principles are the following five developed as argumentation for why PBL works (Marra, Jonassen, Palmer, & Luft, 2014):

- Knowledge is constructed via interactions with the environment
- Reality is in the mind of the knower
- Meaning and thinking are distributed among the culture and community in which we exist
- Knowledge is anchored in and indexed by relevant context
- Knowledge construction is stimulated by a question or desire to know

Situated learning and meta cognition are emphasised as the core learning theories beyond these principles. In line with these, de Graaff and Kolmos have formulated three sets of learning principles: cognitive learning (problem and context), social learning (teams and participatory learning) and the academic content (analytical approach, theory and practice relation) (de Graaff & Kolmos, 2003). Wilkerson and Gijselaers' (1996) findings are also in line with these learning principles, but are condensed into three basic and more abstract formulated learning theory principles:

- Learning is a constructive, not a receptive, process
- Metacognition affects learning
- Social and contextual factors influence learning

Already during the 80s, feminists argued that learning should be understood as both a cognitive and affective process, and if the affective part of learning was not addressed in the classroom, women would not choose engineering and science (Alting, Vonderen, Weyers, & European GASAT Conference, 1992). Illeris (2003, 2007) also worked along these lines and pointed at a more holistic learning approach based on two dimensions: (1) cognitive and affective learning and (2) individual and social learning. Illeris (2003, 2007) used these dimensions to locate a series of learning theories.

Illeris had two main assumptions. The first assumption was that learning would be created by both individual internal learning and collaborative external learning

(Illeris, 2010). Many of the learning theories only deal with one process; cognitive theories (Kolb, 1983; Wilkerson & Gijselaers, 1996) deal with the internal process, whereas learning theories, like situated learning and social constructivism, address the external interaction (Wenger, 2001).

The second assumption is that all learning includes three dimensions: the cognitive dimension of knowledge and skills, the emotional dimension of feelings and motivation and the social dimension of communication, collaboration and social construction.

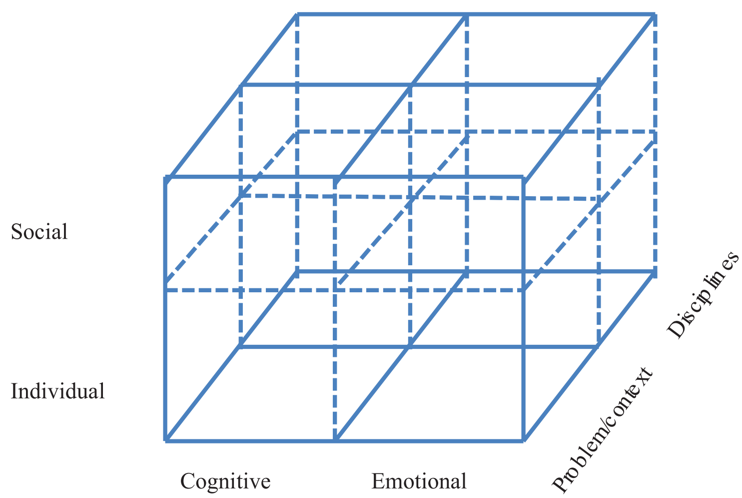

Figure 1. Three dimensions of learning with inspiration from Illeris (2010)

The cube in Figure 1 is an attempt to synthesise the referred theories and Illeris's (2010) reasoning by indicating the individual/social and the cognitive (knowledge/skills)/emotional (motivation).

The third dimension is making the context/disciplines into a dimension, which is an important link to the construction of a curriculum, as disciplines will be the core of any curriculum.

In this cube, the PBL reform universities have created the upper layer as well as the front of the cube. The traditional academic curriculum will be at the "ground floor" and in the back. Bringing in these more theoretical reflections opens up the specific curriculum models and emphasises that the success of PBL might not be dependent on if it is more a case-based PBL model, like the McMaster and Maastricht models, or a problem and project-based model, like the Danish models. There will be differences and the two models aim at different levels of knowledge, skills and competencies. However, for motivational factors, there might be fewer differences, and the importance is that students' learning processes are organised in such a way that address these assumptions: both internal and external learning and cognitive, emotional and social learning. However, this will also involve a more open approach to learning, where students have room to make choices.

The PBL reform universities have played a tremendous role in changing higher education and have served as living laboratories that academic staff could come experience to be inspired. However, the reform universities have also undergone several changes, and Neville and Norman (2007) describe three phases of major curriculum change at McMaster University. The tension concerns the dilemma between a more disciplinary versus a contextual focus. For academic institutions, this is a discussion that most PBL programmes and universities recognise as an important step in the development of a PBL curriculum. However, context has an impact on motivation as well, and STEM studies show that context plays an important role for women in their choice of engineering education (Kolmos et al., 2013). Therefore, the contextual knowledge is important to merge into the STEM subjects, as it creates meaningfulness and motivation for the students that are not primarily driven by a technical/scientific tinkering approach.

PBL – INSTITUTIONAL OR SUBJECT LEVEL

The PBL curriculum models started out at a system level as institutional approaches. All the original PBL universities have built up the PBL curriculum from the ground and, of course, the systemic approach will be much more complicated in a change of existing practices. However, many arguments will underpin the need for combining PBL aspects into a system level such as, e.g. combining PBL skills and competencies into the overall learning outcomes, introducing the students to PBL, combining lectures and projects/cases, resource allocation, space and assessment. The various components in a curriculum impact each other, and if these are not aligned (to a certain degree), the optimal outcome might be limited. Although there always will be a misalignment in a development process, the hypothesis of alignment is widely acknowledged (Biggs & Tang, 2011). Among others, the argument is, for example, that if students only take written tests and achieve their credits simply by reading for the exam, it will be hard to get them to work collaboratively and learn beyond the credits.

A systemic curriculum development can be found in the Conceive-Design-Implement-Operate (CDIO) approach, which emphasises that even if there is PBL in one course, this course interacts with the other components (Edström & Kolmos, 2014). Even the Aalborg PBL model practices PBL on only 50% of the curriculum; however, there is a clear relation in the taught courses (Kolmos, Fink, & Krogh, 2004). It is important that students know what to learn and where they learn it – thus, the overview of learning outcomes and learning methodologies are important. Especially for PBL, it is important to teach students elements of collaboration and project management; in an uncoordinated system, these aspects might not be addressed at all, or there might be a lack of clear scaffolding.

Although the advantages of a systemic approach are obvious, the dissemination of the PBL philosophy to other universities has mostly been characterised by project PBL at a course level, and there are fewer cases of institutional implementation (Shinde, 2014). Changing a course to a project or case PBL approach might be one way to lead to a systemic change at an institutional level; as academic staff experience new practices, they might get motivated and influence other colleagues. However, it will never become a systemic change unless decisions are made at the system level for the entire curriculum.

The same will be the case for subjects in the school system – both primary and secondary. Systemic pedagogical decisions have to be taken at a top-down level at a ministry or municipally unit and be part of a teacher's toolbox. In a school system, it might be much more difficult to apply PBL in one or the other versions, as there will be schedule constraints. PBL will require more coherent time slots for students to be able to work on their cases or projects, which will be nearly impossible to have one hour twice per week between all other subjects.

In the Danish high school system, elements of PBL have been implemented. In the general high school, there are cross-disciplinary theme periods where students are working on projects. In the HTX (technical high school), it is written into the regulation of the technology subject that projects are part of the curriculum (see Bo Hendriksen's chapter in this book). However, this is not any dominating trend for all the subjects in any of the two high schools. There is no doubt that, in many ways, the project oriented PBL models match the technology subject to a higher degree compared to many other subject traditions. In the technology subject, students have to work on innovation, real problem analysis and problem solving; therefore, PBL is an aligned choice.

Regardless of the PBL model, the conditions for a change to PBL in any school subject will not be optimal, and it might be relevant to look into other types of pedagogical models that are similar to PBL.

PBL VERSUS OTHER TYPES OF STUDENT-CENTRED LEARNING

In practice, there are many hybrid variations of the student-centred learning methods. Just within the scope of PBL, there are variations such as cases versus problems, narrow problems versus open/ill-structured problems, small projects versus longer projects, etc.

Reviewing the literature and learning about new practices, even PBL might have limited participatory and self-directing influence in the learning process, and students' decisions might be narrowed to a few choices to fit into a narrow discipline approach. Maybe this will be accepted as part of an overall scaffolding of students' learning and an introduction to more active learning; however, this will not be based on the PBL philosophy.

Even if there is a merging tendency between the two original PBL models, there are other student-centred models at the curriculum level. To gain inspiration for more student-centred learning at the STEM level in school, it is important to broaden the scope of variations and possibilities.

Barrows has developed curricula taxonomies in an attempt to categorise different types of case-based and problem-based learning models ranging from lecture-based cases to more open problem-based learning models (Barrows, 1986). There has been a wave of more student-centred learning activities, such as case-based learning, inquiry-based learning, active learning, problem solving, scenario-based learning, etc. (Savin-Baden, 2014). PBL has not been the only pedagogy that has dominated educational change. For all of these models, there are differences in terms of the degree of student involvement in the identification of the problem, the role of the teacher, the organisation of the learning process, and assessment.

Diversities in the student-centred learning methodologies are only an advantage, and even small group learning has a positive effect on students learning and motivation (Springer, Stanne, & Donovan, 1999). Especially to achieve lifelong learning skills, students should try different learning methodologies; by reflecting on the differences, they may become more aware of work and learning variations. Reflection on one's own learning process by comparing different ways of learning has shown to be very efficient for the learning of process competencies such as collaboration, project management and conflict management (Kofoed & Kolmos, 2004).

Active learning has been a trend within STEM for a long time. It is an overall concept in line with student-centred learning that covers a variety of diverse practices. Within STEM, inquiry-based learning has been widespread (Rocard, 2007). Inquiry-based learning is defined as letting students explore a research inquiry process by asking questions, considering methodologies, collecting evidence, analysing the data, formulating conclusions, and reflecting on the process (Prince & Felder, 2006).

Recently, the Journal on Excellence in College Teaching has published an issue on the similarities and variations in problem-based learning, cooperative learning and collaborative learning. Many of the articles conclude that there are several similarities in the theoretical backgrounds and the guiding principles; however, when it comes to the curriculum practice, there are major differences (Davidson & Major, 2014; Davidson, Major, & Michaelsen, 2014; Michaelsen, Davidson, & Major, 2014). For the development of STEM subjects at the school level, the comparison of various student-centred learning models will create more opportunities.

There is a variety of definitions for each of the student-centred learning systems. Team-based learning (TBL) is when students work in teams that eventually become self-managed learning teams (Michaelsen et al., 2014). This is a very open approach. Davidson and Major (2014) summarise the definitions of cooperative learning by concluding that, "*in all the cooperative learning approaches is that student work and learn together actively in small groups to accomplish a common goal in a mutually helpful manner. Cooperative learning combines active learning and social learning* *via peer interaction in small groups on academic tasks*”. This very broad definition can also cover collaborative learning; however, collaborative learning seems to be a more open approach with a common goal and less structured requirements compared to cooperative learning (Davidson & Major, 2014).

An overview of the various student-centred learning methods is given in Table 3. The differences between TBL, collaborative and cooperative learning seem to be blurred, which is natural, as they have been developed by practice and there are nuances whereas TBL and collaborative learning is more open-ended problem solving, cooperative learning is structured. Compared to PBL, TBL, collaborative and cooperative learning have no requirements for students to work on authentic problems leading to a more self-directed learning path (Davidson & Major, 2014). That means that the contextual part is not included.

Another comparison of the student-centred learning methods is illustrated in Figure 2. There is a more specific comparison of the learning methods according to two much more specific curriculum elements: the degree of teacher instruction and the degree of student influence on the learning process.

The various learning methods have an immense span for the teacher to give very rigorous instruction to facilitate students in their learning process, and opposite do the students in their learning process have a span between being instructed or practicing self-directed and participant directed learning.

Table 3. Comparison of student-centred learning methods according to core dimensions of PBL

	Inquiry-based learning	Team-based learning	Cooperative and collaborative learning	Problem-based learning	Project-based learning
Individual collaborative learning	Can be both	Collaborative and peer learning			Collaborative construction of knowledge
Problem/ context versus discipline	Questions within the discipline	Mostly task within the discipline		Starting out with ill-defined or well defined problems	
Discipline interdisciplinary	Mostly within the single discipline			More interdisciplinary	
Subject/ curriculum levels	Can be used within the subject borders			Require a system approach – at least system coordination	
Assessment/ exam	Mostly done without a change of assessment methods			Requires a change in the assessment methods	

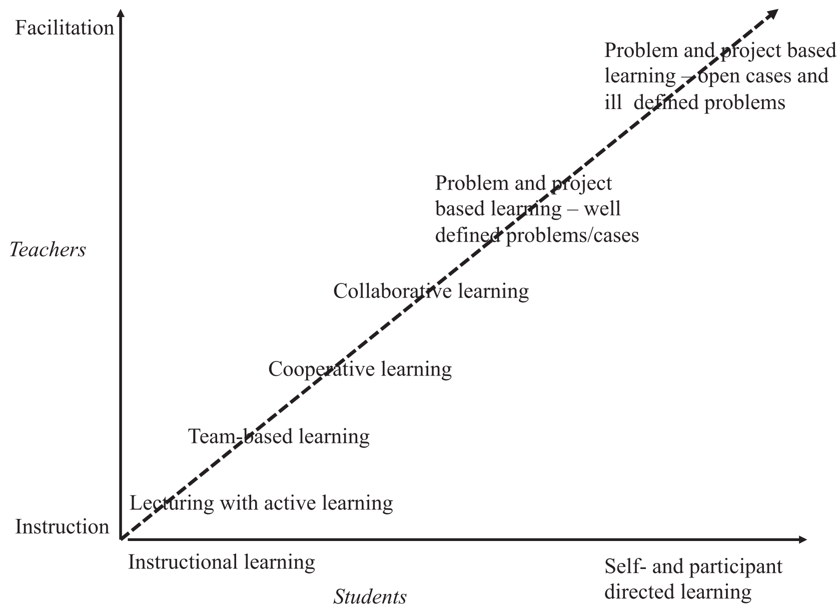

Figure 2. Modes of student-centred learning related to teacher roles and student learning

PERSPECTIVES ON PBL AND STEM

In the Danish School system, practices very much inspired from the two Danish PBL universities have occurred, and there are thematic periods in both primary and secondary schools where students/pupils work on cross-disciplinary projects. Along with that development, the school teachers also have developed teamwork among themselves (Wiedemann, 2005).

There is PBL in STEM in the school system. In the US K–12 system, there is a widespread use of inquiry-based learning and PBL in STEM, and the development is at a stage where there is a dissemination of best practice and examples for others to learn from (Capraro, Capraro, Morgan, & Scheurich, 2010). Searching the internet, there are several organisations promoting project-based learning, such as Edutopia; Wise and the National Science Foundation, which has a special website with an overview of various National Science Foundation (NSF) projects (GK–12). There is a movement in the STEM subjects towards more student-centred learning, including concepts, such as service learning, where students work on community projects. Many of the project proposals that are mentioned can be integrated into the existing school curriculum structures; therefore, this type of PBL will be a much more instructed version with a narrower problem scope. However, there is also a need for scaffolding student-centred learning methods from the school to the university level.

Therefore, there are many opportunities, but also a long list of obstacles. Nevertheless, if the STEM academics and society does not focus on the possibilities, it will be a very slow process. As was discussed at the beginning of this article, young people need new types of skills and competencies, as they will have to create their own future jobs. This involves an educational system that allows our young students to experiment, risk, grow, collaborate, invent, implement and, of course, to acquire disciplinary knowledge, which can be learned in a process of innovation.

For the teachers to change the teaching and learning methods, they must also experiment, risk, collaborate, invent and implement, which should be facilitated by school management. All stakeholders need to be involved if any student-centred learning method is promoted, as it will involve the entire system.

REFERENCES

Alting, A., Vonderen, M. V., Weyers, O., & European GASAT Conference. (1992). *Ten years GASAT activities in a changing Europe*. Eindhoven: Eindhoven University of Technology.

Barrows, H. S. (1986). A taxonomy of problem-based learning methods. *Medical Education, 20*(6), 481–486.

Barrows, H. S. (1996). Problem-based learning in medicine and beyond: A brief overview. *New Directions for Teaching and Learning, 1996*(68), 3–12. doi:10.1002/tl.37219966804

Barrows, H. S., & Tamblyn, R. M. (1980). *Problem-based learning: An approach to medical education*. New York, NY: Springer Publishing Company.

Bedard, D., Lison, C., Dalle, D., & Boutin, N. (2010). Predictors of student's engagement and persistence in an innovative PBL curriculum: Applications for engineering education. *International Journal of Engineering Education, 26*(3), 511–522.

Biggs, J., & Tang, C. (2011). *Teaching for quality learning at university* (4th ed.). Maidenhead: Open University Press.

Bitsch Olsen, P., & Pedersen, K. Å. (2005). *Problem-oriented project work: A workbook* (1st ed.). Frederiksberg: Roskilde University Press.

Capraro, R. M., Capraro, M. M., Morgan, J., & Scheurich, J. (2010). *A companion to interdisciplinary STEM project-based learning.* College Station, TX: Texas A&M University.

Dahlgren, M. A. (2002). *Portraits of PBL: A cross-faculty comparison of students' experiences of problem-based learning*. Linköping: Linköpings Universitet, Department of Behavioural Sciences.

Davidson, N., & Major, C. H. (2014). Boundary crossings: Cooperative learning, collaborative learning, and problem-based learning. *Journal on Excellence in College Teaching, 25*(3/4), 7.

Davidson, N., Major, C. H., & Michaelsen, L. K. (2014). *Small-group learning in higher education: Cooperative, collaborative, problem-based, and team-based learning*. Miami, FL: Miami University.

de Graaff, E., & Bouhuijs, P. A. (1993). *Implementation of problem-based learning in higher education*. Maastricht, The Netherlands:Thesis Publishers.

de Graaff, E., & Kolmos, A. (2003). Characteristics of problem-based learning. *International Journal of Engineering Education, 19*(5), 657–662.

de Graaff, E., & Kolmos, A. (2006). *Management of change*. Rotterdam, The Netherlands: Sense Publishers.

Dochy, F., Segers, M., Van den Bossche, P., & Gijbels, D. (2003). Effects of problem-based learning: A meta-analysis. *Learning and Instruction, 13*(5), 533–568. Retrieved from http://ac.els-cdn.com/S0959475202000257/1-s2.0-S0959475202000257-main.pdf?_tid=4e556592-0780-11e5-a070-00000aacb361&acdnat=1433068515_2810f836d6555da1a673115ed53b1f30

Dolmans, D., & Schmidt, H. (1996). The advantages of problem-based curricula. *Postgraduate Medical Journal, 72*(851), 535–538. Retrieved from http://pmj.bmj.com/content/72/851/535.full.pdf

Edström, K., & Kolmos, A. (2014). PBL and CDIO: Complementary models for engineering education development. *European Journal of Engineering Education, 39*(5), 539–555. doi:10.1080/03043797.2014.895703

Edutopia. Project-based learning. *Edutopia*. Retrieved from http://www.edutopia.org/project-based-learning

EU Commission. (2008). *Improving competences for the 21st century: An agenda for European cooperation on schools*. Brussels: Commission of the European Communities. Retrieved from http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:52008DC0425

Galand, B., Raucent, B., & Frenay, M. (2010). Engineering students' self-regulation, study strategies, and motivational believes in traditional and problem-based curricula. *International Journal of Engineering Education, 26*(3), 523–534.

GK-12. (n.d.). *GK-12: STEM activities and resources for K-12 teachers and students*. Retrieved from http://www.gk12.org/resources/stem-activities-and-resources-for-k-12-teachers-and-students/

Gordon, J., Halász, G., Krawczyk, M., Leney, T., Michel, A., Pepper, D., Putkiewicz, E., & Wiśniewski, J. (2009). Key competences in Europe: Opening doors for lifelong learners across the school curriculum and teacher education. *CASE Network Reports*, (87).

Gordon, J., Rey, O., Siewiorek, A., Vivitsou, M., & von Reis Saari, J. (2012). KeyCoNet 2012 Literature review: Key competence development in school education in Europe. *Reproduced with permission of the copyright owner. Further reproduction prohibited without permission*.

Hodgson, B., Fears, D., Gender and Science and Technology Association, & GASAT Conference. (2008, September 3–8). *Proceedings of the 12th international GASAT conference: 'Challenging and changing in the status quo', held at the University of Brighton, United Kingdom*. Brighton: Albion Press.

Illeris, K. (1974). *Problemorientering og Deltagerstyring: Oplæg til Alternativ Didatik*. Aalborg: Munksg@års.

Illeris, K. (2010). *Contemporary theories of learning: Learning theorists … In their own words* (reprinted ed.). London: Routledge.

Kearney, C. (2011). *Efforts to increase students' interest in pursuing science, technology, engineering and mathematics studies and careers. National measures taken by, 21 of European Schoolnet's member countries, 2011 report*. Brussels: European Schoolnet (EUN Partnership AISBL).

Kofoed, L. B., & Kolmos, A. (2004). Development of process competencies by reflection and experimentation. In V. M. S. Gil & H. H. N. Alarcao (Eds.), *Challenges in teaching & learning in higher education* (pp. 77–90). Portugal: University of Aveiro.

Kolb, D. (1983). *Experiential learning: Experience as the source of learning and development* (1st ed.). Englewood Cliffs, NJ: Prentice Hall.

Kolmos, A., & de Graaff, E. (2014). Problem-based and project-based learning in engineering education: Merging models. In B. M. Olds & A. Johri (Eds.), *Cambridge handbook of engineering education research* (pp. 141–161). New York, NY: Cambridge University Press.

Kolmos, A., Fink, F., & Krogh, L. (Eds.). (2004). *The Aalborg PBL model: Progress, diversity & challenges*. Aalborg: Aalborg University Press.

Kolmos, A., Krogh, L., & Fink, F. K. (2004). *The Aalborg PBL model: Progress, diversity and challenges* (3rd ed.). Aalborg: Aalborg University Press.

Kolmos, A., Mejlgaard, N., Haase, S. S., & Holgaard, J. E. (2013). Motivational factors, gender and engineering education. *European Journal of Engineering Education, 38*(3), 340–358. doi:10.1080/03043797.2013.794198

Marra, R. M., Jonassen, D. H., Palmer, B., & Luft, S. (2014). Why problem-based learning works: Theoretical foundations. *Journal on Excellence in College Teaching, 25*(3/4), 221.

Michaelsen, L. K., Davidson, N., & Major, C. H. (2014). Team-based learning practices and principles in comparison with cooperative learning and problem-based learning. *Journal on Excellence in College Teaching, 25*(3/4), 57.

Neville, A. J., & Norman, G. R. (2007). PBL in the undergraduate MD program at McMaster University: Three iterations in three decades. *Academic Medicine, 82*(4), 370–374.

Prince, M. J., & Felder, R. M. (2006). Inductive teaching and learning methods: Definitions, comparisons, and research bases. *Journal of Engineering education-Washington, 95*(2), 123.

Rocard, M. (2007). *Science education now: A renewed pedagogy for the future of Europe* (pp. 20). Brussels: High Level Group on Science Education, Directorate General for Research. Science, Economy and Science, European Commission.

Raat, J. H., Harding, J., & Mottier, I. (1981). *Girls and science and technology.* Paper presented at the Girls and Science and Technology Conferences, Eindhoven University of Technology, The Netherlands.

Savin-Baden, M. (2014). Using problem-based learning: New constellations for the 21st Century. *Journal on Excellence in College Teaching, 25*, 197–219.

Shinde, V. (2014). *Design of course level project based learning models for an Indian engineering institute – An assessment of students' learning experiences and learning outcomes*. Aalborg: Aalborg University.

Springer, L., Stanne, M. E., & Donovan, S. S. (1999). Effects of small-group learning on undergraduates in science, mathematics, engineering, and technology: A meta-analysis. *Review of Educational Research, 69*(1), 21–51.

Strobel, J., & van Barneveld, A. (2009). When is PBL more effective? A meta-synthesis of meta-analyses comparing PBL to conventional classrooms. *Interdisciplinary Journal of Problem-Based Learning, 3*(1), 4.

Wenger, E. (2001). *Communities of practice: Learning, meaning, and identity* (Reprinted 2001 ed.). Cambridge: Cambridge University Press.

Wiedemann, F. (2005). Teamsamarbejde i folkeskolen. *Tidsskrift for Arbejdsliv, 7*, 73–87.

Wilkerson, L., & Gijselaers, W. H. (1996). *Bringing problem-based learning to higher education: Theory and practice*. San Francisco, CA: Jossey-Bass.

Wise. *WISE Consortium – Pre-K-12 STEM project-based learning*. Retrieved from http://experiencewise.org/pre-k-12-stem-project-based-learning/

Woods, D. R. (1994). *Problem-based learning: How to gain the most from PBL*. Hamilton, Waterdown: McMaster University Bookstore.

Anette Kolmos
Royal Institute of Technology (KTH)/Aalborg Centre for Problem Based Learning in Engineering, Science and Sustainability
Stockholm/Aalborg University
Sweden/Denmark

ANDREA K. AGREE, ANNA E. FALOON
AND JOHANNES STROBEL

10. ACCESS, INCLUSION, AND HETEROGENEITY IN PRE-UNIVERSITY ENGINEERING EDUCATION

INTRODUCTION

In the realm of education, the concepts of access, inclusion and heterogeneity have gained acceptance because of both changing educational philosophies and increased sensitivity to the demographic and personal diversity of students and their classrooms, which necessitates strategies to meet the needs of students (Idol, 2006). Traditionally, STEM fields in the USA have struggled with inclusion and to overcome the reality and image of being male-dominated domains – with associated concepts of machoism, perceived inability of women to perform technical jobs and infrastructure lacking flexibilities for engendered needs. Similarly, students of minority race and ethnicity and low socio-economic status are excluded from pathways into different STEM professions due to inequalities in access to high quality education resulting in structurally reinforced performance gaps.

The impact of discoveries, inventions, and creative developments in science and technology is apparent in practically every facet of our modern world. In response to continuing changes in social and economic life, many countries have introduced design, engineering and technology education as a subject or as a part of an integrated science, technology and mathematical education program. Strategies have included different specialized programs for the primary and secondary education levels. Some countries, including England, Scotland, and the United States, have published national reports to offer recommendations for implementing educational reform (Farmer, 2013; Freeman, Marginson, & Tytler, 2014; Pitt, 2009). Additionally, several countries, including Australia, China, England, Korea, Taiwan, and the USA, have been working to develop specialized pre-university curriculum. Many curriculum efforts have been directed toward having learners make better connections between their early educational experiences and future careers (Chio & de Vries, 2013; Pitt, 2009; Ritz & Martin, 2013).

The STEM fields are struggling to provide access, include and retain all students. Even though it is acknowledged that technical fields hold great promise as a career choice for students, there remain many groups that are underrepresented. In this chapter we propose a model of student heterogeneity and inclusion, we discuss

M. J. de Vries et al. (Eds.), Pre-university Engineering Education, 155–177.

the obstacles facing underrepresented minorities in pre-university engineering education and we make research-based recommendations for curriculum designers and teachers to expand access to programs that will reduce educational disparities.

STEM-Education – Adding or Including New Dimensions in Sci and Tech Education

Design and technology education can offer students a unified subject area that brings together the study of design, science, mathematics, and business into one deliberately interdisciplinary focus area. The closest analogous field of study in the United States is STEM education: the study of science, technology, engineering, and mathematics. This specialized education can be interpreted differently: as either adding teaching enhancements for each of the independent STEM subjects or as an integrative approach to teaching where the core concepts of science, technology, engineering, and mathematics are brought into one curriculum program called STEM. As a result of these various interpretations, multiple initiatives have been developed with policy discussions on STEM mostly emphasizing on improving the teaching of the independent subjects and working to increase students' international testing scores, especially in science and mathematics (Bybee, 2013). STEM fields are diverse and include such areas as computer sciences, physics, engineering, healthcare and pharmaceuticals, agricultural sciences, forestry, and ecology.

Engineering, technology and design activities and curricula hold tremendous value to enrich and change the educational experiences in pre-college education. With a strong focus on project-based, problem-based and hands-on learning, STEM learning opportunities provide different access to knowledge and enact different forms of learning traditionally less valued and less available to learners with different individual differences. As an example: STEM programming and design activities in a community service context might allow visual learners with a passion for improving their community to engage in science and mathematics, which regular school-related activities would not allow.

Technical skills can be taught through on the job training, yet the creative problem solving mindset that effective design and technology education imparts are much more valued and exactly the sort of skills that are needed for our future progress. Education has been an important strategy for the ability to make contributions to one's community, as well as to gain access to a better life. The factors that contribute to the problems that we are facing are complex, but they are identifiable. Most models of access and inclusion focus on visible student differences, such as gender and race. However, there are many other factors to consider that are less visibly apparent, such as: invisible learner variabilities and perceived disabilities, language barriers, psychological barriers, socioeconomic status, and differences in upbringing. Every student is different and one of the purposes of this chapter is to further understand this heterogeneity and its implications.

ICEBERG MODEL OF INDIVIDUAL HETEROGENEITY

As Hall (1998) pointed out "culture hides much more than it reveals and, strangely enough, what it hides, it hides most effectively from its own participants" (p. 59). Similarly, the individual make-up of a person, the personal experience and its impact on this person's interactions are mostly hidden. For purposes of visualization, we utilize the metaphor of the "iceberg of culture" for individual heterogeneity, an image widely used in the study of intercultural relationships, (see Weaver, 1986). If an individual is an iceberg, then there are some aspects of that person that are visible, or above the water. However, there is a larger portion that is hidden beneath the surface. The external characteristics and behavior of a student are what we can see and is the 'tip of the iceberg'. Internal characteristics are below the surface and include aspects such as the student's socioeconomic status, invisible disabilities, learning variabilities, difficulties with language, cultural beliefs, values and thought patterns. Many of these characteristics can affect behavior.

The discourse within the US-academic community on access, inclusion and heterogeneity is dominated by a focus on visible aspects of diversity, particularly gender and ethnicity/race (Jesiek & Beddoes, 2013) with a small body of work focusing on invisible and hidden aspects of diversity. For example, learning disabilities such as dyslexia etc. have been often overlooked in design considerations of technology and engineering learning environments (Sevo, 2011; Fitzpatrick, 2014). While many structural problems of the U.S. educational system have direct impact on visible minorities' educational access and performance (race, ethnicity and socio-economic status as classic examples), a change in mindset towards inclusion of hidden differences would allow for more nuanced awareness and sensitivity and structural support for diverse students not being addressed in educational research in STEM and traditional support structures. The image of the iceberg encourages us to look below the visible activities and characteristics of a student to deeper and less visible features of the student. What this model teaches us is that we cannot judge an individual based only on what we see when we first encounter them. Every single student is different. While similar language, skin color, and other identity markers may be important in understanding structural inequities; they do not necessarily indicate group affiliations or unified views. When we homogenize race, ethnic and gender groups, we ignore the various backgrounds, experiences, values, and beliefs within these groups. Diversity and dissimilarities within all groups should be assumed.

Adopting the iceberg model for STEM fields, not only provides stronger awareness and support for diverse student populations; recent discourse on core competencies in STEM fields emphasizes the notion of empathy (standing in somebody else's shoes) as a core meta-competency or process skills contributing to the necessary toolbox for engineers (Strobel, Hess, Pan, & Wachter Morris, 2013) and the value of empathy for the innovation process (Hess, Fila, Purzer, & Strobel, 2015).

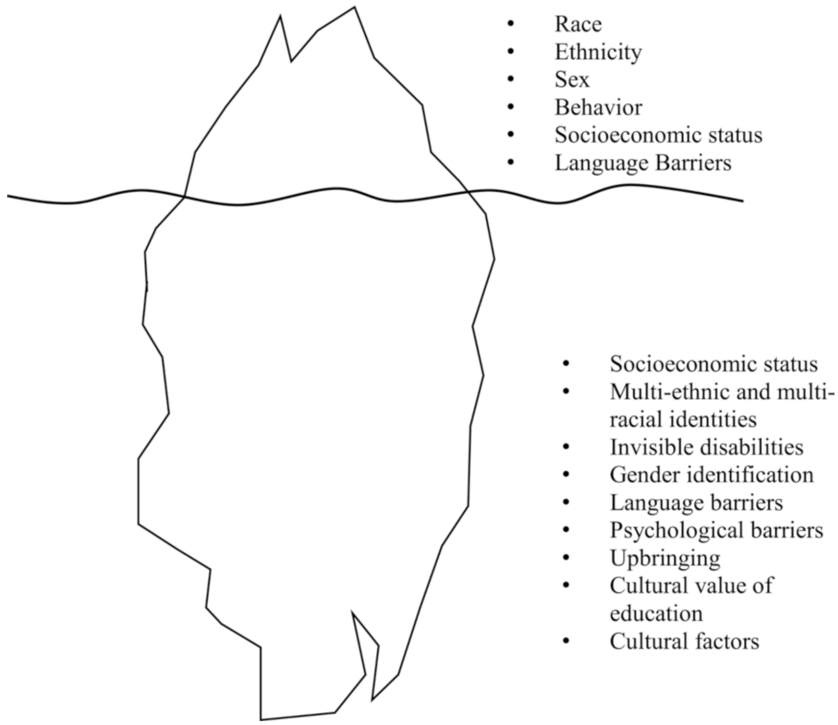

Figure 1. Illustration of individual heterogeneity

UNDERREPRESENTED GROUPS – WHO ARE THEY?

Student bodies are increasingly diverse, yet this diversity is not represented in technical fields of study. Diversity is an asset, both a resource for and strength of our society and economy. Obviously all students need attention and support. It is however important for teachers to identify students/groups of students that for various reasons, seem to opt out of the STEM subjects. To meet these students and to understand the reasons behind their attitudes is an important mission to both STEM-education and society. According to our analyses the following four groups of individuals are underrepresented in the field of technology and therefore in need of special attention regarding education within the STEM-subjects:

Women

In the U.S., women today occupy only a small percentage of STEM-related jobs. Each year the number of women studying and pursuing careers in a STEM field decreases (Glass, 2013), which means we as a society are missing out on valuable perspectives that 50% of the population could bring to designing the technologies of the future. In the U.S., minority students, Asians excepted, are also underrepresented in the STEM fields. Additionally, minority students enter university less prepared than non-minority students (Slovacek et al., 2011).

Racial and Ethnic Minorities

The current disproportional representation of certain racial and ethnic minorities in science disciplines grows increasingly problematic. In the U.S., minority students, Asians excepted, are underrepresented in the STEM fields. Additionally, minority students enter university less prepared than non-minority students (Slovacek et al., 2011). It is necessary to increase the minority pre-university interest and success in key fields, such as technology, for those disciplines to remain representative of the rapidly changing and increasingly diverse population. Minorities may be cognizant of particular societal, health and political issues that most non-minority students would not normally consider. The STEM disciplines rely on individuals with diverse perspectives working together. If the underrepresentation of minority groups in these fields perpetuates, we're not going to have professionals that are responsive to those demographics. The personal and social costs of educational underachievement for these groups in particular are considerable for individuals, their families, their communities and for national economic viability. Additionally, these effects are often passed onto the next generation, as there is a connection between parents' social class and their children's level of educational attainment (Lareau, 2003).

Student with Disabilities

Similarly, students with disabilities perform lower than their peers without disabilities on standardized measures and often become disenfranchised with science and mathematics content (Perkin & Croft, 2007) as early as middle school; one of the outcomes of this disengagement is that students with disabilities rarely ever enter the technical workforce, even though they are highly capable of making valuable contributions (Leddy, 2010).

OBSTACLES FACING UNDERREPRESENTED GROUPS

Pre-university engineering education faces a number of challenges. Some of these challenges include, but are not limited to, the inadequate preparation of our students, as well as the lack of mentoring and socialization of women, ethnic minorities and people with disabilities for future careers in the field. In order to accomplish this, barriers that hinder concerned individuals/groups from pursuing and earning appropriate degrees must be identified and ultimately overcome.

Ethnic and racial disparities in education follow a pattern in which minorities continue to underperform academically. This is particularly concerning because these educational disparities mirror ethnic and racial disparities in socioeconomic status as well as in healthcare (Miech, Pampel, Kim, & Rogers, 2011). Additionally, these disparities are reflected in test scores, drop-out and graduation rates, proportions of students involved in gifted programs, enrollment in higher education, as well as in behavioral markers of adjustment such as: rates of being disciplined, suspended, and expelled from schools (Wiley, Brigham, Kauffman, & Bogan, 2013).

To complicate the issue further, students' awareness of discrimination and of their stigmatized racial status is associated with educational disparities. There are complex connections between ethnic and racial identity and academic adjustment. A strong sense of affiliation and identification with one's ethnic or racial group can be negatively or positively associated with academic achievement, depending on the context. In contexts involving high levels of stereotype threat, strong affiliation for the stereotyped groups is inversely related to academic performance. Conversely, strong identification with academically successful role models is positively associated with achievement.

Structural Barriers

Within pre-university education, structural barriers impact minority and low-income students in the lack of access to equitable school funding, science resources and facilities, high-quality teachers, technology and computer courses, and advanced coursework (Goode, 2010). This limits the opportunities for success and competitiveness in technical fields of study. Additionally, within higher education, barriers facing underrepresented minorities include a lack of sufficient high school academic preparation and advanced coursework, lack of mentorship from same-race role models and faculty (Price, 2010), and the perception of a non-welcoming, hostile climate (Thiry, Laursen, & Hunter, 2011).

As a result of these barriers, these students demonstrate much lower proficiency rates in science and mathematics than their majority peers, are less likely to access and achieve success in advanced coursework, and demonstrate lower levels of university readiness than their peers. These pre-university outcomes have significant implications for persistence in higher education and degree completion.

Social and Psychological Barriers

Underrepresented students also face social and psychological barriers to pursuing STEM education, stemming in part from coping with stigma and marginalization. Major and O'Brien (2005), summarized the mechanisms of stigmatization using four categories: (a) negative treatment and direct discrimination, (b) expectancy confirmation processes, (c) automatic stereotype activation, and (d) stigma as identity threat.

a. Negative treatment and direct discrimination affects the social status, mental and physical health, and educational opportunities of the stigmatized group by limiting access. This direct discrimination includes structural barriers and inequities in pre-university education. It also includes any direct experiences with bias, discrimination, and micro-aggressions.

b. Expectancy confirmation processes describe the interaction between institutions and the individual, where confirmed expectations are created by the treatment of the offender. Brophy (1983), described this dynamic and termed it the "self-fulfilling prophecy". In elementary classrooms he observed teachers form expectations about students, communicate these expectations to students through conscious and unconscious mechanisms, and the students then modified their self-perceptions and achievement, in accordance with the initial expectations. Racial and gender differences in teacher perceptions of math and science ability, as well as stereotypes held by teachers about which students are capable of success in math and science can potentially impact student outcomes.
c. Automatic stereotype activation operates on an individual level and involves the activation of dominant cultural stereotypes in the absence of discriminatory behavior and often results in stereotype-consistent behavior among the stigmatized group. Steele and Aronson (1995) laid the foundations for what came to be known as stereotype threat; "the apprehension targets feel when negative stereotypes about their group could be used as a lens through which to judge their behaviors". This threat of confirming negative stereotypes introduces extra-task concerns, which distract from performance and can ultimately result in stereotype confirmation. Stereotype threat has been shown to negatively impact standardized test performance among African American students (Steele & Aronson, 1995), math performance among women (Spencer, Steele, & Quinn, 1999), and white males when compared to Asians in math (Aronson, Lustina, Good, & Keough, 1999). In addition to affecting performance, stereotype threat has also been shown to negatively impact attitudes, including engagement and identification within specific fields of study (Fogliati & Bussey, 2013; Good, Rattan, & Dweck, 2012).
d. Stigma as identity threat suggests that stigma affects a person's own social identity by affecting their interpretation of social contexts and their understanding of how they are viewed by others.

In examining minorities within STEM fields, the mechanisms of stigmatization can be observed in: inequitable access to resources and educational opportunities, self-fulfilling prophecies, stereotype threat, underperformance, avoidance of certain subjects and fields of study, endorsement of stereotypical beliefs, and perceptions of bias and anticipation of bias. Despite high levels of academic achievement and interest in science and mathematics, girls and underrepresented minority students still overwhelmingly anticipate facing internal barriers, including not feeling as confident, smart, or prepared as other students (Grossman & Porche, 2014). Research demonstrates that student attitudes about themselves and perceptions about the difficulty of a technical field provide valuable information about attrition and persistence. Some research has found that initial attitudinal differences are attributable to the students' gender and ethnic background and that retention is more linked to students' attitudes and perceptions than to their academic credentials (Besterfield-Sacre, Moreno, Shuman, & Atman, 2001).

Language

Access to bilingual education is essential for many language-minority children. In order to benefit from their education, language minority students need to engage with the subject knowledge of the curriculum, so that learning a language and learning a subject do not become unhelpfully separated. Conclusions from several studies confirm that children who receive instruction in their native language have higher rates of academic achievement, even when the markers of achievement are in English, compared to their peers who receive less instruction in their native language (Guglielmi, 2012; Hayes, Rueda, & Chilton, 2009). Quality bilingual programs can close academic achievement gaps between language minority and majority children, yet access to these programs is limited and is often dependent on the economic status of their parents.

Test items tend to function differently for different groups of students and language can be a barrier to both interpreting and answering questions. Often, our expectations about the content knowledge students use to answer test items are not consistent with the content knowledge language minority students describe using to answer the items. False negative item responses occur when students answer items incorrectly despite demonstrating the target knowledge during an interview; these types of responses are much more common for language minority students (Noble et al., 2012).

Invisible Disabilities

Invisible disabilities are the unseen conditions that affect the ability to read, compute, pay attention, and interact with others, to name a few (Davis, 2005). Students with learning disabilities have average to above average intelligence but have difficulties acquiring information and expressing knowledge. These disabilities cover a spectrum of conditions that may include sensory, learning, attention, physical, and communication differences. These students often require multiple formats of instruction, organizational aids, and a range of assistive devices to effectively contribute in a classroom setting.

Common barriers to accessing equitable design and technology education for all students with disabilities include: lack of role models (Napper, Hale, & Puckett, 2002), parent and teacher misperceptions that students with disabilities cannot be successful, resulting in a lack of encouragement to take courses in these areas (Alston, Bell, & Hampton, 2002), teacher lack of knowledge and skill regarding how to include students with disabilities (Rule & Stefanich, 2012), and lower participation rates in structured and unstructured STEM-related activities (Eriksson, Welander, & Granlund, 2007). Common features of STEM classrooms produce issues amongst students with disabilities such as the difficulty for near-blind and blind students with the typically high level of visual content in STEM education (Moon et al., 2012). Similarly, the field, laboratory and "hands-on" learning approaches in STEM produce environmental and self-imposed barriers of access to STEM fields as students feel inadequate or awkward in such activities (Hall et al., 2002).

Teacher Beliefs and Biases

Teacher expectations of students in their classrooms have long been a topic of study in educational literature. In general, this body of research has found that teachers have differential expectations for students in their classrooms. For example, research indicates that teachers, and even some parents, perpetuate gender stereotypes in academic achievement, with lower expectations for boys' general academic skills, even after controlling for actual academic performance. Girls across racial groups are exposed to gender stereotyping, particularly related to their ability to perform in science and math domains. Although the impact of teacher expectations has been well documented, it has also been found that during the early secondary years, the effects of teachers' expectation bias may be partly dissipated; however, the bias remains stable over time (de Boer, Bosker, & van der Werf, 2010). Teachers need to be aware of the potential impact their expectations may have on their students, particularly in the influential early secondary years. This is the time when persistence in technology education can be nurtured and interest in careers in these areas cultivated, or tragically discouraged and, even worse, dismissed (Jenkins & Nelson, 2005; Kuechler, McLeod, & Simkin, 2009).

It is important that all students experience well-integrated learning and have access to courses that emphasize this integration, yet often, engineering courses are reserved only for advanced students (Payne & Heilbronner, 2009). Explicit integration is important for knowledge transfer and is required if students are to apply their classroom learning to novel contexts. Do we only want to target the intellectually gifted? Or, should we aim to offer these opportunities to all students? Findings from recent studies shed light on how differences among teacher beliefs mirror these two separate goals (Nathan, Tran, Atwood, Prevost, & Phelps, 2010).

Teachers' classroom practices are shaped by the knowledge, beliefs, and expectations teachers have for their students, and how those beliefs may frame teachers' perceptions of the purposes of learning experiences. For example, higher levels of expectation from science teachers have been found to be positively and directly associated with student expectations, academic performance, and postsecondary academic attainment (Benner & Mistry, 2007). Level of support from teachers and parents regarding math instruction is associated with students' beliefs about mathematics, achievement goals, and their efforts directed at learning mathematics (Chouinard, Karsenti, & Roy, 2007).

Teachers' views have implications for the perceived place and purpose of engineering education in the pre-university curriculum. Yaşar and colleagues (Yasar, Baker, Robinson-Kurpius, Krause, & Roberts, 2006) used a survey instrument to measure pre-university teachers' knowledge and perceptions of engineers and engineering practice. They learned that all of the teachers in their sample were unfamiliar with design and engineering and had low confidence in their ability to teach it. However, they also subscribed to the value of integrating engineering into their pre-university curriculum and recognized its importance for preparing their students for later careers.

The Engineering Education Beliefs and Expectations Instrument for Teachers (EEBEI-T), developed by (Nathan et al., 2010) illustrated that teachers tend to support enrollment in engineering classes and agree that engineering learning takes place in multiple contexts, in and out of school. Teachers generally believed that to become an engineer a student must show high academic achievement in their math, science, and technology courses. This instrument also illustrated that teachers predicted higher rates of career success for students from more economically privileged family circumstances, though it appears that teachers are not consciously aware of those influences.

Students with invisible disabilities encounter additional obstacles. For example, many people do not view invisible disabilities as authentic and perceive individuals with invisible disabilities as lazy, trying to use their disability to get out of work, or incapable (Denhart, 2008). Additionally, people generally have very low expectations of the capability of students with disabilities in STEM content. Consequently, they are not encouraged to consider and prepare for careers in the STEM areas. These low expectations and the lack of adequate accommodations are key barriers that impede the success of persons with disabilities in STEM curricula and fields.

PRINCIPLES OF INCLUSIVE CURRICULUM DESIGN

Education must simultaneously balance the goals of creating thoughtful, well-rounded individuals and preparing those individuals for the existing workforce. A robust concept of inclusive curriculum design assists with both goals by ensuring that every student receives adequate instruction and access to relevant educational materials. The modern workplace benefits from having diverse individuals in various roles, as evidenced by the significant efforts expended on increasing workplace diversity. Recruiting, educating and graduating an adequate pool of qualified graduates into STEM fields continues to be a challenge. This supply problem is likely to get worse in the near future, as the number of students who choose and maintain a major in these fields is declining (Whalen & Shelley, 2010). Pre-university engineering education programs are increasingly suggested to be a solution to this problem. These programs combine knowledge and motivation to enable students to intervene creatively to improve the human-made world. They require students to be creative and reflective problem solvers. Researchers and schools around the world are experimenting with various approaches to pre-university engineering education with the intent to (a) respond to the global economic challenges that every nation faces, (b) focus on the changing needs of the workforce which require more integrated and flexible knowledge and skills, (c) provide hope and opportunities to the next generation of citizens, and (d) emphasize the demand for technological literacy that is needed to solve our current and future global problems.

The businesses that will hire future engineers and scientists don't operate within subject disciplines; for them the integration of STEM knowledge and skills is automatic. Workplaces require the practical application of science, technology, engineering and mathematics, as well as other attributes such as: creativity, collaboration, critical thinking, and problem solving. In design and technology lessons students have the opportunity to work in this way too – working in teams, taking risks, taking leadership roles, being creative are all attributes which they make use of when designing and creating products in a classroom setting. These skills are transferable and applicable to any class in school and career path later in life.

Researchers have identified some of the characteristics of science and technology that alienate underrepresented groups; for example, science is often presented as a very technical field that has been stripped of all human elements and is practiced only by highly intelligent individuals. Additionally, research has shown that some pre-university students have a very poor understanding of what engineers are and thus have difficulty visualizing themselves in the career (Exter et al., 2014), in addition to difficulty distinguishing between different fields of engineering (Sohn & Ju, 2010). Science education research has also concluded that it is necessary to address disparities in access and exposure to science at an early age because students' interest in science tends to decline after elementary school (Brotman & Moore, 2008; Reid & Skryabina, 2003).

Providing all students, and especially those with disabilities and diverse learning needs meaningful access to STEM education is primarily about effective curriculum design. How do we design educational experiences that are engaging and effective for *ALL* students? Traditionally, engineering activities highlight competitive, decontextualized projects. These types of experiences fail to attract girls and underrepresented minorities who tend to favor cooperative work and real-world tasks. Below are some of the key elements to consider when designing or selecting an inclusive engineering curriculum:

Demonstrate the Relevance of Engineering to the Real World

Many students view the knowledge they learn in school as irrelevant for their careers and future lives. In order to increase the interest of students (particularly those who are underrepresented) in engineering, educators should help students see the relevance of what they are learning to the real world. The study of real-world contexts has been found to increase students' engagement, enthusiasm, and achievement (Kang & Lundeberg, 2010). An emphasis on the social and societal connections with engineering and science increases interest and motivation of students to drive their own learning and achievement (Brotman & Moore, 2008).

Labs and class activities that engage students in experiences that resemble those of real science can be very effective in conveying an understanding about the sociological processes of science (Cunningham & Helms, 1998). Similarly, a design-based curriculum that incorporates the engineering design process can greatly increase student interest in engineering careers by providing access to the creative process typical of the field (Reynolds, Mehalik, Lovell, & Schunn, 2009). Classroom experiences need to model the features of a dynamic scientific community, which include division of labor, communication, networks of peers, and collaboration. Engaging students in more authentic scientific and engineering design work will help them to see that science and engineering are not the exclusive domain of people with certain traits, such as intelligence, race, or gender.

Students connect to stories on a personal level; presenting material in this format helps to place the classroom engineering activity in a larger context. The story's protagonists should represent diverse races, ethnicities, and abilities and the plots should relate to students' own experiences (Jonassen & Hernandez-Serrano, 2002).

An example of successful integration of service learning in pre-college engineering education, the Engineering Projects In Community Service EPICS High program has seen widespread success in promoting active engagement by students for the purpose of community service projects. Originally conceived as an undergraduate program at Purdue University, the concept was later extended to high schools throughout the United States as part of a simultaneous push for access to both STEM education and service learning projects in pre-university engineering education (Dutta & Mathur, 2013). This program fulfills a need within the community for access to low-cost, high impact technical expertise for solving problems in the everyday lives of community members. The student participants are able to interact with the public and integrate their teamwork, communication, and technical knowledge while improving the lives of others (Coyle, Jamieson, & Oakes, 2005).

Highlight How Engineers and Technologists Help Others

Research finds that many students, particularly girls and underrepresented minorities, are interested in people-oriented "helping" careers (Miller, Slawinski-Blessing, & Schwartz, 2006). Students of both genders hold stereotypical views about physical science topics and activities as "for boys" and biological activities as "for girls". It has been determined that girls prefer and choose to participate more frequently in biological sciences than in physical science and engineering (Buccheri, Gurber, & Bruhwiler, 2011). Looking at university-bound high school students, Miller, Blessing and Schwartz (2006) found that girls tended to choose fields of study that were focused on helping people, and when choosing a science or engineering major, they tended to focus on fields like biology. Engineering activities at the grade school level overwhelmingly tend to focus on the physical sciences. Some common examples of activities include robot design, egg drop challenges, and vehicle races.

According to Miller et al. (2006) girls perceive science as uninteresting, and leading to an unattractive lifestyle (Miller et al., 2006). Miller suggests that girls receive mixed messages about careers and gender roles from the media, but positive role models can be influential. A variety of role models of both genders, from a variety of races and ethnicities, with different abilities and disabilities are necessary to combat these perceptions.

In western countries, because girls often want to understand the social value of what they're studying, it's beneficial to choose activities that highlight how engineering helps people, animals, the environment, and society. Sometimes simply reframing an activity already in use so that it emphasizes the altruistic aspect sparks student interest.

Present Authentic Design Challenges

Research indicates that students learn concepts and skills through experience as they work and learn in contexts that mirror disciplinary problems and practices (Duschl, 2008). Research has also shown that inquiry-based instruction emphasizing active student engagement is superior to techniques emphasizing passive student learning when assessing students' gains in conceptual understanding (Blanchard et al., 2010; Cuevas, Lee, Hart, & Deaktor, 2005; Geier et al., 2008; Minner, Jurist-Levy, & Century, 2010) and problem-based learning is superior for long-term knowledge retention and skill development (Strobel & van Barneveld, 2009). A variety of studies have shown that girls in particular benefit from hands-on and inquiry-based learning (Brotman & Moore, 2008; Cavallo & Laubach, 2001). Similarly, research has shown that unlike traditionally delivered science instruction, inquiry-based instruction equally benefits boys and girls (Cuevas et al., 2005) as well as students from ethnic minority groups (Blanchard et al., 2010; Cuevas et al., 2005). Hands-on instruction and applied experiences not only increase content knowledge and learning, but they also contribute to increased self-confidence and career knowledge, motivation, and access (Lam, Doverspike, Zhao, Zhe, & Menzemer, 2008; Mastropieri & Scruggs, 1992). Calls for more authenticity in education have increased since the 1980s to counteract the perception that school education is less relevant to real-world experiences. Lesson plans can be evaluated along several dimensions of authenticity, including authenticity of tasks, authenticity of impacts, and personal/value relevance. Research has shown that the varying types of educational authenticity may differently affect different learners, so a robust curriculum needs to incorporate multiple dimensions of relevance (Strobel, Wang, Weber, & Dyehouse, 2013).

Many textbooks drive students to arrive at one correct answer. This approach can lead to disengagement, especially if students experience failure repeatedly. Students begin to categorize themselves as “good” or “bad” at science, based on their performance on these narrowly defined tasks. Open-ended activities that enable problem solvers to generate a variety of solutions foster creativity, encourage risk taking, and invite exploration of original ideas. These types of activities invite a more profound understanding, which can be attractive to girls. Research has shown that girls strive for deep conceptual understanding and reject more formulaic, rote learning (Zohar, 2006). Open-ended questioning, inquiry, and problem solving have also shown benefits for the achievement and attitudes of urban minority students. With open-ended activities, students can more readily make connections with their interests and prior experiences (Jarvinen & Twyford, 2000).

Cultivate Collaboration and Teamwork

Engineers routinely work in teams. Cultivating the skill of teamwork is particularly important because competitive environments can be discouraging to girls and to children from cultures that value interaction and collaboration (Baker, 2013). When students work productively in groups, they often identify stronger design solutions. Collaborating helps students see that when you work with different people, you might generate a more diverse range of ideas, which increases the likelihood that one will succeed. Collaboration across teams shows students how they can learn from the successes and failures of others, and when groups pool their data, trends become more apparent. Collaborative learning environments allow students to be valued as contributors in a variety of ways, reducing the disparate impacts of race and socioeconomic status by allowing students multiple routes to gain social status (Olitsky, Loman-Flohr, Gardner, & Billups, 2010).

Scaffold Student Work

Students need guidance in order to learn complex processes and to transfer what they have learned to new problems. Tackling an open-ended engineering design problem can be daunting for students. Scaffolding by making the engineering design process explicit and by supporting each step with questions and prompts can increase students’ success and achievement. Breaking the problem down into smaller steps with discrete goals can help to focus children’s efforts.

Children enter schools with a wide range of experiences and backgrounds that can affect their achievement in school (Lee & Buxton, 2008). To minimize the effects of prior experiences on children’s success with engineering tasks, lessons should introduce children to the materials and terminology that will be used prior to attempting the engineering task. Activities that provide students relevant experience with the new materials and terms before they need to use them in the design challenge can be helpful. This type of exposure and exploration can help level the playing field and can help children who come from more disadvantaged backgrounds.

Engineering challenges are well suited for differentiated learning. The developmental and cognitive abilities of children in elementary classrooms can differ greatly. Offering challenges that can be successfully accomplished by a range of students requires that activities can be scaled up or down. Once a basic challenge has been developed, it can be made increasingly complex by adding additional criteria and constraints.

Plan Intentionally for Learner Variability

As Dalton, Morocco, Tivnan, and Mead, (1997) noted, students with disabilities who participate in science learning activities frequently: (a) have limited prior knowledge, (b) are reluctant to pose questions, (c) are less likely to have a plan for solving problems, (d) struggle to implement teacher recommendations, (e) have difficulty with inductive and deductive reasoning, and (f) seldom transfer knowledge to other contexts. In addition, these students often have fundamental misconceptions about scientific phenomena. Samsonov, Pederson, and Hill, (2006) pointed out that struggling learners often require a great deal of teacher scaffolding to manage the vast amount of information necessary to solve complex problems such as those included in pre-university engineering curricula. It is imperative that educators and administrators select engaging curricular materials that offer a wide range of instructional supports.

Teaching students with disabilities presents unique challenges for educators, particularly in inclusive classrooms where diverse learners may or may not have well-developed literacy or group work skills. Many inclusive models focus on giving students the opportunity to participate; for example, students with disabilities may be present in heterogeneous groups with peers, take part in hands-on activities, and perhaps be assigned a specific (usually nonacademic) role within the group. Students with disabilities could achieve far more if given effective instruction and support specifically tailored to design and engineering in inclusive settings. An inclusive curriculum that also integrates the individual's accommodations and/or modifications specified in students' Individualized Education Programs would ensure that all students' learning needs are addressed.

Many teachers lack the knowledge and skills to meaningfully include students with disabilities in math and science courses (Rule, Stefanich, & Boody, 2011). That is, they do not know how to adapt instruction and materials so that content is easier to understand and remember and do not know how to provide appropriate accommodations. To plan curriculum for presumed and known levels of learner variability the instruction and related materials should provide multiple representations of key concepts, principles and vocabulary. Many students with disabilities need nontraditional ways of learning and an array of teaching methods (Sternberg & Grigorenko, 2002). In a technology-enhanced STEM context, this can be accomplished by presenting information using graphics, simulations, video, and sound (Curry, Cohen, & Lightbody, 2006). When considering learner variability, a curriculum encompasses everything that a learner encounters within a learning experience including curricular standards and goals, instructional materials and tools, and instruction, as well as the means by which outcomes are assessed.

Instruction should be intentionally planned so that it is personally challenging for all learners, including individuals with identified disabilities, students who are considered average, and students who are gifted. In planning for learner variability, teachers should take into account specific considerations such as individual and group strengths, weaknesses, abilities, understanding of background knowledge, and even motivation for participating in the learning. Educators should provide options for students to carry out different activities to demonstrate understanding. Additionally, throughout the instructional process, students should be monitored using a variety of assessment practices. Using varied and continual data points that are based on authentic tasks enables educators to reflect on the success of the instructional experience.

Whether children wish to be engineers or not, we know that students are more engaged, interested, and confident when they have both the responsibility and the opportunity to become more competent and to make choices about what forms of competence they wish to specialize in. Students benefit when they are engaged in working collaboratively rather than competitively, when they have choices for how to show their competencies, and when they are evaluated based on their effort. When students are evaluated based on their effort and their contributions are valued, they are more likely to be engaged and interested in the task. These environments are less likely to reinforce socioeconomic inequalities or ethnic and cultural differences, and more likely to promote broad engagement (Gresalfi, Martin, Hand, & Greeno, 2009; Olitsky et al., 2010).

SPECIAL CONSIDERATIONS AND ACCOMMODATIONS

One of the key predictors of persistence in STEM programs for students with disabilities is the ability to communicate needs and identify appropriate accommodations (Mason, Field, & Sawilowsky, 2004). Many of the skills associated with self-determination, such as acknowledging, understanding, and accepting one's disability; knowing one's strengths, weaknesses, and needs; and self-advocating to ensure proper accommodations are provided, have been linked to students with disabilities' persistence and success in STEM (Lee, 2011). Jonassen and Grabowski, (1993), identify several methods for matching learner style with instructional style including preferential (teaching to support an existing preferred style), remediation (trying to overcome limitations) and compensatory (adding additional tools in the repertoire of learning) matching.

The authors suggest that such changes are best implemented in a task-oriented fashion, termed content-by-treatment interactions. This approach is more feasible for classroom implementation as opposed to individualized lesson plans for each student.

Although inclusive curriculum design principles benefit all students, they do not eliminate the need for specific accommodations for students with disabilities. Moon et al. (2012) gives a comprehensive list of adapting the learning environment and instruction to needs for different audiences. An accommodation is an adjustment or modification to make a product or environment accessible to an individual with a disability. Accommodation is grounded in the medical model of disability, in which a professional identifies an individual's functional "deficit" and prescribes adjustments that allow him or her to participate to some degree in the "normal" environment. Examples of accommodations include printed materials in alternate formats, extra time on tests, sign language interpreters, and assistive technology. Using technology has been recognized as an effective practice to increase students with disabilities' participation in STEM areas. Computers, assistive technology, and network resources can link the communication and accessibility for students with disabilities (Burgstahler, Corrigan, & McCarter, 2004). Among the many available technologies are variable speech-control tape recorders, reading machines, listening aids, voice output systems that read back text displayed on the computer screen, speech-recognition systems, data managers, and talking calculators. Unfortunately, the use of assistive technologies has often been considered for only those students with severe physical disabilities. Assistive technology devices, for example, now help "support students with memory, organization, problem solving, reading, writing, and math" (Lee & Templeton, 2008). Assistance in these areas is especially relevant to students with high-incidence disabilities because often these students have deficits in these areas.

Mentors and role models can serve as educational partners and possess both the practical knowledge and personal experience that can be crucial in breaking down barriers and encouraging students to persist in their chosen disciplines. Mentoring can occur in many ways, such as one-on-one or in small groups and through personal meetings, e-mail exchanges, telephone conversations, or other forms of correspondence (Sword & Hill, 2003). Students tend to be more successful academically when placed in supportive environments. Mentoring minority undergraduate STEM majors has been shown to progressively improve students' academic performance (Kendricks, Nedunuri, & Arment, 2013).

When mentoring students with disabilities, some practices that have been identified as important when developing mentoring programs, include opportunities for relationship building via direct contact or the Internet, flexibility in approach related to individuals' preferences, styles, and needs, and mentor training (Stumbo, Blegen, & Lindahl-Lewis, 2008). It was also noted that in effective programs, mentoring is just one component of an overall program that provides multiple exposure opportunities to STEM.

Pre-university programs offered at many institutions provide secondary students with experiences in math, science, engineering, health care, and technology, as well as an orientation to the university environment. Some programs are for students with and without disabilities, whereas others are specifically for students from underrepresented groups, including students with disabilities.

CONCLUSION

Increasing the number of role models for minority students, expanding opportunities for relevant experience and ensuring adequate pre-university preparation would help alleviate the current disparities in STEM disciplines. For STEM, quality preparation is a prerequisite for later success. Researchers offer many explanations for the persistent achievement gaps while recognizing that there are many interrelated factors, including family and community differences, school context, low expectations, and lack of exposure. In this chapter, we highlighted the complexity of what it means to be underrepresented in engineering and technology education introducing the iceberg model as a way to communicate that many differences often exist – unnoticed and underserved. We make a case that a holistic view of all students as unique does not contradict yet rather complements existing prevalent views of heterogeneity as only visible individual differences.

Following our model, we advocate for different curriculum and learning environments. Most of the education products on the market are aids to teach the existing curriculum, yet a new core of subjects and approaches is needed, focusing on the competencies that will equip our students for the future and addressing individual and heterogeneous experiences. We are confronted with contradictory purposes for offering pre-university engineering opportunities. Do we intend to provide educational opportunities for only our advanced students or the ones perceived a having interest? Or, are efforts being made to include all students in order to provide technological literacy for all? And if our educational efforts are intended to include all – who is all? STEM education is more than simply teaching a set of skills and a list of facts; it is about teaching students to be innovative and to use a wide range of resources and processes when designing and making solutions to real challenges. These are opportunities that should be accessible to all our students.

Success in a STEM field will require the necessary acquisition of knowledge, skills, and habits of mind. It will also require opportunities to put these into practice as well as a motivation to be in, or self-identy with the respective practice. These components require attention in some way for all students at every stage along the STEM educational continuum. However, there are issues that are specific to underrepresented minorities – with visible and invisible differences – focused on preparation, access and motivation, academic support, and social integration.

Strategies for encouraging these students include facilitating students' personal development skills; providing access to content by providing inclusive curriculum design, technology, and accommodations, as needed: encouraging students' participation in activities that provide authentic experiences in the STEM areas, as well as access to role models and mentors. Intelligence and talents are not simply traits; every student can learn based on their abilities and their unique setup and every student can contribute to the engineering and technology enterprise.

REFERENCES

Alston, R. J., Bell, T. J., & Hampton, J. L. (2002). Learning disability and career entry into the sciences: A critical analysis of attitudinal factors. *Journal of Career Development, 28*(4), 263–275.

Aronson, J., Lustina, M. J., Good, C., & Keough, K. (1999). When White men can't do math: Necessary and sufficienet factors in stereotype threat. *Journal of Experimental Social Psychology, 35*, 29–46.

Baker, D. (2013). What works: Using curriculum and pedagogy to increase girls' interest and participation in science. *Theory into Practice, 52*, 14–20.

Benner, A. D., & Mistry, R. S. (2007). Congruence of mother and teacher educational expectations and low-income youth's academic competence. *Journal of Educational Psychology, 99*(1), 140–153.

Besterfield-Sacre, M., Moreno, M., Shuman, L. J., & Atman, C. J. (2001). Gender and ethnicity differences in freshman engineering student attitudes: A cross-institutional study. *Journal of Engineering Education, 90*(4), 477–489.

Blanchard, M. R., Southerland, S. A., Osborne, J. W., Sampson, V. D., Annetta, L. A., & Granger, E. M. (2010). Is inquiry possible in light of accountability?: A quantitative comparison of the relative effectiveness of guided inquiry and verification laboratory instruction. *Science Education, 94*(4), 577–616.

Brophy, J. E. (1983). Research on the self-fulfilling prophecy and teacher expectations. *Journal of Educational Psychology, 75*(5), 631–661.

Brotman, J. S., & Moore, F. M. (2008). Girls and science: A review of four themes in the science education literature. *Journal of Research in Science Teaching, 45*(9), 971–1002.

Buccheri, G., Gurber, N. A., & Bruhwiler, C. (2011). The impact of gender on interest in science topics and the choice of scientific and technical vocations. *International Journal of Science Education, 33*(1), 159–178.

Burgstahler, S., Corrigan, B., & McCarter, J. (2004). Making distance learning courses accessible to students and instructors with disabilities: A case study. *Internet and Higher Education, 7*, 233–246.

Bybee, R. W. (2013). *The case for STEM education: Challenges and opportunities*. Arlington, VA: National Science Teachers Association Press.

Cavallo, A. M. L., & Laubach, T. A. (2001). Students' science perceptions and enrollment decisions in differing learning cycle classrooms. *Journal of Research in Science Teaching, 32*(3), 243–257.

Chio, D. G., & de Vries, H. J. (2013). Integrating standardization into engineering education: The case of forerunner Korea. *International Journal of Technology and Design Education, 23*, 1111–1126.

Chouinard, R., Karsenti, T., & Roy, N. (2007). Relations among competence beliefs, utility value, achievement goals, and effort in mathematics. *British Journal of Educational Psychology, 77*, 501–517.

Coyle, E. J., Jamieson, L. H., & Oakes, W. C. (2005). EPICS: Engineering projects in community service. *International Journal of Engineering Education, 21*(1), 139–150.

Cuevas, P., Lee, O., Hart, J., & Deaktor, R. (2005). Improving science inquiry with elementary students of diverse backgrounds. *Journal of Research in Science Teaching, 42*(3), 337–357.

Cunningham, C. M., & Helms, J. V. (1998). Sociology of science as a means to a more authentic, inclusive science education. *Journal of Research in Science Teaching, 35*(5), 483–499.

Curry, C., Cohen, L., & Lightbody, N. (2006). Universal design in science learning. *Science Teacher, 73*(3), 32–37.

Dalton, B., Morocco, C. C., Tivnan, T., & Mead, P. L. R. (1997). Supported inquiry science: Teaching for conceptual change in urban and suburban science classrooms. *Journal of Learning Disabilities, 30*(6), 670–684.

Davis, A. N. (2005). Invisible disability. *Ethics, 116*(1), 153–213.

de Boer, H., Bosker, R. J., & van der Werf, M. P. C. (2010). Sustainability of teacher expectation bias effects on long-term student performance. *Journal of Educational Psychology, 102*(1), 168–179.
Denhart, H. (2008). Deconstructing barriers: Perceptions of students labeled with learning disabilities in higher education. *Journal of Learning Disabilities, 41*(6), 483–497.
Duschl, R. (2008). Science education in three-part harmony: Balancing conceptual, epistemic, and social learning goals. *Review of Research in Education, 32*(1), 268–291.
Dutta, S., & Mathur, R. (2013). EPICS high: STEM's impact on community service. *2013 Ieee Integrated Stem Education Conference (Isec)*.
Eriksson, L., Welander, J., & Granlund, M. (2007). Participation in everyday school activities for children with and without disabilities. *Journal of Developmental and Physical Disabilities, 19*, 485–502.
Farmer, S. (2013). Supporting Scotland's STEM education and culture. *School Science Review, 95*(351), 67–68.
Fitzpatrick, V. (2014). *Cognitive diversity in undergraduate engineering: Dyslexia* (Ph.D.). Purdue University, West Lafayette, IN.
Fogliati, V. J., & Bussey, K. (2013). Stereotype threat reduces motivation to improve: Effects of stereotype threat and feedback on women's intentions to improve mathematical ability. *Psychology of Women Quarterly, 37*(3), 310–324.
Freeman, B., Marginson, S., & Tytler, R. (2014). *Routledge research in education: Age of STEM: Educational policy and practice*. New York, NY: Routledge.
Geier, R., Blumenfeld, P. C., Marx, R. W., Krajcik, J. S., Fishman, B., Soloway, E., & Clay-Chambers, J. (2008). Standardized test outcomes for students engaged in inquiry-based science curricula in the context of urban reform. *Journal of Research in Science Teaching, 45*(8), 922–939.
Glass, J. L. (2013). What's so special about STEM? A comparison of women's retention in STEM and professional occupations. *Social Forces, 92*(2), 723–756.
Good, C., Rattan, A., & Dweck, C. S. (2012). Why do women opt out? Sense of belonging and women's representation in mathematics. *Journal of Personality and Social Psychology, 102*(4), 700–717.
Goode, J. (2010). Mind the gap: The digital dimension of college access. *The Journal of Higher Education, 81*(5), 583–618.
Gresalfi, M., Martin, T., Hand, V., & Greeno, J. (2009). Constructing competence: An analysis of student participation in the activity systems of mathematics classrooms. *Educational Studies in Mathematics, 70*(1), 49–70.
Grossman, J. M., & Porche, M. V. (2014). Perceived gender and racial/ethnic barriers to STEM success. *Urban Education, 49*(6), 698–727.
Guglielmi, S. R. (2012). Math and science achievement in English language learners: Multivariate latent growth modeling of predictors, mediators, and moderators. *Journal of Educational Psychology, 104*(3), 580–602.
Hall, E. T. (1998). The power of hidden differences. In M. J. Bennett (Ed.), *Basic concepts of intercultural communication. Selected readings* (pp. 53–68). Yarmouth & Maine, ME: Intercultural Press, Inc.
Hall, T., Healey, M., & Harrison, M. (2002). Fieldwork and disabled students: Discourses of exclusion and inclusion. *Transactions of the Institute of British Geographers, 27*(2), 213–231.
Hayes, K., Rueda, R., & Chilton, S. (2009). Scaffolding language, literacy, and academic content in English and Spanish: The linguistic highway from Mesoamerica to Southern California. *English Teaching: Practice and Critique, 8*(2), 137–166.
Herbert, J., & Stipek, D. (2005). The emergence of gender differences in children's perceptions of their academic competence. *Journal of Applied Developmental Psychology, 26*(3), 276–295.
Hess, J., Fila, N., Purzer, S., & Strobel, J. (2015). *Exploring the relationship between empathy and innovation among engineering students*. Proceedings of the American Society for Engineering Education (ASEE) Annual Conference and Exposition, Seattle, WA.
Idol, L. (2006). Toward inclusion of special education students in general education: A program evaluation of eight schools. *Remedial and Special Education, 27*(2), 77–94.
Jarvinen, E.-M., & Twyford, J. (2000). The influences of socio-cultural interaction upon children's thinking and actions in prescribed and open-ended problem solving situations (An Investigation Involving Design and Technology Lessons in English and Finnish Primary Schools). *International Journal of Technology and Design Education, 10*(1), 21–41.

Jenkins, E. W., & Nelson, N. W. (2005). Important but not for me: Students' attitudes towards secondary school science in England. *Research in Science & Technological Education, 23*(1), 41–57.

Jesiek, B., & Beddoes, K. (2013). Diversity in Engineering (DinE) bibliography research brief. *Engineering Studies*, *5*(1), 90–92.

Jonassen, D. H., & Grabowski, B. L. H. (1993). *Handbook of individual differences, learning, and instruction*: Hillsdale, NJ: Lawrence Erlbaum Associates.

Jonassen, D. H., & Hernandez-Serrano, J. (2002). Case-based reasoning and instructional design: Using stories to support problem solving. *Educational Technology Research and Development*, *50*(2), 65–77.

Kang, H., & Lundeberg, M. A. (2010). Participation in science practices while working in a multimedia case-based environment. *Journal of Research in Science Teaching, 47*(9), 1116–1136.

Kendricks, K. D., Nedunuri, K. V., & Arment, A. R. (2013). Minority student perceptions of the impact of mentoring to enhance academic performance in STEM disciplines. *Journal of STEM Education, 14*(2), 38–46.

Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential and inquiry-based teaching. *Educational Psychologist, 41*(2), 75–86.

Kuechler, W. L., McLeod, A., & Simkin, M. G. (2009). Why don't more students major in IS? *Decision Sciences Journal of Innovative Education, 7*, 463–488.

Lam, P., Doverspike, D., Zhao, J., Zhe, J., & Menzemer, C. (2008). An evaluation of a STEM program for middle school students on learning disability related IEPs. *Journal of STEM Education, 9*(1&2), 21–29.

Lareau, A. (2003). *Unequal childhoods: Class, race, and family life*. Berkeley, CA: University of California Press.

Leddy, M. H. (2010). Technology to advance high school and undergraduate students with disabilities in science, technology, engineering, and mathematics. *Journal of Special Education Technology, 25*(3), 3–8.

Lee, A. (2011). A comparison of postsecondary Science, Technology, Engineering, and Mathematics (STEM) enrollment for students with and without disabilities. *Career Development for Exceptional Individuals, 34*(2), 72–82.

Lee, H., & Templeton, R. (2008). Ensuring equal access to technology: Providing assistive technology for students with disabilities. *Theory Into Practice, 47*, 212–219.

Lee, O., & Buxton, C. (2008). Science curriculum and student diversity: A framework for equitable learning opportunities. *The Elementary School Journal, 109*(2), 123–137.

MacPhee, D., Farro, S., & Canetto, S. S. (2013). Academic self-efficacy and performance of underrepresented STEM majors: Gender, ethnic, and social class patterns. *Analyses of Social Issues & Public Policy, 13*(1), 347–369.

Major, B., & O'Brien, L. T. (2005). The social psychology of stigma. *Annual Review of Psychology, 56*, 393–421.

Mason, C., Field, S., & Sawilowsky, S. (2004). Implementation of self-determination activities and student participation in IEPs. *Exceptional Children, 70*(4), 441–451.

Mastropieri, M. A., & Scruggs, T. E. (1992). Science for students with disabilities. *Review of Educational Research, 62*(4), 377–411.

Miech, R., Pampel, F., Kim, J., & Rogers, R. G. (2011). The enduring association between education and mortality: The role of widening and narrowing disparities. *American Sociological Review, 76*(6), 913–934.

Miller, P. H., Slawinski-Blessing, J., & Schwartz, S. (2006). Gender differences in high-school students' views about science. *International Journal of Science Education, 28*(4), 363–381.

Minner, D. D., Jurist-Levy, A., & Century, J. (2010). Inquiry-based science instruction – What is it and does it matter? Results from a research synthesis years 1984 to 2002. *Journal of Research in Science Teaching, 47*(4), 474–496.

Moon, N. W., Todd, R. L., Morton, D. L., & Ivey, E. (2012). *Accommodating students with disabilities in Science, Technology, Engineering, and Mathematics (STEM)*. Atlanta, GA: Center for Assistive Technology and Environmental Access, Georgia Institute of Technology.

Napper, S. A., Hale, P. N., Jr., & Puckett, F. J. (2002). An educational brief: Motivating students with disabilities to prepare for SEM careers. *Journal of Engineering Education, 91*(3), 361–365.

Nathan, M. J., Tran, N. A., Atwood, A. K., Prevost, A., & Phelps, L. A. (2010). Beliefs and expectations about engineering preparation exhibited by high school STEM teachers. *Journal of Engineering Education, 99*(4), 409–426.

Noble, T., Suarez, C., Rosebery, A., O'Connor, M. C., Warren, B., & Hudicourt-Barnes, J. (2012). "I Never Thought of it as Freezing": How students answer questions on large-scale science tests and what they know about science. *Journal of Research in Science Teaching, 49*(6), 778–803.

Oakes, J. (1990). Opportunities, achievement, and choice: Women and minority students in science and mathematics. *Review of Research in Education, 16*(1), 153–222.

Olitsky, S., Loman-Flohr, L., Gardner, J., & Billups, M. (2010). Coherence, contradiction, and the development of school science identities. *Journal of Research in Science Teaching, 47*(10), 1209–1228.

Payne, D., & Heilbronner, N. (2009). Mentoring talented science students: Knowing the options. *Gifted Education International, 25*(3), 259–269.

Pitt, J. (2009). Blurring the boundaries – STEM education and education for sustainable development. *Design and Technology Education: An International Journal, 14*(1), 37–48.

Price, J. (2010). The effect of instructor race and gender on student persistence in STEM fields. *Economics of Education Review, 29*, 901–910.

Reid, N., & Skryabina, E. A. (2003). Gender and physics. *International Journal of Science Education, 25*(4), 509–536.

Reynolds, B., Mehalik, M. M., Lovell, M. R., & Schunn, C. D. (2009). Increasing student awareness of and interest in engineering as a career option through design-based learning. *International Journal of Engineering Education, 25*(4), 788–798.

Ritz, J., & Martin, G. (2013). Research needs for technology education: An international perspective. *International Journal of Technology and Design Education, 23*, 767–783.

Rule, A. C., & Stefanich, G. P. (2012). Using a thinking skills system to guide discussions during a working conference on students with disabilities pursuing STEM fields. *Journal of STEM Education, 13*(1), 43–54.

Rule, A. C., Stefanich, G. P., & Boody, R. M. (2011). The impact of a working conference focused on supporting students with disabilities in Science, Technology, Engineering, and Mathematics (STEM). *Journal of Postsecondary Education and Disability, 24*(4), 351–367.

Samsonov, P., Pederson, S., & Hill, C. H. (2006). Using problem-based learning software with at-risk students: A case study. *Computers in the Schools, 23*(1/2), 111–124.

Sevo, R. (2011). *Basics about disabilities and science and engineering education*. Atlanta: Under the direction of Robert L. Todd, Center for Assistive Technology and Environmental Access, Georgia Institute of Technology.

Slovacek, S. P., Peterfreund, A. R., Kuehn, G. D., Whittinghill, J. C., Tucker, S., Rath, K. A., & Reinke, Y. G. (2011). Minority students severely underrepresented in science, technology, engineering, and math. *Journal of STEM Education, 12*(1/2), 5–16.

Spencer, S. J., Steele, C. M., & Quinn, D. M. (1999). Stereotype threat and women's math performance. *Journal of Experimental Social Psychology, 35*, 4–28.

Steele, C., & Aronson, J. (1995). Stereotype threat and the intellectual test performance of African Americans. *Journal of Personality and Social Psychology, 69*(5), 797–811.

Sternberg, R. J., & Grigorenko, E. L. (2002). Difference scores in the identification of children with learning disabilities: It's time to use a different method. *Journal of School Psychology, 40*(1), 65–83.

Strobel, J., & van Barneveld, A. (2009). When is PBL more effective? A meta-synthesis of meta-analyses comparing PBL to conventional classrooms. *Interdisciplinary Journal of Problem-based Learning, 3*, 1, 4.

Strobel, J., Hess, J., Pan, R., & Wachter Morris, C. A. (2013). Empathy and care within engineering: Qualitative perspectives from engineering faculty and practicing engineers. *Engineering Studies, 5*(2), 137–159.

Strobel, J., Wang, J., Weber, N. R., & Dyehouse, M. (2013). The role of authenticity in design-based learning environments: The case of engineering education. *Computers & Education, 64*, 143–152.

Stumbo, N. J., Blegen, A. R., & Lindahl-Lewis, P. (2008). Two mentorship case studies of high school and university students with disabilities: Milestones and lessons. *Journal of Rehabilitation, 74*(3), 45–51.

Sword, C., & Hill, K. (2003). Creating mentoring opportunities for youth with disabilities: Issues and suggested strategies. *American Rehabilitation, 27*(1), 14–17.

Thiry, H., Laursen, S. L., & Hunter, A.-B. (2011). What experiences help students become scientists? A comparative study of research and other sources of personal and professional gains for STEM undergraduates. *The Journal of Higher Education, 82*(4), 357–388.

Tyson, W. (2011). Modeling engineering degree attainment using high school and college physics and calculus course taking and achievement. *Journal of Engineering Education, 100*(4), 760–777.

Weaver, G. R. (1986). Understanding and coping with cross-cultural adjustment Stress. In R. M. Paige (Ed.), *Cross-cultural orientation. New conceptualizations and applications*. Lanham, MD: University Press of America.

Whalen, D. F., & Shelley, M. C., II. (2010). Academic success for STEM and Non-STEM majors. *Journal of STEM Education, 11*(1 & 2), 45–60.

Wiley, A. L., Brigham, F. J., Kauffman, J. M., & Bogan, J. E. (2013). Disproportionate poverty, conservatism, and the disproportionate identification of minority students with emotional and behavioral disorders. *Education and Treatment of Children, 36*(4), 29–50.

Yasar, S., Baker, D., Robinson-Kurpius, S., Krause, S., & Roberts, C. (2006). Development of a survey to assess K-12 teachers' perceptions of engineers and familiarity with teaching design, engineering, and technology. *Journal of Engineering Education, 95*(3), 205–216.

Zohar, A. (2006). Connected knowledge in science and mathematics education. *International Journal of Science Education, 28*(13), 1579–1599.

Andrea K. Agree
Texas A&M University
USA

Anna E. Faloon
Texas A&M University
USA

Johannes Strobel
University of Missouri
USA

DAVID BARLEX

11. INDUSTRY'S ROLE IN PRE-UNIVERSITY ENGINEERING EDUCATION

The UK Experience

This chapter is in three parts. The first part will give an account of how industry has become increasingly involved in pre-university engineering education in the UK over the past 15 years. The second part will describe a range of current activities that exemplify this involvement. The third part will provide a commentary on the activities from the perspectives of intention and effectiveness.

Pre-university engineering education has become intertwined with the growing STEM (science, technology, engineering and mathematics) agenda in schools. Science subjects, particularly physics, and mathematics are gatekeeper subjects for many university engineering courses and are clearly significant for those wishing to increase the numbers of young people who study engineering at university. But it is widely acknowledged, as detailed in the first part of this chapter, that these subjects do not provide an 'engineering experience'. Hence this chapter will concentrate on how industry has attempted to influence the curriculum to provide such an experience through both the formal and informal curriculum.

THE GROWING INVOLVEMENT OF INDUSTRY IN PRE-UNIVERSITY ENGINEERING EDUCATION

Significant Reports 2000–2007

There has been an increasing interest by industry in pre university engineering education over the past 15 years. This can be seen in the comments made in significant documents concerned with engineering and the UK economy and their influence on the school curriculum. The Universe of Engineering (Malpas, 2000) presented a usefully broad definition of engineering (shown in Box 1), emphasized its economic significance and lamented the generally 'invisible' nature and poor understanding of much engineering activity with regard to the general public. Concentrating very much on the role of higher education in developing the knowledge, skill and understanding required by engineers there are the beginnings of a realization that schools may have a part to play evidenced by the statement "Encourage in schools at A-levels, the teaching of the relevant science underpinning recognized major engineering and technological achievement" (p. 22). Within two years this

M. J. de Vries et al. (Eds.), Pre-university Enineering Education, 179–203.

realization had developed into a clear understanding of the importance of the school curriculum and some of the problems faced. SET for Success The supply of people with science, technology, engineering and mathematical skill (Roberts, 2002) was commission by the government. Part 2 is devoted to school and further education (some 25% of the report) and identified the following deep-seated issues;

- shortages in the supply of physical science and mathematics teachers/lecturers;
- poor environments in which science, and design and technology practicals are taught;
- the ability of these subjects' courses to inspire and interest pupils, particularly girls; and
- other factors such as careers advice which affect pupils' desire to study science, technology, engineering or mathematics at higher levels.

Box 1. Malpas Definition of Engineering

Engineering is the knowledge required, and the process applied, to conceive, design, make, build, operate, sustain, recycle or retire, something with significant technical content for a specified purpose: a concept, a model, a product, a device, a process, a system, a service, a technology.

Five years later *The Race to the Top A review of Government's Science and Innovation Policies* (Sainsbury, 2007) made specific suggestions as to address the issues identified in the Roberts Review.

> Demand for science, technology, engineering and mathematics (STEM) skills will continue to grow. The UK has a reasonable stock of STEM graduates, but potential problems lie ahead. There has been a 20-year decline in the number of pupils taking A-level physics. The Review recommends a major campaign to address the STEM issues in schools. This will raise the numbers of qualified STEM teachers by introducing, for example, new sources of recruitment, financial incentives for conversion courses, and mentoring for newly qualified teachers. The Government should continue its drive to increase the number of young people studying triple sciences, and consider entitlement for all pupils to study the second mathematics GCSE (due to be introduced in 2010). (Sainsbury, 2007 p. 6)

A National STEM Programme 2008

In direct response the government produced a report The Science, Technology, Engineering and Mathematics (STEM) Programme Report (DFES & DTI, 2006) to initiate a national strategy.

Our proposals work towards a vision that aims to ensure that STEM support is delivered in the most effective way to every school, college, learning provider and learner. For the first time we will have:

> One high level STEM Strategy Group that will join up STEM across all phases of education and make recommendations to Ministers about national STEM priorities;
>
> And
>
> A National STEM Director who will drive delivery forward. (p. 3)

John Holman was appointed National STEM Director and under his leadership an action plan for the national programme was developed. It was organised into 5 themes, involving 11 action programmes overall with each action programme supported by a lead organisation (National Science Learning Centre 2008). This is summarised in Table 1. It is significant that the lead organization for Action Programmes 4 and 6 was the Royal Academy of Engineering. In its own words from the website www.raneg.rog.uk "The Royal Academy of Engineering provides leadership and promotes excellence across all fields of engineering, to the benefit of society. The Academy's activities are shaped, led and delivered by its exceptional Fellowship, which represents the nation's best practising engineers, innovators and entrepreneurs, often in leading roles across business and academia". Extracts from the Academy's Strategic Plan for 2011–2015 (Royal Academy of Engineering, 2011) indicates clearly the intention of the Academy, and by implication the engineering industry, to play a strong role in pre-university education.

Under role

> We support engineering in the UK by: nurturing engineering education and skills through leadership, policy advice and programmes to enhance teaching and learning inspiring young people to become engineers, increasing diversity across the profession and celebrating engineering excellence and innovation.
>
> Under Strategic Challenges
>
> Foster better education and skills
>
> The strategic challenge is to create a system of engineering education and training that satisfies the aspirations of young people while delivering the high calibre engineers and technicians that businesses need. We shall work with partners to ensure that more young people study STEM subjects in schools, FE colleges and universities, where we shall enrich outcomes by bringing real-world engineering practice into the student experience. We shall encourage more people, especially young women and people from a wider range of backgrounds, to work as engineering technicians, graduate engineers and engineering researchers.

Table 1. The STEM national programme

Action programme	*Lead organisation*
Getting and training the right teachers and lecturers of STEM subjects in the first place	
AP1 Improving the recruitment of teachers and lecturers in shortage subjects	Training and Development Agency for Schools (TDA)
Providing the right continuing professional development for teachers of STEM subjects	
AP2 Improving teaching and learning through CPD for mathematics teachers	National Centre for Excellence in the Teaching of mathematics (NCETM)
AP3 Improving teaching and learning through CPD for science teachers	National Science Learning Centre (NSLC)
AP4 Improving teaching and learning by engaging teachers with engineering and technology	Royal Academy of Engineering (RAEng)
Providing the right activities and careers advice that bring real world context and applications of STEM into the classroom	
AP5 Enhancing and enriching the science curriculum	SCORE[1]
AP6 Enhancing and enriching the teaching of engineering and technology across the curriculum	Royal Academy of Engineering (RAEng)
AP7 Enhancing and enriching the teaching of mathematics	Advisory Committee on Mathematics Education (ACME)
AP8 Improving the quality of advice and guidance for students (and their teachers and parents) about STEM careers, to inform subject choice	The National STEM Careers Co-ordinator (at Sheffield Hallam University)
Getting the STEM curriculum in the classroom right	
AP9 Widening access to the formal science and mathematics curriculum for all including access to triple science GCSE	Department for Children, schools and Families (DCSF)
AP10 Improving the quality of practical work in science	SCORE
Getting the STEM education support infrastructure right	
AP11 Programme to build capacity of the national, regional and local infrastructure	Department for Children, schools and Families (DCSF)

[1] *Science Community Representing Education is convened by the Royal Society. The other founding partners are the Institute of Physics, the Royal Society of Chemistry, the Institute of Biology, the Biosciences Federation, the Science Council and the Association for Science Education.*

The rise of Engineering in the Specialist School Movement 2005

This growing industrial interest in promoting an engineering dimension in the school curriculum was mirrored in the Specialist Schools movement in England. This growing industrial interest in promoting an engineering dimension in the school curriculum was mirrored in the Specialist Schools movement in England (1986–2012). During this time schools could apply to the government for Specialist School status, which brought additional funding, and nominate an area of the curriculum in which they school would specialize and through this specialization raise pupil attainment across all subjects. Hence some schools nominated engineering as their specialism and became known as Engineering Colleges. The report *Becoming an Engineering College* (Barlex, 2005) described the emerging and developing good practice that was taking place in twelve such colleges. Of particular relevance to involvement of industry in pre-university engineering education was the role of the Engineering Education Alliance (EEA) in supporting Engineering Colleges.

The EEA brought together the Professional Engineering Institutions and Affiliates, the Engineering Employers Federation (eef), the manufacturers organisation, the Royal Academy of Engineering, Sector Skills Council for Science, Engineering, Manufacturing Technology (SEMTA) and The Science, Engineering, Technology and Mathematics Network (SETNET), with membership of the Engineering Council UK (ECUK) and the Engineering and Technology Board (etb). The EEA was particularly keen to support and be involved in the development of new approaches to teaching and learning that embraced the 'engineering experience' as indicated here:

> The EEA should also encourage the development of more innovative and creative courses of study at all levels so that more students can experience the real excitement of achieving tangible outcomes through engineering.
>
> There should also be more creative support material produced for teachers, not of the traditional 'careers promotional' type, but aimed at informing subject teachers so that they can:
>
> - 'Debunk the myths' which abound about the engineering world;
> - Access more objective evidence from many initiatives to support their teaching;
> - Use cross-curricular material to enrich their own subject areas based on engineering topics;
> - Encourage more creative, project led work that meets real needs and includes synthesis and student autonomy in decision making, thus both developing and rewarding enthusiasm. (p. 64)

This has considerable resonance with the rhetoric of the soon to follow National STEM Programme.

The Impact of the Demise of the Specialist Schools Programme 2010

The Specialist Schools programme was discontinued by the Coalition Government in 2010 and funding was absorbed into general school budgets. Hence schools that had promoted engineering as part of their ethos and developed courses accordingly found themselves without access to ring fenced funding to continue with this endeavour.

The Labour Government (1997–2010) was committed to the idea of 'applied learning' and this gave rise to a suite of 'diploma qualifications' for pupils aged 14–19 years. The engineering diploma required schools to work in a consortium which included a local FE College, a local University and provide significant work place based learning. The development of the overall scheme had significant contribution from industry including companies such as Rolls Royce, BAE Systems and JCB. The numbers of candidates was initially small but grew modestly between 2009 and 2011. However the Coalition administration downgraded the significance of such qualifications with regard to school accountability measures in response to the recommendations of the Wolf Report (2011) and schools ceased to offer the Engineering Diploma (Harrison in Barlex, 2014). In response the engineering education community worked with teachers, curriculum developers awarding organizations to redevelop a qualification that could form the core of 14–16 technical curriculum and would meet the accountability requirements (ibid). One such qualification is the Cambridge Nationals in engineering related subjects offered by OCR with first inclusion the school accountability measures in 2016 (OCR, 2015). Uptake has so far been minimal but it is interesting to note that support materials for this course have been developed by the F1 in Schools project. F1 in Schools is a multi-disciplinary challenge in which teams of students aged 9 to 19 deploy CAD/CAM software to collaborate, design, analyse, manufacture, test, and then race miniature gas powered balsa wood F1 cars. Over the past 10 years it has grown from operating in just England to involve students from 34 countries. The organisers believe that participating in the competition will help change young peoples' perceptions of engineering, science and technology and enable them to develop an informed view about careers in engineering, Formula One, science, marketing and technology (ref F1 in Schools: http://www.f1inschools.com/). Here is an interesting example of an industry funded enhancement and enrichment activity supporting an engineering qualification.

The Emergence of University Technical Colleges 2010

But another facet of government policy has given opportunity for the provision of an engineering experience in some schools. As part of the Academies Programme initiated by the Labour Government and continued and extended by the Coalition Government University Technology Colleges (UTCs) came into existence. The key features of UTCs are shown in Box 2. Although growing in number, from 1 in 2010 to a proposed 30 by the end of 2016 the UTC curriculum with its heavy emphasis on engineering in some schools and reliance on the involvement of local industry in all cases will only reach a minority of young people.

Box 2. Key Features of University Technical Colleges.
(Taken from website http://www.utcolleges.org/)

- A focus on one or two technical specialisms
- Working with employers and a local university to develop and deliver their curriculum
- Providing essential academic education and relating this to the technical specialisms
- Having the latest equipment and technology used by industry
- Dedicating at least 40% of time to the technical specialism including design and building, working in teams and problem solving

Employers influence the teaching and learning that students receive, provide leadership in the structure of the curriculum and endorse the qualifications offered at a UTC. They play a central role in UTCs right from the very beginning to identify business needs and the skills shortages in the local region. This shapes the technical specialisms of the UTC and ensures it meets the needs of local employers.

The Revision of the Design & Technology Curriculum 2013

Although a qualification in design & technology, which some see as providing young people with an engineering experience, can contribute to a schools performance with regard to accountability measures the emphasis on other subjects has led to a situation that in many schools the subject finds itself marginalized as reported by the Design & Technology Association (D&TA National Survey 2014–2015) This is ironic as a lobby from industry was responsible to a large extent for its inclusion in the National Curriculum against the advice of the Government's Expert Panel (Design & Technology Association, 2011) and the detail of the eventual Programme of Study was very much the result of industrial intervention. The Programme of Study originally proposed by the then Parliamentary Under Secretary Of State at the Department for Education, Elizabeth Truss, was greeted with derision and seen as a hotchpotch of miscellaneous and unconnected content that lacked disciplinary coherence. Dick Olver, chairman of BAE Systems, one of the UKs biggest companies, was particularly critical. Olver, who is also chair of E4E, an organisation of 36 engineering institutions, said the draft proposals for design and technology did "not meet the needs of a technologically literate society. Instead of introducing children to new design techniques, such as biomimicry (how we can emulate nature to solve human problems), we now have a focus on cookery. Instead of developing skills in computer-aided design, we have the introduction of horticulture. Instead of electronics and control, we have an emphasis on basic mechanical maintenance tasks," he told a conference of educators in March 2013. As part of this criticism E4E developed the document New Principles for Design & Technology in the National Curriculum (Morgan, Barlex, & Jones, 2013) and this was presented to the Minister. The response to this criticism was the involvement of the Royal Academy of Engineering and the wider design & technology community in developing a revised Programme of Study to which the Minister agreed. The intervention of the engineering community had ensured that design & technology was a subject that could provide an 'engineering experience' for pupils up to the age of 14 years but the accountability measures introduced by the government have made it difficult for many young people aged 14–16 years to continue with the subject and gain a qualification.

Engineering in the Scottish 'Curriculum for Excellence' 2013

In Scotland Learning and Teaching Scotland (LTS) has developed and promoted an approach to pre-university engineering education in which the school subject technology is included and makes strong links with both mathematics and science. Some of the STEM resources for the new 'curriculum for excellence' involve strong links with and support from industry. One example is that of an interdisciplinary unit of work aimed at providing an 'engineering experience' concerned with renewable energy (LTS, 2013). This required the support and involvement of Whitlee Windfarm (at the time Europe's largest wind farm) and The European Marine Energy Centre (which develops marine based renewable energy technologies by harnessing wave power and tidal streams). The resources developed included short videos of interviews with young professional engineers working in these industries.

Latest Development

The current conservative government, in office since 2015, has emphasized the importance of a broad academic education and there is clearly support for science and mathematics in that they feature strongly in the school accountability measures (DfEa, 2015). Many in the engineering community feared for the future of practical subjects in the school curriculum. However at the time of writing the Department for Education has just completed a consultation on the content of a GCSE (16+) qualification in both design & technology and engineering. Content relating to the design process has been reduced following concerns raised by stakeholders that it provided too much overlap with design and technology GCSE. The emphasis is now on the technical requirements needed to produce detailed engineering drawings or schematics, and to produce a functioning product. Students are still required to carry out a design and make project, but the emphasis is now clearly on responding to a given brief, both to ensure less overlap with other subjects and to reflect real – world engineering practice (DfEb, 2015). Young people will be able to take this qualification from 2017.

This first part of the chapter has given a brief account of how industry has become increasingly involved in pre-university engineering in the past 15 years. The next part of the chapter will describe several current initiatives exemplifying this involvement.

CURRENT INITIATIVES

The current initiatives that involve industry in pre-university engineering education will be categorised under the following broad headings and present brief descriptions of the activities as listed:

Enhancement and enrichment activities

- The Bloodhound Project
- *The Land Rover 4×4 in Schools Technology Challenge*
- The Big Bang Programme

Support for providing an engineering experience in the school curriculum,

- Primary Engineer
- CREST Award Scheme
- Connecting STEM Teachers project
- The Design & Technology Association Skills Gap Programme
- Developing a new design & technology 14–16 qualification

Providing role models

- STEMNET's STEM Ambassador Scheme

Providing clarity with regard to the nature of the engineering experience

- Thinking like an Engineer
- Big Ideas in Engineering Education Workshop

Note that these categories are not mutually exclusive.

Enhancement and Enrichment Activities

The bloodhound project. The Bloodhound Project is an ambitious global engineering project using a 1000 mph World Land Speed Record attempt to inspire the next generation about science, technology, engineering and mathematics. The Mission statement and objectives shown in Box 3 indicate a clear intention to attract young people into STEM careers including engineering. The Project began in 2008 and the record attempt is expected to take place in 2016 in South Africa.

Box 3. Bloodhound Project Mission Statement

Create a unique, high-technology project, focused around a 1000 mph World Land Speed Record attempt. Share this Engineering Adventure with a global audience and inspire the next generation by bringing science, technology, engineering and mathematics to life in the most exciting way possible.

Bloodhound Project Objectives

1. Inspire the next generation about science, technology, engineering and mathematics.
2. Share an iconic research and development programme with a global audience.
3. Set a new World Land Speed Record of 1000 mph.

Such an endeavour requires considerable financial and intellectual resources and the Project has attracted a wide range of industrial and academic sponsors including the main sponsors providing significant finance (Rolls-Royce, Castrol, Jaguar), the founder sponsors supporting the necessary cutting edge research (Swansea University, Engineering and Physical Sciences Research Council, Serco Group, University of the West of England and STP), the stripe sponsors providing finance (Rainham Industrial Services, Institution of Mechanical Engineers, Swagelok) and over 200 Product Sponsors which help run the programme and build the car by supplying goods and services. The Project is supported by an extensive website (http://www.bloodhoundssc.com/) embracing Facts about the project, resources for schools, families and groups, careers information, competitions and links to the STEM ambassador programme (see below) through which young STEM professionals visit schools. The resources for schools provide Bloodhound related learning activities for science, mathematics, computer science and design & technology. The infographic posted on the Project website sites 6000 UK schools using Bloodhound resources with 2 million children enjoying Bloodhound activities. This is endorsed to some extent by the latest available evaluation of the Project carried out by NfER in 2012 (Straw and Dawson 2012). The report acknowledged some impressive achievements in that the team had been very effective at engaging with, and inspiring, a large number of young people in schools and colleges and tackling gender stereotypes but noted the need for increasing the range of online resources to encourage schools' sustained involvement in Bloodhound.

The land rover 4x4 in schools technology challenge. The Land Rover 4x4 in Schools Technology Challenge is to build a radio controlled four-wheel drive (4x4) vehicle to the specifications provided that will successfully navigate and complete obstacles on an off road test track that is just as demanding as the real thing, and emulates the capabilities of a full size 4x4 vehicle. Information about the challenge can be found at this website http://www.4x4inschools.co.uk/index.phtml?d=397817

The organisers maintain that the challenge is an excellent opportunity for young people to work in teams and gain an awareness and understanding of project management using key skills. The challenge is open to pupils aged 11–19 in schools and other young people of that age in any out of school initiative. It operates in 12 different countries including the UK with regional finals taking place to decide which teams will compete in the national championships. Each nations champion team then compete in the world final. It is sponsored and associated with Land Rover, the IET, WNT (UK) Ltd., Denford, Young Engineers, SEMTA, The Design & Technology Association, FrogTrade Ltd, IROB (UK) Ltd., with educational partners Cranfield University and Harper Adams University. To enter schools have to buy a starter kit for each team. The kit consists of a basic r/c vehicle, battery pack, battery charger and 2.4MHz transmitter and receiver at a cost of £225.00 plus VAT. There is a registration fee of £75.00 and each team can spend up to a further £175. The activities required by the challenge have been aligned to UK school qualifications in design & technology and engineering. The organisers see young people developing a wide range of technical knowledge and skills plus the personal qualities needed for successful collaboration through the Challenge. The numbers of schools participating is not large but is growing. Since 2010 148 schools have taken part in the Challenge with 60 taking part in the 2014/15 season. Since 2010 131 students have attended the UK finals with 75 competing in the world final.

The Big Bang programme. According to the organisers the Big Bang programme (see http://www.thebigbangfair.co.uk/) exists to show young people the range and number of exciting and rewarding opportunities available to them with the right experience and qualifications. The programme is made up of a national event, The Big Bang UK Young Scientists and Engineers Fair, and related regional events The Big Bang Near Me and the new Big Bang @ School. The Fair plays host to the finals of the National Science & Engineering Competition. It is led by EngineeringUK and delivered in partnership with over 200 organisations, with the shared aim of inspiring the next generation of scientists and engineers. 75,000 people attended the The Fair in 2014. The Big Bang Near Me and the new Big Bang @ School events take place across the UK, providing young people with the opportunity to experience, close to home, the sorts of activities available at the Big Bang Fair. In 2014 over 82,000 young people took part in a Near Me Fair or an @ School event. It is expected that 80,000 people will attend The Big bang Fair in 2016 and the ambition for 2020 is that 100,000 children and young people each year will experience The Big Bang Fair for themselves. The ultimate goal is that every child in the UK should know someone involved with it. Visits to the Fair involve a single day out of school and can be seen as a 'school trip'. EducationUK reports on its website (http://www.engineeringuk.com/research/) that feedback from The Big Bang Fair 2014 showed that over half the key age-group of 11–14 year-olds agreed they learned a lot by visiting The Fair and were significantly more likely to regard careers in science and engineering as appealing. The increased appeal of science and engineering jobs was especially evident among girls. For girls aged 14–16, the desirability of engineering rose from 19 % pre-event to 37% as a result of their visit.

Support for Providing an Engineering Experience in the School Curriculum

Primary engineer. Primary Engineer (see www.primaryengineer.com) is a not-for-profit organisation established in 2005 aiming to encourage young people to consider careers in STEM related professions especially engineering. The work is supported by the Institution of Mechanical Engineers various industrial sponsors including Roll-Royce, Siemens, Ford and Nissan and higher education including the University of Strathclyde and Sussex University. The organisation offers three main services: courses, challenges and the Leaders award for STEM. Primary Engineer courses which focus on the application of practical Mathematics and Science. The courses are delivered to Primary teachers who may be looking for fresh and exciting ways to support the delivery of Design and Technology projects, and Secondary teachers who can cascade the training to primary colleagues as part of their primary liaison programme. Primary Engineer Challenges in which students can compete against one another with what they have designed and made in the classroom. These operate throughout the year and are a natural follow up for the teachers who have received Primary Engineer CPD. The Leaders Award for STEM is open to all pupils aged between 5 and 19, and is expected to increase young people's awareness of the breadth of opportunities open to them within the STEM subjects. It also aims to develop vital literacy and communication skills and give the students a chance to speak directly with professionals from different fields in STEM. The uptake of the services is impressive and underpinned by the availability of teacher in service. The organisation reports (Scurlock 2015) that during the academic year 2014/2015 over 1000 teachers attending the training courses with their work then reaching over 70,000 pupils. Data collected from schools who have been involved in Primary Engineer for some time indicates that 90% of schools are still using project materials three years after their initial training.

CREST award scheme. The CREST Awards scheme (British Science Association 2015) requires young people at school to undertake projects of their own choice in the STEM subjects and, depending on the demand of the project, pupils can achieve bronze, silver or gold awards. Bronze Awards are typically completed by 11–14 year olds; around 10 hours of project work is expected. Students experience the project process: improving their enquiry, problem solving and communication skills. Silver Awards are typically completed by 14–16 year olds; around 30 hours of project work is expected. CREST Silver Awards can be achieved through coursework (e.g., GCSE design & technology which, depending on the nature of the course work may provide an engineering experience) and projects in work related learning. Gold Awards are typically completed by 16–19 year olds and allow these students to conduct some authentic research and development; these longer-term projects require around 70 hours work. Again such projects may, if the young person wishes, provide an engineering experience. Importantly UCAS (the organisation responsible for managing applications to higher education courses in the UK) have endorsed CREST Awards for inclusion in young people's personal statements in their application for admission into University. The CREST Award scheme places a high priority on student choice of project topic but also on progression so that young people's enthusiasm can be captured whilst they are young and then maintained by increasing the challenge but without a decrease in ownership of the projects. A key feature here is that course work completed for the school subject design & technology can be submitted for an award without any extra work being undertaken by the young person. Each year, according to the organisers, over 32,000 CREST Awards are undertaken by 11-to-19-year-olds so the number of young people taking the award is significant.

Connecting STEM teachers project. This is one of a series of school focused engineering education programmes currently being undertaken by the Royal Academy of Engineering. The Connecting STEM Teachers project (see http://www.raeng.org.uk/education/schools/education-programmes-list/connecting-stem-teachers#London) which was founded by BG Group and has subsequently been additionally supported by Petrofac, aims to provide local support for the teachers of STEM subject so they can develop the knowledge and confidence to:

- illustrate the role of engineering in society to young people
- explain how engineers shape the world and improve our lives
- highlight how STEM learning at school is applied in the real world
- enrich the STEM curriculum
- engage a greater number and wider spectrum of students in STEM.

Central to this project is a national network of Teacher Coordinators, engaged as consultants by the Royal Academy of Engineering, who provide STEM teachers in their local schools with free training, ideas and resources to help them enhance STEM learning. The programme aims to help teachers engage a greater number and a wider spectrum of students with STEM by providing them with ideas for great STEM learning through free termly training that is led by Teacher Coordinators. Hence one can see this project as having the professional development of teachers at its heart; a much more complex activity compared with that of providing role models. Since September 2011, 470 STEM teachers in over 400 schools have received support and free resources through the project, and nearly 50,000 pupils are estimated to have benefited from this support. In July 2015 the RAEng hosted a celebration event for the Connecting STEM Teachers project. The presentations from teachers and pupils showed examples of quite outstanding work in which the combined contributions from science, mathematics and design & technology were plain to see. However, nearly all these examples were from extracurricular activities from outside the mainstream curriculum and as such did not involve large numbers of pupils.

The design & technology association skills gap programme. This is a relatively new initiative (Design & Technology Association, 2013). The Programme is delivered over a five month period and includes the following activity between one secondary school and one business per programme:

1. Skills check for a D&T department
2. Bespoke training, coaching & industry insights for teachers
3. Skills Project – Led by teachers for young people
4. Teachers and employers co-deliver the project
5. Final assessment for teachers and young people

After training and coaching, teachers are supported by the programme to implement their new skills during curriculum time with their own students. Employee volunteers from the participating businesses support teachers to develop an industry linked project for students to undertake which utilises the new skills & knowledge developed. Employee volunteers co-deliver technical aspects to help build confidence among teachers and students alike whilst also providing an industry perspective. Four programmes are featured on the Skills Gap website:

- ACE Academy and Alucast, West Midlands
- Marling School and Renishaw, Gloucestershire
- The adi Group and Handsworth Wood Girls Academy, Birmingham
- Airbus and Ysgol Clywedog, Wales

The endorsements from senior figures in the participating companies reveal that they see the benefits of the Programme as three fold: providing professional development for D&T teachers and hence enhancing the curriculum, engaging local young people with technical careers with the possibility of employing them, and developing important 'soft' skills for their own employees.

Developing a new design & technology 14–16 qualification. As part of the current and previous administration attempts to overhaul the examinations system the GCSE in design & technology has been radically reformulated. To overcome the fragmented nature of pupil experience and address the lack of overall coherence the subject has been reconfigured as a single subject as oppose to the six different but related subjects that existed previously. Significantly there is much more technical content that is related to engineering than in the previous qualifications and there is a much more open approach to the project work that will be submitted as course work assessment. Both these features are to some extent the result of industrial influence. The DfE identified a number of expert stakeholders to help in this process including the Royal Academy of Engineering and the James Dyson Foundation. Representatives from both these organisations made significant input into both the technical content and the nature of the project work. The recommendations made by the expert stakeholder group have now been assembled into document for consultation and although there may be minor modifications the overall nature of the proposed qualification is unlikely to change (DfEb, 2015, Ofqual, 2015). The significant difference between this and the precursor design & technology GCSE qualifications makes this a high risk venture for the subject and one that can be seen as contrived by industrial influence from the engineering sector.

Providing Role Models

STEMNET's STEM ambassador scheme. STEMNET (http://www.stemnet.org.uk/about-us/) is an independent charity, which receives funding from the:

- UK Government Department for Business, Innovation, and Skills (BIS)
- UK Government Department for Education (DfE)
- The Scottish Government
- The Gatsby Charitable Foundation

It has three core activities: supporting afterschool STEM Clubs, offering advice to schools concerning the STEM curriculum and managing the STEM Ambassadors scheme. In the belief that providing role models will encourage and enable more young people to opt for a STEM career STEMNET manages the activities of some 27,000 volunteers who visit schools with the express intention of acting as role models. The STEMNET website (http://www.stemnet.org.uk/ambassadors/) highlights this as follows. STEM ambassadors are people who are working or have worked in STEM related industries and visit schools with the aim of inspiring young people to enjoy STEM subjects and consider pursuing a STEM career. They support teachers in the classroom by explaining current applications of STEM industry and research. STEM Ambassadors get involved in a huge range of activities. According to the website STEM Ambassadors demographics are

- from 18 to 70 years of age
- 60% are under 35 years of age
- 40% are women and around
- 13% describe themselves as from BAME (Black & Minority Ethnic) backgrounds

A summary of the evaluation of STEMNET's operations 2011 to 2015 carried out by NfER (http://www.stemnet.org.uk/wp-content/uploads/Evaluation-of-STEMNET_summary-of-report.pdf) paints a positive picture of impact on pupils who have engaged with STEM ambassadors with the ambassadors valuing the experience. It is worth noting that several of the initiatives discussed here make use of the STEM Ambassador scheme e.g. The Bloodhound Project, The Land Rover 4x4 Challenge, and CREST.

Providing Clarity with Regard to the Engineering Experience

Thinking like an engineer. The report (Lucas, Hanson, & Claxton, 2014) was commissioned by the Royal Academy of Engineering Standing Committee for Education and Training and published in 2014. The authors were Professor Bill Lucas, Dr Janet Hanson, Professor Guy Claxton from the Centre for Real- World Learning at the University of Winchester. The research underpinning the report took the idea of habits of mind and explored with a wide range of practicing engineers the ways in which they worked in order to identify those habits of mind associated with engineering activity. The report identifies six engineering habits of mind (EHoM) which, taken together, describe the ways engineers think and act:

Systems thinking
Adapting
Problem-finding
Creative problem solving
Visualising
Improving

The report presents these habits of mind in relationship to learning habits of mind as shown in Figure 1. This is a significant piece of research using the industrial practice of engineering to identify aspects of that practice that might be taught to young people at school. The report makes three broad recommendations:

1. The Royal Academy of Engineering to disseminate its findings to ensure wide engagement in the conversation about how engineering is taught.
2. The engineering teaching and learning community to seize the opportunity of the National Curriculum and the report's new thinking to bring about a mind- set shift in schools and redesign engineering education, especially at Primary level.
3. For employers, politicians and others to engage in a dialogue with schools and colleges about the EHoM they think are most important, suggesting practical ways in which they can help.

The extent to which the report influences practice in schools has still to play out but already it has informed the Big Ideas In Engineering Workshop that took place in June 2015.

Big ideas in engineering education workshop. In June 2015 the Institution of Mechanical Engineers and Royal Academy of Engineering organised a Big Ideas in Engineering Education workshop. The organisers argued that this was in response to the situation that despite decades of effort by a multitude of bodies, the UK is still not producing enough engineers to meet projected industry needs, and some groups – such as women – remain alarmingly under-represented in the UK engineering workforce. Rather than 'more of the same', they wanted the Big Ideas workshop to explore whether radical approaches to address these challenges could be developed.

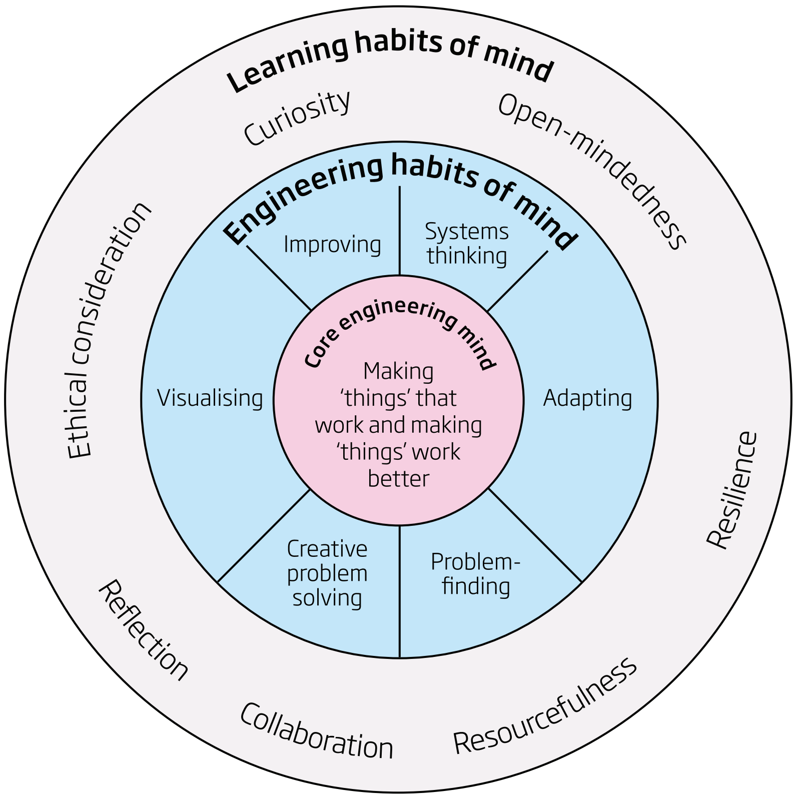

Figure 1. Engineering habits of Mind (EHoM) presented diagrammatically

The event aimed to provide a forum for innovative thinking and discussion on what can be done to improve the experience and perceptions of engineering in our schools and beyond. A total of 39 people attended the workshop and included academics, members of engineering professional bodies, representatives of engineering and technology industries and educationalists.

To provoke discussion six educationalists and creative thinkers were asked to write a 'think paper' and make a presentation based on this summarising some of their radical thoughts about what could be done to enhance the numbers and quality of young people studying and training in engineering and related subjects beyond the age of 18.

- Professor Bill Lucas, Director of the Centre for Real-World Learning and Professor of Learning at the University of Winchester gave a presentation entitled "Inculcating engineering habits of mind" which asked the question "Can innovative teaching methods such as problem-based learning help to develop the

‘thinking skills’ characteristic of engineers – and encourage more young people to consider engineering careers?”
- Professor Louise Archer, Professor of Sociology of Education at King’s College London gave a presentation entitled “Stop this crazy specialisation” which asked the question “Would a more balanced education, encompassing both science and arts/humanities subjects, benefit future engineers and increase the numbers of under-represented groups (including girls) studying engineering?”
- Professor Mark Miodownik, Professor of Materials and Society at UCL gave a presentation entitled “Making space for making things” which asked the question “Should schools devote more time – and physical space – to the making of things and the practical application of learned knowledge?”
- Professor Peter Goodhew, Emeritus Professor of Engineering at the University of Liverpool gave a presentation entitled “Speaking up for engineering” which asked the question “Is a lack of understanding of engineering – and particularly its social value – hindering attempts to attract young people into engineering professions?”
- Dr Ioannis Miaoulis, president and director of the Museum of Science, Boston, USA, and formerly Dean of the School of Engineering, Tufts University gave presentation entitled “Mainstreaming engineering” which asked the question “School education overwhelmingly favours teaching of the natural world over the manufactured – is it time to correct this anomaly and integrate engineering into the curriculum in primary and secondary education?”
- Clive Grinyer, currently Customer Experience Director at Barclays gave a presentation entitled “Time for some creative thinking” which asked the question “Does engineering need to embrace creativity and design more enthusiastically, both to widen its appeal to young people and to make its products more user-oriented?”

As a follow up to the workshop the organisers posted a questionnaire for those who attended in the context of bringing about change in education that will both develop wider technological literacy while increasing numbers, quality and diversity of young people studying engineering post-18. The questionnaire consisted of 10 statements concerning possible change and respondents had to give a score to each statement according to its desirability and feasibility from 1–10. A score of 10 indicated high desirability or feasibility and a score of 1 indicated low desirability or feasibility. The statements were as follows:

- Broaden routes into engineering degree courses by having more flexible entry requirements
- Promote engineering as a people-focused, problem-solving, socially beneficial discipline
- Ensure that apprenticeships and other technical pathways not only deliver high-quality technicians but also enable individuals to progress to the highest levels of engineering

- Work to enhance the presence of engineering and the 'made world' at all stages from primary level upwards
- Maintain a broad curriculum for all young people up to the age of 18
- Change the structure of school education to embed engineering explicitly at all levels
- Use Design & Technology as a platform for integrating STEM and creative design and for raising the profile of engineering in schools
- Shift the emphasis in STEM teaching towards problem-based, contextualised learning and the development of engineering thinking skills
- Create more spaces and opportunities for young people to make things by working collaboratively in interdisciplinary groups
- Nurture engineering ways of thinking in all young people to enhance general life skills

The discussions, commissioned research and think-pieces will feed into a report to be published in autumn 2015. This will be a significant document by which the industries associated with the Royal Academy of Engineering and the Institute of Mechanical Engineers and those consulted at the Big Ideas in Engineering Education Workshop will attempt to further their influence on pre- university engineering education.

Having exemplified the four categories of current initiatives in this second part of the chapter the third and final part will provide a commentary on each of the categories from the perspectives of perspectives of intention and effectiveness.

DISCUSSION

The Royal Academy of Engineering (Harrison, 2012) hosted a series of workshops on the theme of evaluating STEM initiatives. The overall purpose of the programme of workshops was to promote quality debate and discussion on current and future evaluation practice amongst the STEM community. Each session attracted around 30 people with many being able to join all three session. Each workshop benefited from pre-prepared inputs from a number of people and then semi-structured discussion and feedback to the wider meeting.

The key finding from this series of workshops as far as this chapter is concerned was: As a community, take steps to gather evidence on what works and why as widely as possible. Publish this online, hosted by a trusted STEM organisation, with contact details for those supplying the source material.

For the author this needs to be unpacked in terms of a) the intention of any intervention – what was it meant to achieve – and b) if there is evidence that it did or did not achieve its intentions then c) particular attention should be paid to interpreting why or why not this was the case. So this final part of the chapter will discuss the intention of the four categories of initiatives identified, the extent to which they are or are not successful and a speculation on why this might be the case.

Considering Enhancement and Enrichment Activities

The Bloodhound Project and the Land Rover 4x4 in Schools Technology Challenge are typical of many enhancement and enrichment activities in that their intention is to engage young people more fully with pre-university engineering education and, as a result, encourage more of them than would otherwise be the case to consider and ultimately choose engineering or a STEM based occupation. And, also typically, the numbers of young people they reach are small compared to the entire cohort. There is little doubt as to the enthusiasm and enjoyment of those involved, both teachers and pupils. However one must ask to what extent are these activities "preaching to the already converted?" And even if this is not the case then the numbers of young people influenced will be small. The Big Bang Programme differs in that it attracts very large numbers of young people with the intention of 'touching' the entire cohort by 2020. A significant difference between the Big Bang and the much smaller scale enhancement and enrichment activities is that the engagement with the smaller activities often involves multiple contacts over a significant time period. So one must ask if a "day out" at the Big Bang Fair will really have much in the way of impact on the majority of young people attending. A more generous interpretation would be that a young person might visit the Fair every year for his/her entire secondary schooling and that there is the possibility of a cumulative effect taking place.

One cause for concern regarding mathematics enhancement and enrichment activities raised by Wai Yi Feng (2012) was that there can sometimes be confusions as to the purpose of an activity and that stakeholders do not always agree on the purposes of a particular activity. This does not appear to be the case in the enhancement and enrichment activities described here but it is something that needs to be born in mind when developing further such activities.

Considering Support for Providing an Engineering Experience in the School Curriculum

It is generally acknowledged by those that support the provision of an engineering experience in the schools curriculum that lessons in design & technology can be framed to achieve this. The CREST Award Scheme is very economical in its approach here in that the work carried out by pupils in their design & technology lessons can be submitted for an award thus requiring little further effort on the part of the teacher or the pupil. However others trying to increase the availability of the engineering experience see the teacher as the gatekeeper and go to some lengths to enhance both the subject knowledge and pedagogic knowledge of the teachers involved. It is noteworthy that the Primary Engineer, the Connecting STEM Teachers project and the The Design & Technology Association Skills Gap Programme work explicitly towards enhancing both these dimension of professional development. However the provision of effective professional development is no easy matter. Developing Great Teaching Lessons from the international reviews into effective professional development (Teacher Development Trust, 2015) has highlighted the following features (appropriate duration, rhythm, designing for participants needs, creating a shared sense of purpose and alignment across various activities) that make it more likely it will have a lasting impact on teacher practice and student outcomes. All these initiatives go some way to accommodating these features, especially Connecting STEM Teachers in which local area coordinators work towards developing communities of practice which have the opportunity to devise their own professional development in ways which can embrace those features that research has shown are effective.

The development of a new design & technology qualification which is significantly different from previous qualification can be viewed as a high risk strategy. Opinions are divided as to its likely success (Green, 2015). A small minority of teachers see it as providing a superior educational experience for young people, enhancing the status of the subject considerably and enabling it to become a 'gatekeeper' subject. Another small minority see it as needing too much change too quickly and requiring a teaching force that does not exist and hence leading to the demise of the subject. The majority of teachers are reluctant to commit to a position at the time of writing preferring to wait until they see the detail of the qualification specifications which will become available in September 2016 before deciding. Given the extent of the change in practice that will be required the need for quality professional development is both obvious and paramount.

Considering the Provision Role Models

There has been the general assumption that the provision STEM ambassadors, with similar gender and ethnicity to the young people they talk with will lead to those young people seeing them as role models to emulate. This may not necessarily by the case. Clare Gartland has looked at the way ambassadors from higher education interact with school students (Gartland, 2014). Her work questions this prevailing wisdom. School students can sometimes be suspicious of the 'marketing approach' and can feel alienated because they are seen as lacking appropriate ambition. Gartland's work shows that a much more nuanced approach is required with ambassadors working more closely with teachers in subject-specific contexts as opposed to simply providing 'look what I've done – you can do it too' sessions. This has implication for the amount of time such ambassadors and teachers need to give if they are not to fall into this trap. Data that just records the number of visits made and young people 'interacted with' do not provide the necessary insight into whether the activity has been successful. The Aspires Project (Archer et al., 2012) provides a further cautionary tale. This extensive longitudinal study revealed that the emerging identity of the children influenced their aspirations with regard to science careers. The majority of the children enjoyed science lessons at school, agreed that they learned interesting things in science and had enthusiastic teachers who expected them to do well yet those that aspired to be scientists were in a small minority. Louise and her colleagues argue that the family environment, popular perception of science and gender shape science aspirations. Of particular interest is the family environment and their findings that science capital and 'family habitus' are very important (ibid). Science capital refers to the extent to which there are science-related qualifications within the family, interest in science and contacts with the science community. Habitus is related to this but extends further embracing family values, practices and a sense of 'who we are' and 'what we do'. For some children becoming a scientist is actually unthinkable, going against all that is likely to be expected of them. So a challenge for those attempting to influence pre-university engineering education is to make science, and science-related careers such as engineering a 'thinkable' option.

Considering Providing Clarity with Regard to the Nature of the Engineering Experience

A key recommendation from the report *Thinking like an Engineer* (Lucas, Hanson, & Claxton, 2014) is "to seize the opportunity of the National Curriculum and the report's new thinking to bring about a mind- set shift in schools and redesign engineering education, especially at Primary level" (p. 3). It has to be noted that engineering education as such does not exist in the National Curriculum and that the closest proxy is widely regarded as design & technology. It is not difficult to align both National Curriculum Programme of Study for design & technology and the proposed new design & technology qualification with this recommendation. Both the National Curriculum Programme of Study and the new qualification include the act of designing as a major feature. One can envisage the act of designing as being a combination of the features of the engineering habits of mind. This significance mirrors that given to designing by Ropohl (1997) in his description of engineering.

> [The development and design of] a novel technical system, anticipat[ing] the object to be realised through mental imagination. [The designer] has to conceive of a concrete object which does not yet exist, and he [*sic*] has to determine spatial and temporal details which cannot yet be observed, but will have to be created by the designing and manufacturing process. (p. 69)

The *Thinking like an Engineer* report acknowledges the significance of design & technology as an "excellent vehicle for introducing engineering to large numbers of children through the curriculum" (p.36). But the rhetoric for design & technology is not necessarily mirrored by the reality of practice. It is noteworthy that design & technology in primary schools is deemed as more successful than in secondary schools. The report *Meeting Technological Challenges? Design and Technology in schools 2007–2010* (Ofsted, 2011) notes:

> Good teaching, observed in more than two thirds of the primary schools (89 were visited), was characterised by careful planning and challenging practical tasks. (p. 4)

> And
>
> Pupils' work in D&T from their primary schools was rarely built upon by the secondary schools in the sample. Teachers planned the curriculum without reference to what had gone before. This lack of continuity led, in the less effective schools, to weak curriculum planning at Key Stage 3 (pupil age 11–14 years). Pupils said they found projects and units of work in D&T easy and the nature of the work was pitched too low or duplicated earlier learning of the type commonly seen in primary schools. This did not challenge pupils sufficiently, particularly the most able. (p. 5)

The recent presentation given by Diane Choulerton, National Lead HMI for Design & Technology, at the Design & Technology Association National Conference in 2015 reiterated this. Diane also noted the declining numbers taking design & technology as an examination at 16 years "In 2014 201,252 students were entered for a D&T GSCE. That is 35.46% of the total cohort, but a reduction of 16.10% since 2008 when it was 52.14%" (slide 11). Although declining these numbers are at least two orders of magnitude greater than the numbers of young people taking 'named' engineering qualifications. So the potential for providing an engineering experience for young people aged 14–16 years is significant but only if the subject significantly improves the current offering for pupils aged 11–14 years and rises to the challenge of the proposed new 16+ years qualification. It will be interesting to see the extent to which the recommendation from the Big Ideas in Engineering Workshop to use design & technology as "a platform for integrating STEM and creative design and for raising the profile of engineering in schools" is developed in the final report. There is the opportunity to harness the energy and financial resources of industry to support the necessary professional development and curriculum innovation to enable design & technology teachers to embed engineering habits of mind into their teaching. But this is unlikely to happen unless there is a very strong steer from the Royal Academy of Engineering and the Institute of Mechanical Engineers – the institutions responsible for the final report.

SUMMARY

The first part of this chapter gave an account of how industry has become increasingly involved in pre-university engineering education in the UK over the past 15 years. The second part described a range of current activities that exemplify this involvement under the following categories: Enhancement and enrichment activities, Support for providing an engineering experience in the school curriculum, Providing role models and Providing clarity with regard to the engineering experience. The third part provided a commentary on these types activities from the perspectives of intention and effectiveness with some speculation as to reasons for their success or otherwise. It is clear that various facets of industry have tried to influence pre-university education particularly with the aim of increasing engineering and other

STEM careers uptake. The extent to which this has been successful so far is debatable and the most recent initiatives have still to prove themselves.

REFERENCES

Archer, L., DeWitt, J., Osborne, J., Dillon, J., Willis, B., & Wong, B. (2012). Science aspirations and family habitus: How families shape children's engagement and identification with science. *American Educational Research Journal, 49*(5), 881–908.

ASPIRE. (n.d.). Retrieved from http://www.kcl.ac.uk/sspp/departments/education/research/aspires/ASPIRES publications.aspx

Barlex, D. (2005). *Becoming an engineering college.* London: Specialist Schools Trust.

British Science Association. (2015). Information about the CREST Awards scheme can be found at http://www.britishscienceassociation.org/crest Accessed 8 July 2105

Choulerton, D. (2015). *The current state of design and technology, What we know, What the data is telling us and the threats, challenges and opportunities ahead.* The slides for this presentation are available at http://www.slideshare.net/Ofstednews/design-and-technology-association-data-summer-school-keynote-2015 Accessed 19 July 2015

Design & Technology Association. (2011). *We believe in design & technology campaign manifesto*. Wellesbourne: Design & Technology Association. Retrieved July 8, 2015, from http://blogs.osc-ib.com/wp-content/uploads/2011/02/DT-Manifesto.pdf

Design & Technology Association. (2103). *Skills gap programme*. Retrieved July 8, 2015, from https://www.data.org.uk/for-partners/skills-gap-programme/

Design & Technology Association (2015) *National survey 2014 – 2015* Survey instrument available at https://www.surveymonkey.com/r/?sm=z8iSheaOgdTeW4uY%2bCYrGA%3d%3d Accessed 8 July 2105

DfEa. (2015). Information about the English Baccalaureate as an accountability measure is available at https://www.gov.uk/government/publications/english-baccalaureate-ebacc Accessed 8 July 2105

DfEb. (2015). *Consultation of GCSE design & technology*. Retrieved July 8, 2015, from https://www.gov.uk/government/consultations/gcse-reform-design-and-technology

DFES & DTI. (2006). *The Science, Technology, Engineering and Mathematics (STEM) programme report*. London: DFES.

Feng W. Y. (2012). *The development of a framework for understanding mathematics enrichment: A case study of initiatives in the UK*. Paper presented at BERA 2012, University of Manchester. Retrieved from http://www.bera.ac.uk/bera2012/pdf/BERA2012_0695.pdf

Gartland, C. (2014). *STEM ambassadors and social justice in HE*. London: Trentham Books.

Green, R. (2105). Private communication to the author concerning the views of teachers attending the Design & Technology Association National Conference.

Harrison, M. (2012). *Evaluating STEM support programmes: gauging a return on investment.*

Harrison, M. (2104). In F. Banks & D. Barlex (Eds.), *Teaching STEM in the secondary school*. London: Routledge

LTS. (2013). *STEM central, learning and teaching Scotland*. Retrieved July 8, 2015, from http://www.ltscotland.org.uk/stemcentral/contexts/index.asp

Lucas,B., Hanson, J., & Claxton, G. (2014). *Thinking like an engineer Implications for the education system.* London: Royal Academy of Engineering.

Malpas. R. (2000). *The universe of engineering - A UK perspective*. London: The Royal Academy of Engineering.

Morgan, R., Barlex, D., & Jones, L (2013) *New principles for design & technology in the national curriculum.* London: E4E.

National Science Learning Centre. (2008). *The STEM framework.* New York, NY: National Science Learning Centre.

OCR. (2015). Details of engineering related subject qualifications can be found at http://www.ocr.org.uk/qualifications/by-type/cambridge-nationals/ Accessed 8 July 2105

OfQual. (2015). *Consultation of GCSE design & technology*. Retrieved July 8, 2015, https://www.gov.uk/government/consultations/gcse-reform-regulations-for-design-and-technology

Ofsted. (2011). *Meeting technological challenges? Design and technology in schools 2007 – 2010.* London: HMSO.

Roberts, G. (2002). *SET for success The supply of people with science, technology, engineering and mathematics skills*. London: HMSO. Retrieved July 8, 2015, from http://www.hm-treasury.gov.uk/ent_res_roberts.htm

Ropohl, G (1997). Knowledge types in technology. *International Journal of technology and Design Education*, *7*, 65–72.

Royal Academy of Engineering. (2011). *Strategic plan for 2011 to 2015.* London: Royal Academy of Engineering.

Sainsbury. (2007). *The race to the top: A review of government's science and innovation policies*. London: HMSO. Retrieved July 8, 2015, from http://www.hm-treasury.gov.uk/sainsbury_index.htm

Scurlock, S. (2015). Private communication with the author.

Straw, S., & Dawson, A. (2012). *A follow-up audit of activities for the bloodhound education programme.* Slough: NFER.

Teacher Development Trust. (2015). *Developing great teaching lessons from the international reviews into effective professional development*. London: Teacher Development Trust

University Technical Colleges. (n.d). Information at http://www.utcolleges.org/Accessed 8 July 2105

Wolf, A. (2011). *Report review of vocational education.* London: HMSO. Retrieved July 8, 2015, from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/180504/DFE-00031-2011.pdf

David Barlex
Visiting Lecturer Roehampton University
Director Nuffield Design & Technology
UK

ELIZABETH PARRY, PAMELA LOTTERO-PERDUE
AND STACY KLEIN-GARDNER

12. ENGINEERING PROFESSIONAL SOCIETIES AND PRE-UNIVERSITY ENGINEERING EDUCATION

INTRODUCTION

Engineers have long formed professional and informal alliances to capitalize on synergies, address deficiencies and solve problems. The oldest engineering professional society in the United States (US), the American Society of Civil Engineers (ASCE), was formed in 1852 (ASCE, 2015a). Today, ASCE is a global society, with nearly 150,000 members in 174 countries, and stands among dozens of other engineering societies.

Each engineering professional society connects its members through common disciplines, demographics or geographic regions. The role of societies has traditionally revolved around practicing engineers in the field and issues such as licensure, professional learning, mentoring, and standards. Increasingly, engineering professional societies have begun to devote resources towards pre-university level education, encompassing students in preschool through grade 12 (P12). This interest has been driven by the need for more engineers to address increasingly complex global problems, and the related need for more diverse people and perspectives within the engineering team to solve those problems.

In what follows, we outline our approach to studying engineering professional societies. We then share how we categorized types of engineering professional societies, and examine the ways these societies have addressed pre-university engineering education. In particular, we explore how societies: focus on how their members can directly assist P12 students, teachers, and schools; and provide resources for use in P12 education. The chapter ends by considering the impacts of these efforts and by suggesting opportunities for societies to contribute to pre-university engineering education in additional, deeper, and more measureable ways.

METHOD

Our study of pre-university engineering education as it has been addressed by engineering professional societies was motivated by our collective involvement as members or past members in organisations such as the American Society for Mechanical Engineering (ASME), the Biomedical Engineering Society (BMES), the Society of Women Engineers (SWE), and the American Society for Engineering

M. J. de Vries et al. (Eds.), Pre-university Engineering Education, 205–220.

Education (ASEE). Further, we have served as leaders within the K12 & Precollege Division of ASEE. We have benefited from our participation and leadership in these engineering professional societies, and we have observed the multifaceted ways in which these and other societies have engaged in the pre-university space.

A note about abbreviations and what we mean by "pre-university space": For many years, pre-university education as it pertained to the school day was synonymous with "K12" or "K-12" education, both of which refer to kindergarten through grade 12 education. In the US, grade 12 represents the end of pre-university education. More recently, however, the term "P12" has been used to expand the range of pre-university education to include preschool (including children as young as two years of age) through grade 12. Throughout this chapter, we will refer to P12 education, broadly, but will use K12 or K-12 if these abbreviations are part of a formal title of a program or organisation.

To begin our study, we first identified and categorized a purposeful sample of engineering professional societies, which included disciplinary, demographic affinity, educational and "overarching" (i.e., inclusive of other organizations) societies (Table 1). Although not exhaustive, the societies included in our review included the largest and widely recognizable engineering societies, most of which had at least some involvement and investment in pre-university efforts. We collaboratively developed the list of key indicators of societal involvement in P12 engineering education – sometimes identified within Science, Technology, Engineering and Mathematics (STEM) education – that we would investigate. Given that in-print descriptions of engineering societies' most recent work in P12 engineering or STEM education was not readily available, we used the societies' websites as our primary information source. Websites represent the "public face" of each society that serves to communicate up-to-date information to any person interested in that society's work.

We developed an instrument using the program SurveyMonkey® to gather information regarding key indicators of societal involvement in P12 engineering education. The questionnaire employed a combination of multiple choice and open-text-box question formatting. Using the questionnaire, we collected the following information from each societal website:

- overall mission and vision of the society;
- whether the organization had a charitable foundation and if so, the extent to which and how the charitable foundation invested in P12 engineering or STEM education;
- what grade bands the society addressed through outreach or other efforts (i.e., early or and/or upper elementary, middle and/or high school);
- basic information about the type of P12 engineering or STEM education involvement the society reported;
- whether there is evidence that results, research and/or evaluation on P12 engineering or STEM education efforts are collected and/or reported.

After gathering data via the use of the instrument, we then identified commonalities and differences among the societies with regard to the extent to which the societies had a pre-university engineering presence.

A TAXONOMY OF ENGINEERING PROFESSIONAL SOCIETIES

We have identified four different categories of engineering professional societies to which we will refer throughout this chapter: disciplinary, demographic affinity, educational, and overarching. These categories, as well as examples within each, are shown in Table 1.

Disciplinary Engineering Professional Societies

The vast majority of engineering professional societies are organised by engineering discipline. Civil, mechanical, electrical and chemical engineering are long recognized specialisations and therefore have some of the oldest and largest societies. These include the aforementioned ASCE for civil engineers and ASME for mechanical engineers, IEEE (formerly the Institute of Electrical & Electronics Engineers), and the American Institute for Chemical Engineering (AiChE). Other large disciplinary societies include the American Institute of Aeronautics & Astronautics (AIAA) and the Society of Automotive Engineers (SAE). As technology and engineering have grown, so has the number of disciplines – and therefore societies – to address the

Table 1. Engineering professional societies: Categories & examples

	Categories			
	Disciplinary	*Demographic affinity*	*Engineering education*	*Overarching*
Examples	American Society of Civil Engineers American Society of Mechanical Engineers IEEE American Institute for Chemical Engineers American Institute of Aeronautics & Astronautics Society of Automotive Engineers	National Society of Black Engineers Society of Hispanic Professional Engineers Society of Women Engineers	American Society for Engineering Education (P12 – college) International Technology & Engineering Education Association (P12)	World Federation of Engineering Organisations American Association of Engineering Societies

specific interests and needs of these professionals. These newer disciplines reflect both refinement of the broader groups engineering has traditionally identified and recognition of newer fields and specialities in the profession (e.g., BMES).

Demographic Affinity Engineering Professional Societies

Professional engineering societies have also been formed around affinities in ethnicity, gender or culture. These organisations are multidisciplinary and not exclusive to the particular subgroup, although they tend to draw the majority of members from those populations. We examine three of the largest of these affinity groups: the National Society of Black Engineers (NSBE), the Society of Hispanic Professional Engineers (SHPE) and SWE, mentioned earlier.

Affinity professional societies typically organise to educate the engineering profession at large regarding inclusive and equitable practices and policies, and to enhance the experiences that underrepresented groups have as they contribute to the engineering field. Historically, the engineering profession is severely underrepresented by women, people of colour and ethnic or cultural diversity. To that end, affinity societies aim to address these issues through collaboration, community, mentoring and modelling. Professional engineering affinity societies are formed in large part to increase the participation and success rate of like students and professionals in engineering. The mission of NSBE, for example, is to "increase the number of culturally responsible Black engineers who excel academically, succeed professionally and positively impact the community" (NSBE, 2015, para. 1). Similarly, SHPE aims to "change lives by empowering the Hispanic community to realize its fullest potential and to impact the world through STEM awareness, access, support and development" (SHPE, 2015, para. 1). The goal of SWE is to help women not only become engineers, but to also become leaders and role models to diversify the engineering field with respect to gender.

Engineering Education Professional Societies

A further distinction in professional engineering societies is in those who specialise in engineering *education* – i.e., the pedagogical practices of teaching engineering. ASEE was founded in 1893 as a nonprofit organisation committed to furthering education in engineering and engineering technology (ASEE, 2015a). A primary goal of ASEE is promoting excellence in engineering education through instruction, research, public service and practice. In addition, its 12,000+ members, mostly higher education leadership, faculty and staff, aim to foster the technological education of society. Ten years ago, ASEE expanded its focus to include the rapidly growing field of pre-university engineering education via its K12 & Precollege Division, one of approximately 40 divisions within the organization (ASEE, 2015b).

We also include another organisation, the International Technology and Engineering Education Association (ITEEA), in this category. ITEEA is primarily a pre-university teacher organisation, first founded in 1939 as the American Industrial Arts Association to support the study of industrial arts in schools (ITEEA, 2015). As technological change has occurred, ITEEA has evolved to reflect the inclusion of technology and technological design into pre-university education. The organisation changed its name from the International Technology Education Association (ITEA) to ITEEA to include the increasing presence of engineering design principles in pre-university education. Today, ITEEA is an organisation comprised of 35,000 technology and engineering educators in secondary schools across the country.

Overarching Engineering Professional Societies

Finally, regional and global engineering societies are formed based on combinations of one or more of these disciplinary, affinity and/or engineering education groups to represent their interests in global aspects of the profession. In 1968, the United Nations Educational, Scientific and Cultural Organisation (UNESCO) sponsored the creation of a non-governmental organisation, called the World Federation of Engineering Organisations (WFEO) to discuss engineering matters on an international level. Currently, WFEO represents around 20 million engineers in over 90 countries. The organisation offers policy advice on issues pertaining to the engineering sciences. In partnership with the UNESCO Engineering Initiative, WFEO has been involved in promoting engineering education and skills development (WFEO, 2015a). In the United States, the American Association of Engineering Societies (AAES), a multidisciplinary society and member organisation of WFEO, aims to leverage the impact of engineering societies by being a single voice of the US engineering profession (AAES, 2015a). Included within AAES are eight of the societies within the disciplinary, demographic affinity, and engineering education categories listed in Table 1.

PRE-UNIVERSITY EFFORTS FOCUSED ON PROFESSIONAL MEMBERS

One way that professional engineering societies aim to address pre-university engineering education is by focusing on their own members. They do so by: preparing them with resources or training to conduct outreach in P12 settings (typical of disciplinary and affinity societies); positioning them as role models for P12 students (typical of affinity societies); or supporting divisions, committees, work groups or other communities of practice focused on P12 engineering education (typical of engineering education and overarching societies).

Disciplinary Societies – Professional Member Efforts

The most prevalent involvement in pre-university education among our sample of disciplinary societies involved programs and information targeted to association members who will typically be volunteering in short term outreach or longer-term engagement in pre-university schools. The majority of these organisations have included resources for volunteers to go into schools for: classroom visits; career-related activities such as Engineers Week, a nationally recognized week in the US in February celebrating the engineering field (DiscoverE, 2015); or for use in more sustained engagement such as out-of-school time clubs and events.

IEEE purports to be one of the world's largest technical professional associations at 400,000 members and is primarily engaged in efforts to facilitate career preparation and knowledge (IEEE, 2015a). To that end, IEEE sponsors several career familiarization programs such as TryEngineering.org (IBM, IEEE & TryScience, n.d.). TryEngineering.org, co-sponsored by IBM Corporation, is an online repository for lesson plans and/or activities intended for members to do with students in schools, both as classroom lessons and for short-term career oriented events. Through its Teacher In-Service Program (TISP), IEEE volunteers undergo training to deliver professional development to teachers.

AIAA supports pre-university engineering education in a number of ways (AIAA, 2015). One is through lesson plans and activities intended for their career professional members to use during Engineers Week, career fair and other outreach visits. In addition, AIAA provides a mechanism for members to interact with pre-university teachers and students through the AIAA K-12 STEM Event Planning and Volunteer Coordination Database, a member benefit aimed at connecting educators and engineers for the benefit of students.

ASCE has a foundation to support its pre- and post-university educational efforts (ASCE, 2015b). For members, pre-university resources include outreach activities for middle primary school through secondary school grades; pre-packaged materials for lessons (for a cost); an outreach material store to purchase branded merchandise to share and resources for members to learn how to do outreach. As with other societies, ASCE members participate in mostly short-term visits, career oriented events and special events such as Engineers Week.

SAE is unique in its pre-university approach. The SAE Foundation has facilitated the development of the A World in Motion (AWIM) curriculum units/kits for use in primary through middle school (SAE, 2015). These resources are available for purchase by members and non-members. SAE encourages their volunteer members to assist teachers in the implementation of the units.

Despite the popularity of chemical engineering, AiChE does not have a foundation or a large presence in the pre-university space. AiChE focuses on supporting professional engineering preparation and practice, and utilizes volunteer members to support the profession locally by aiming to increase interest and awareness of engineering and science in pre-university students (AiChE, 2015). AiChE provides its members with a means to communicate with volunteer mentors who can assist them in conducting outreach with K12 students.

Demographic Affinity Societies – Professional Member Efforts

All three affinity societies provide some mechanisms (e.g., camps and clubs) and resources (e.g., mentorship information) for professional members to interact with pre-university students and sometimes teachers or parents. For example, Texas A&M University's SWE chapter has eight different programs aimed at connecting working engineers and faculty, graduate and undergraduate students, high school students, teachers and parents, and middle school and elementary students with women in engineering at all stages (Texas A&M University-SWE, 2015). Overall, the resources of the affinity societies may not be as extensive as are those provided by the disciplinary societies; however, societies like SWE, NSBE and SHPE also serve an important role in pre-university education by holding up their professional members as trail blazers, role models and inspiration for the next generation of engineers. SWE's vision is to "be key to the success of women in engineering and technology" (SWE, 2015a). NSBE's goal is to expand their efforts world wide, "creating a global network of Black engineers, scientists and technologists" (NSBE, 2015a). Likewise, SHPE envisions a world "where Hispanics are highly valued and influential as the leading innovators, scientists, mathematicians and engineers" (SHPE, 2015).

Engineering Education Societies – Professional Member Efforts

Professional members of ITEEA and ASEE share a vested interest in technological and engineering literacy in general, and increasing participation and diversity in the field specifically. ITEEA is primarily comprised of pre-university teachers as well as the higher education faculty and staff who prepare them for these careers (ITEEA, 2015). Typically, these higher education members are affiliated with a college or university of education and may or may not have a proximate relationship or partnership with a college or university of engineering. ITEEA, then, serves its professional members through a variety of ways, including: the development of curricula for pre-university teaching and learning in technology and engineering; teacher professional development and advocacy for pre-university technology and engineering education at the state and national levels.

The majority of ASEE's members, by contrast, are typically higher education faculty and staff at colleges and universities of engineering (ASEE, 2015). These institutions characteristically offer a variety of disciplinary degrees. Although growing, only about 10 US universities currently offer Ph.D. degrees in engineering education (university level). ASEE's involvement in pre-university education has increased markedly in the last decade, as reflected by: the formation and growth of the K12 & Precollege division and its body of work, the formation of a Board of Directors Committee on P12 Education two years ago, and most recently the inclusion of pre-university engineering education as one of four key areas for the overall organisation in ongoing strategic realignment. ASEE serves its professional members by providing opportunities for dissemination, collaboration and impact in pre-university engineering education.

Overarching Societies – Professional Member Efforts

Both WFEO and AAES have standing committees or working groups aimed at impacting education. The WFEO Education committee is primarily focused on university engineering education, and the WFEO Committee on Women in Engineering places some effort on increasing the participation of women going into schools and colleges of engineering (WFEO, 2015b, 2015c). The AAES K-12 STEM Working Group aims to leverage their member organizations' efforts and resources in pre-university engineering education (AAES, 2015b). In both cases, representatives from member organisations (e.g., from ASME or ASEE) are called upon to contribute to conversations about how organizations can come together to: advocate for the importance of high-quality engineering education, and to affect national policy on P12 education. A persistent challenge for AAES, and many of the professional engineering societies in general, is the reliance on members to volunteer their time towards these efforts.

PRE-UNIVERSITY EFFORTS FOCUSED ON STUDENTS & TEACHERS

In addition to supporting member volunteers to work with students and teachers, professional engineering societies have also contributed more directly to students and teachers. Collectively, these societies have provided teachers with: lesson plans, units or other curricular material; grant opportunities; affiliate or teacher membership in the society; and connections to practicing engineers to assist with lesson delivery or to visit a class. Engineering professional societies have also provided students with online coursework, videos and career information, and opportunities to participate in competitions and clubs.

Disciplinary Societies – Student and Teacher Efforts

Nearly all of the societies surveyed indicate involvement in pre-university programs focused on students. These offerings include activity and lesson plans for both in and out-of-school use, engineering program and career preparation resources, and links to other activities and organisations in engineering, particularly for students from groups underrepresented in engineering. A digital in-school engineering course is the primary offering from ASME through its INSPIRE initiative (ASME Foundation, n.d.). INSPIRE's targeted audience is secondary school students (and their teachers) throughout the country. Through this 8–10 hour digital course intended for in school use, ASME aims to increase STEM interest through INSPIRE's online gaming and simulations. Significantly, the ASME Foundation fully underwrites the INSPIRE program, providing it at no cost to schools throughout the US. In its first year, over 550 middle and high schools have implemented INSPIRE, involving 21,000 students in 39 states.

ASCE provides an online resource of lesson plans for use both in and out of school (ASCE, 2015). In addition, their Pre-college Outreach page includes video clips about civil engineering for classroom use and links to other organisations involved in engineering education as well as civil engineering competitions. Teachers can also request a civil engineer to come to their classroom and find ways to start a civil engineering club. IEEE also offers resources for teachers and students, including teacher in-person training via its members (see previous discussion of TISP) (IEEE, 2015b).

Finally, AIAA's Foundation funds a wide variety of pre-university programs for students and teachers (AIAA, 2015). Teachers can apply for classroom grants for hands-on activities to supplement lessons plans in math and science. AIAA awards $200 grants to 100 teachers each year. Middle school teachers can also apply to receive a STEM Experience @ AIAA Forums grant to participate in an AIAA Forum. AIAA Forums engage middle school students, teachers and aerospace professionals in interactive ways to increase interest and engagement in aerospace careers. The Foundation also supports a K12 Educator Achievement award program. AIAA is one of the few organisations sampled that offer an "Educator Associate" Membership option; free to qualifying teachers. As mentioned previously, AIAA also provides connections with practicing engineers to assist with student learning in aerospace concepts through its K12 STEM Event Planning and Volunteer Coordination Database.

Demographic Affinity Engineering Societies – Student and Teacher Focus

The affinity groups we examined are heavily invested in impacting students, from early primary through secondary school. All offer memberships for pre-university students as well as opportunities to participate in activities, clubs and programs geared toward their organisational missions. Local SHPE university student or professional chapters in the US and Puerto Rico form SHPE Jr. (with Jr. referring to "Junior") chapters by developing partnerships with school administrators (SHPE Foundation, 2015). SHPE Jr. chapters provide opportunities to participate in STEM activities, such as engineering summer camps, national and local competitions.

NSBE and SWE also offer opportunities for pre-university student membership and participation. SWE encourages the formation of middle and high school clubs under the SWE name, called SWENext (SWE, 2015c). Students in secondary school can become NSBE Jr. members for a nominal fee, offering them opportunities to participate in national and local camps, activities and competitions (NSBE, 2015c).

All three organisations provide opportunities for pre-university members to participate in their organisation's national conferences through associated symposia, special events or stand-alone programming. SWE's Program Development Funds support efforts such as the *Invent it, Build it* event held in conjunction with their annual conference (SWE, 2015d). In addition to the networking and mentoring opportunities provided by these programs, the affinity organisations aim to build long-term connections with pre-university students that will continue through university and into professional careers.

SWE, NSBE and SHPE websites all offer career advice, classroom resources such as posters, branded merchandise and magazines, and lesson plans geared to out-of-school time programs. NSBE and SHPE both sponsor summer camps and after school clubs and activities. Interestingly, while the activity and programming of these organisations is intended to develop long term relationships with students, investment and involvement with *teachers* is not prevalent.

Engineering Education Societies – Student and Teacher Efforts

Both ITEEA and ASEE have efforts devoted to pre-university teachers. For teachers, ITEEA has developed *Engineering by Design,* curricula in wide use in twenty consortium states (ITEEA, 2011a), as well as the STEM Center for Teaching and Learning for professional learning opportunities (ITEEA, 2011b). Memberships are available for practicing teachers and both faculty and students at the university level.

ASEE's K12 & Precollege Division members focus on scholarly research and best practice in pre-university engineering education (ASEE, 2015b). Results are disseminated through the annual conference and P12 workshop, as well as in science and engineering education journals and publications. Members lead collaborative efforts to develop tools for teaching engineering at the pre-university level. For example, to aid in assisting pre-university teachers who wish to or will be teaching engineering, a group of ASEE members recently led the development and publication of the *Standards for Preparation and Professional Development for Teachers of Engineering,* with an accompanying matrix to evaluate current educational or professional learning programs (Klein-Gardner, Farmer, & Nadelson, 2014; Reimers, Farmer, & Klein-Gardner, 2015).

Each year, ASEE headquarters and the K12 & Precollege division collaborate on a P12 Engineering Teacher Workshop in conjunction with the annual technical conference (ASEE, 2015c). In addition, the organisation's website provides information on careers, preparation, classroom lesson plans and out of school time activities. While available to anyone accessing the site, these resources are aimed at teachers and parents more than pre-university students directly. Overall, ASEE's impact and involvement directly with pre-university students is member driven, typically through P12 division members' research and practice.

Overarching Societies – Student and Teacher Efforts

Overarching engineering societies such as WFEO or AAES have been formed to provide a collective voice for disciplinary, demographic affinity and education societies in engineering. To that end their focus tends to be on advocacy, policy and professional connections and collaboration, rather than on pre-university students and teachers.

DISCUSSION

From our investigation, we have learned that there is a wide range of how engineering professional societies address pre-university engineering education and to what audience they aim their efforts. Table 2 reflects the primary way in which the different engineering professional society categories positioned their members with respect to pre-university engineering education. Certainly, some societies may position members in multiple ways; however, Table 2 is a useful way to consider how the societies largely position their volunteers to serve and address pre-university education. Table 3 summarizes whether or not each society category directly supports pre-university students or teachers. One finding made clear in this table – and discussed earlier in the chapter – is that affinity societies may do well to reach out to P12 teachers more to enact their societal missions.

Table 2. Primary way in which engineering professional societies position members with respect to pre-university education

	Categories			
	Disciplinary	*Demographic affinity*	*Engineering education*	*Overarching*
As expert volunteers, working with teachers and students	✓			
As role models and examples of successful engineers from underrepresented groups		✓		
As experts in P12 education research, curriculum, and/or practice.			✓	
As advocates and change agents for P12 engineering education.				✓

Table 3. Direct service to students or teachers by engineering professional societies

	Categories			
	Disciplinary	*Demographic affinity*	*Engineering education*	*Overarching*
Students	✓	✓	✓	
Teachers	✓		✓	

In addition to this potential opportunity for affinity engineering professional societies to address teachers, all engineering professional societies may benefit from expanding or enhancing the range of services they provide to students and teachers that have been summarized in this chapter. Further, we have identified three opportunities for engineering professional societies to consider that arise from our investigation: 1) measuring the impact of pre-university education efforts; 2) generating support through charitable foundations, grants, and industry; and 3) making connections within the community of engineering professional societies.

Measuring Impact

The measures of impact of the efforts of engineering societies in pre-university, like the programming and opportunities they provide, are widely varied. In large part, the primary measure of impact seems to be in participation numbers; that is, in the number of schools, teachers and/or students who participate in their offerings. In some cases, year-to-year participation is reported but primarily, participation numbers are for current or recent offerings rather than growth or sustained impact.

Certainly, any effort or participation by engineers and their professional organisations in pre-university education is a positive thing in almost any context. Increasing general public knowledge of the contribution of the engineering profession to the advancement of society overall will likely result in more, and hopefully more diverse, students choosing engineering as a career. But there is scant longitudinal impact or research data on the pre-university efforts of the disciplinary engineering professional societies in particular, making it difficult to quantify impact on the profession overall.

Particularly in the present P12 educational environment in the US, it is becoming increasingly important that the professional learning experiences that we offer to teachers and the curricula and instruction we provide for students generate positive outcomes for teaching and learning. It is important that engineering professional societies connect their resources to standards, and wherever possible, measure the ways in which their resources and activities benefit teachers and students.

Generating Support through Foundations, Grants & Industry

When organizations increase their scope in any aspect, additional resources are needed to support and sustain this new effort. Utilizing volunteers to support pre-university initiatives is but one approach. The additional resources that engineering professional societies provide towards pre-university engineering education vary widely and seem to be strengthened by the existence of an associated charitable foundation. Of the 12 societies that we examined, five of them cited support from charitable foundations. These foundations participate in underwriting the more intensive effort by volunteers or the cost of expertise to develop and implement curricula and programs such as clubs and camps. Of note is AIAA, whose charitable foundation funds the majority of their pre-university initiatives; and ASME, whose foundation fully funds their current pre-university efforts.

Affinity societies often use grants and donations from industry partners also invested in their overall mission to fund their operational and pre-university efforts, rather than charitable foundations. An exception is SHPE, whose foundation underwrites their significant program of effort in pre-university engagement. The educational and overarching societies we examined do not have charitable foundations, magnifying the need to accomplish the plan of the work through the involvement and dedication of volunteers.

We must note that a significant part of societies' efforts in the pre-university space occur because of the unpaid contributions of their members. These individual members utilize company policies on community engagement as well as off the clock volunteerism or vested personal interest. Further, industry and higher education supports pre-university efforts by taking part in large-scale national or regional efforts such as Engineers Week.

Making Connections

The opportunity for collaboration between engineering professional societies to impact pre-university engineering is substantial. All types of societies share common interests and impetus, even while focusing on their specific aspects of engineering. Overarching foundations are an existing way to utilise the collective interests, resources and expertise to sustainably operate in the pre-university setting, as well as in forming policy. Many engineering professionals have multiple organizational affiliations, offering the opportunity to share and maximize the vital resource of volunteer time.

In addition, engineering education societies like ASEE already generate research, standards and information about best practices that can be considered when they and other engineering professional societies plan or conduct their outreach and engagement in pre-university classrooms and environments. Electronic resources can be employed to connect the societies with each other and with pre-university partners as well as to provide a common dissemination and communication outlet accessible by all stakeholder groups. The (US) National Academy of Engineering is currently conducting a study on the development of one such resource, called *LinkEngineering,* to address some of the need and realize some of the opportunities in a more connected community (NAE, 2015). In essence, engineering societies operating in pre-university education would benefit when they approach the effort utilizing the professional skills in research, analysis, problem solving and collaboration that engineering is known for.

Concluding Thoughts

In the past decade, the recognition of the need to increase awareness and knowledge of engineering and engineering careers in younger audiences has grown enormously. As society becomes more technologically advanced and the recognition of global challenges grows, it is no longer enough for the engineering profession to assume sufficient interest in the field to provide enough engineers to address these issues. Concurrently, awareness of the critical need to develop solutions utilizing a team comprised of engineers with varied backgrounds and perspectives has also grown. The need for more engineers, as well as the need for a broader perspective in the profession in general, is now generally recognized, as is the necessity to engage students earlier in their pre-university academic careers.

Engineering professional societies are a primary source of both expertise and energy to help address these problems, and they have begun to make inroads into impacting the P12 space. Success, however, is measured not only by the number of participants but also on the long-term impact of the effort on the students and the field itself. To make sustained and institutional change, however, it is critical that engineering professionals – supported by the societies in which they participate – collaborate with those who prepare engineers and educators. Together, these individuals can enact the team spirit of engineering, working together to design, fund, and employ innovative efforts to improve P12 engineering education. Additionally and importantly, they can find sustainable ways to both measure and disseminate the impact of engineering societies' efforts on P12 engineering education.

REFERENCES

AAES. (2015a). *About us – Advancing the knowledge, understanding and practice of engineering.* Retrieved June 26, 2015, from http://www.aaes.org/about-us

AAES. (2015b). *K-12 working group (STEM).* Retrieved June 26, 2015, from http://www.aaes.org/working-groups#k-12

AIAA. (2015). *STEM K12 outreach*. Retrieved June 3, 2015, from https://www.aiaa.org/Secondary.aspx?id=257

AIChE. (n.d.). *K-12 initiative*. Retrieved June 3, 2015, from http://www.aiche.org/community/k-12

ASCE. (2015a). *About ASCE.* Retrieved June 28, 2015, from http://www.asce.org/about_asce/

ASCE. (2015b). *Pre-college outreach.* Retrieved June 3, 2015, from http://www.asce.org/pre-college_outreach/

ASEE. (2015a). *Who we are*. Retrieved June 28, 2015, from https://www.asee.org/about-us/the-organization

ASEE. (2015b). *ASEE K12 & precollege division*. Retrieved June 28, 2015, from http://k12division.asee.org

ASEE. (2015c). *Highlights of ASEE's past K12 workshops*. Retrieved June 28, 2015, from https://www.asee.org/conferences-and-events/conferences/k-12-workshop/past-conferences

ASME Foundation. (n.d.). *Inspire*. Retrieved June 28, 2015, from https://www.asme.org/about-asme/asme-foundation/inspire

BMES. (2014). *BMES advancing human health and wellbeing*. Retrieved June 3, 2015, from http://bmes.org

DiscoverE. (2015). *Engineers week*. Retrieved June 3, 2015, from http://www.discovere.org/our-programs/engineers-week

IBM, IEEE & TryScience. (n.d.) *TryEngineering*. Retrieved June 28, 2015, from http://tryengineering.org

IEEE. (2015a). *History of IEEE*. Retrieved June 22, 2015, from https://www.ieee.org/about/ieee_history.html

IEEE. (2015b). *IEEE pre-university education*. Retrieved June 3, 2015, from http://www.ieee.org/education_careers/education/preuniversity/tispt/home.html

ITEEA. (2015). *A brief history of ITEEA*. Retrieved June 28, 2015, from http://www.iteea.org/AboutITEEA/ABriefITEEAHistory.pdf

ITEEA. (2011a). *Engineering by design*. Retrieved June 28, 2015, from http://www.iteea.org/EbD/ebd.htm

ITEEA. (2011b). *Engineering by design – STEM center for teaching & learning.* Retrieved June 28, 2015, from http://www.iteea.org/EbD/CATTS/catts.htm

Klein-Gardner, S., Farmer, C., & Nadelson, L. (2014, April 14). *Standards for preparation and professional development for teachers of engineering.* Retrieved June 28, 2015, from https://www.asee.org/documents/papers-and-publications/papers/outreach/Standards_for_Preparation_and_Professional_Development.pdf

National Academy of Engineering (NAE). (2015) *Guiding implementation of PreK-12 engineering in the United States.* Retrieved June 28, 2015, from https://www.nae.edu/Projects/108076.aspx

NSBE. (2015a). *About NSBE*. Retrieved June 5, 2015, from http://www.nsbe.org/About-Us.aspx - .VZAtpGCsn8k

NSBE. (2015b). *NSBE mission & objectives*. Retrieved June 28, 2015, from http://www.nsbe.org/About-Us/NSBE-Mission-Objectives.aspx#.VZB1YUv_TG5

NSBE. (2015c). *NSBE Jr*. Retrieved June 28, 2015, from https://www.nsbe.org/Membership/Membership-Types/NSBE-Jr.aspx#.VZCgp0v_TG4

Reimers, J. E., Farmer, C. L., & Klein-Gardner, S. (2015). An introduction to the standards for preparation and professional development for teachers of engineering. *Journal of Precollege Engineering Education Research*, *5*(1), 40–60.

SAE. (2015). *SAE foundation – The charitable arm of SAE international K-12 STEM programs.* Retrieved June 3, 2015, from http://foundation.sae.org/k12/

SHPE. (2015). *Mission & vision*. Retrieved June 22, 2015, from http://www.shpefoundation.org/about-us/mission-vision/

SHPE Foundation. (2015). *About SHPE Jr. chapter programs*. Retrieved June 28, 2015, from http://www.shpefoundation.org/shpejr/

SWE. (2015a). *Organization*. Retrieved June 28, 2015, from http://societyofwomenengineers.swe.org/about-swe

SWE. (2015b). *Society of women engineers – Aspire, advance, achieve*. Retrieved June 22, 2015, from http://societyofwomenengineers.swe.org

SWE. (2015c). *What is SWENext*? Retrieved June 28, 2105, from http://societyofwomenengineers.swe.org/swenext

SWE. (2015d). *Invent it, build it.* Retrieved June 28, 2105, from http://societyofwomenengineers.swe.org/invent-it-build-it

Texas A&M University-SWE. (2015). *Programs.* Retrieved June 29, 2015, from http://swe.tamu.edu

WFEO. (2015a). *Who we are*. Retrieved June 25, 2015, from http://www.wfeo.org/about/
WFEO. (2015b). *Committee on Education in Engineering (CEIE)*. Retrieved June 25, 2015, from http://www.wfeo.org/stc_education_in_engineering/
WFEO. (2015c). *Committee on Women in Engineering (WIE)*. Retrieved June 25, 2015, from http://www.wfeo.org/stc_women_in_engineering/

Elizabeth A. Parry
The Engineering Place
North Carolina State University College of Engineering
USA

Pamela S. Lottero-Perdue
Towson University
USA

Stacy Klein-Gardner
Vanderbilt University and The Harpeth Hall School
USA

ANNE-LOTTE MASSON, TANJA KLOP, PATRICIA OSSEWEIJER
AND MARC J. DE VRIES

13. THE ROLE OF ENGINEERS IN PRE-UNIVERSITY EDUCATION

Success-Factors and Challenges

1. INTRODUCTION

In this chapter we will discuss the role of engineers in pre-university education. To do so, we seek the answers to four questions.

- What value can be added to pre-university education when engineer gets involved?
- Why would engineers want to get involved?
- What are the challenges regarding the involvement of engineers in pre-university education?
- What would be possible solutions?

To answer these questions, we will discuss relevant literature and use examples from research and experience. All examples are set within secondary education in the Dutch educational system. In this system, there are three levels of education: pre-vocational (four years), general (five years) and pre-university (6 years). Most children enter their secondary education in one of these levels and graduate from that level as well. In the given examples, the level and year of the pupils participating will be briefly explained.

2. VALUE ADDED TO PRE-UNIVERSITY EDUCATION WHEN ENGINEERS GET INVOLVED

In general, one could say there are two ways in which engineers can be involved in pre-university education. The first is to offer pupils the opportunity to work alongside professionals in a company or institution in the form of an apprenticeship. Second, engineers can be involved in classroom activities within the school-setting. In these programs, the involvement may either be incidental or structural and take place at school or at the working venue of the engineer. Apprenticeships mostly involve individual pupils, whereas in classroom-activities pupils are more often involved as a group.

There are several merits that can follow the involvement of engineers in pre-university education. First of all, the engineer can add a professional or authentic

M. J. de Vries et al. (Eds.), Pre-university Engineering Education, 221–236.

context for textbook concepts. Dutch pupils in secondary school are offered physics, biology, and chemistry, but the interdisciplinary nature of the work of an engineer cannot be fully dealt with in separate school-subjects. Although in a recent renewal of the programs for these subjects more practical contexts were added for these subjects, concepts are still divided into disciplinary subdomains, such as mechanics, electricity, and magnetics (Vries, 2012). Having an engineer explain about his or her daily work can show pupils how theoretical concepts are put into practice. Indeed, Braund and Reiss (2006) describe how out-of-school contexts contribute to pupils' learning in science and technology.

Results for increased conceptual understanding of science and technology are not the same in all reported activities and may depend on the type of involvement and the activities undertaken between engineers and pupils. Bleicher (1996) for instance finds limited growth of conceptual understanding, more limited than developers had intended.

On the other hand: Ritchie and Rigano (1996) report pupils gaining a sophisticated chemistry knowledge by participating in an apprenticeship programme. The authors suggest that time and being fully immersed in the culture of their laboratory caused this.

Literature also suggests that the interaction between pupils and engineers challenges pupils more than regular technology education in school, or 'school science'. This is especially true in situations where engineers and pre-university pupils work together. This can either be in the form of an apprenticeship or in a project where the engineer's function is that of a mentor or mandator. As Cobb (1994) and Greeno, Moore et al. (1993) describe, school science and technology can be perceived by pupil as only applying within the boundaries of the formal environment in which it is told: the classroom. Learning in an authentic context, with an engineer as a mentor, challenges pupils to apply knowledge to 'real' problems. Abraham (2002) for instance showed that working together with an engineer resulted in an increased self-reported gain of knowledge among the pre-university pupils involved.

An example of a project where pre-university pupils work together with engineers is the Imagine competition, founded by the Delft University of Technology. In this competition engineers formulate proposals for possible use of technology based on their own work and pre-university pupils further design the application of that technology for a developing country. A qualitative study by (Masson, Klop, & Osseweijer, 2014) used the *expectancy-value model of achievement related choice* (Eccles & Wigfield, 2002) to analyse factors in the pupils' motivation to participate in the Imagine competition. The study found that interest-enjoyment values and attainment values were most important in the pupils' motivation to participate in the Imagine competition. In this specific activity these values were linked to the fact that the pupils were working on 'real' problems instead of text-book exercises and that they felt that by working on these problems together with professionals they could contribute to improving people's live in developing countries. Pupils reported that they were motivated more by this project than they are by their regular school work.

A follow-up study by (Masson et al., in process) studied the cognitive effect for pupils participating in the Imagine competition. This study concludes that when the interaction between the engineers and pupils is well established, the pupils report that they learn more about the topic than they could or would in their regular curriculum. Both qualitative studies confirm the possibility of motivating pupils by offering them the opportunity to work alongside professionals on real-life problems and the possible learning effect that can be achieved with such educational activities.

Another merit of having engineers involved in pre-university education is that engineers can be role models for young people who have yet to decide upon the trajectory of tertiary education and career. Research shows that the public opinion about studying technology is not very positive (Johansson, 2009). Young people tend to think that working in industrial environments involves hard and dirty labour, boring working conditions and bad working hours.

Who better than an engineer can show them the career possibilities in engineering? Literature indeed suggests that engineers and scientists as role models can motivate pupils to pursue a career in science and technology (Sadler, Burgin, McKinney, & Ponjuan, 2010). There is evidence that the interaction between professionals (scientists, engineers, etc) and pre-university pupils can increase the pupils' interest in a career in science and technology (Cooley & Bassett, 1961; Davis, 1999; Abraham, 2002).

Interaction between pupils and STEM-professionals (which includes scientists and engineers) is often suggested as a way to counter the falling enthusiasm among young people in Western societies to pursue a career in STEM (OECD, 2008; Jenkins, Jensen, & Henriksen, 2010; United ations Educational Scientific and Cultural Organization, 2010; Bøe, Henriksen, Lyons, & Schreiner, 2011).

Especially in pre-vocational education technology education focusses on preparing pupils for a career in technology operations, rather than focussing on technological literacy (Rossouw, Hacker, & de Vries, 2011). The pre-vocational track takes four years to complete. After two years of pre-vocational education, pupils (around the age of 14) choose a sector in which they want to continue their education. This can either be *economics, technology, health and well-being,* or *agriculture.* It is important for pupils to have a realistic idea about possible careers in each sector, before they have to make such an important decision. Moreover, since the pupils who have chosen the *technology* sector are being prepared for a career in technology it is important for them to have a realistic idea of what a career in technology comprehends. Interaction with engineers may contribute to realistic ideas about career perspectives, before they choose their sector as well as for those pupils enrolled in the *technology* sector.

A program that shows pupils in pre-vocational education the possibilities of a career in engineering is the 'Chocolate Challenge'. For this project, a large oil-company (Shell), together with the *Stichting C3* (C3 foundation[1]) created a mock-factory in a truck. This factory travels to secondary schools so that pupils can experience the profession of process-operator. A professional process-operator accompanies the factory and tells the pupils about his or her work, career prospects and experience. In this project stereotypes are actively contradicted. For example. some of the process-operators involved are young women, something most pupils do not expect. Another stereotype actively contradicted is that a career in technology means hard, dirty labour with a low salary. The process-operators show that a lot of their work consists of digitally monitoring the processes in the factory and they openly discuss regular salaries for process-operators. An assessment of the effect (pre- and post-questionnaire) of the Chocolate Challenge (Koeman & Meijer, unpublished) shows an increase in the number of pupils expressing interest in the job of process-operator a few weeks after participating in the Chocolate Challenge. It also shows an increase of awareness about the job and what being a process operator actually comprehends.

In the Dutch educational system there are secondary schools where the involvement of engineers is institutionalised. These schools are called *technasia*.[2] These schools (general- and pre-university-level) offer the course "Research and Design". For this course there is no textbook. Instead, pupils work together on projects, submitted by companies or institutions. There has yet to be a thorough, peer reviewed study to conclude if and how this form of institutionalising the involvement of engineers is effective.

Another initiative that aims to facilitate or institutionalise the involvement of engineers in secondary and – recently- primary education in the Netherlands is Jet-Net. This organisation aims to bring together professionals from industry with pupils in general- and pre-university secondary education. Their focus is on establishing direct cooperation between a school and a company (Jet-Net).

As one can see, a lot of initiatives aim to involve engineers in pre-university education. However, an issue that arises in most, if not all, initiatives is to find engineers willing, able and allowed by their employer to participate. This challenge, and possible solutions, will be discussed in the following sections.

3. WHY WOULD ENGINEERS WANT TO GET INVOLVED?

The benefits for pupils when engineers get involved in education seem clear and ample. But why would engineers want to get involved in pre-university education? What's in it for them? Engineers can participate in pre-university education on their own initiative, or because they are asked to do so by their supervisor. Of course, a combination of personal motives and encouragement from the engineer's supervisor is also possible.

For companies, a reason to engage in secondary education can be to ensure a future workforce. To this end, it can be most interesting for companies to engage in secondary education in a certain region or target specific pupils. By showing pupils what kind of technology-related jobs are available, companies hope to raise enthusiasm for those jobs. An example is the Chocolate Challenge project.

One reason for engineers to get involved in pre-university is to fulfil their social responsibility. This is mostly the case for engineers working in an academic setting.

These engineers often face the challenge of applying for grants to conduct their research. Often a prerequisite to get a grant is to include some sort of valorisation of the research. Outreach-activities with secondary school pupils are a possible way to fulfil this 'obligation' of valorisation.

Another reason why engineers might get involved in pre-university education is out of personal interest. Some engineers may feel intrinsically motivated to tell young people about their work, because they enjoy the interaction with young people or the element of transferring knowledge. An example of a STEM-professional who joined an existing program out of personal interest is can be found in the Imagine competition (explained in Section 2). In a qualitative study, Masson et al. (2014) studied pupils' experiences from participating this activity to disentangle factors in reaching or not reaching the potential benefits of activities in which pupils and engineers are involved. This study concluded that when the interaction between pupils and professionals did not meet the pupils' expectations, this could cast a negative sentiment over the activity as a whole. A follow up study (Masson et al., in process) looked into possible ways to improve the interaction between pupils and professionals. To this end, professionals participating in the Imagine competition were interviewed. One professional clearly stated that one of the main reasons to participate was because he enjoyed transferring knowledge and raising enthusiasm about his field of research. Besides enjoying the interaction with pupils and the transferring of knowledge, engineers may also benefit from their engagement in secondary education in another way. The interaction with people outside their usual peer group or target audience can challenge engineers to diversify their own perspectives and expertise (Masson et al., in process).

Related to the motive of personal interest is the idealistic motive. An engineer may feel that it is his or her duty to communicate with young people about their work or the things they are working on. An example of engagement from such an idealistic stance is the *Viruskenner*[3]-project of the Erasmus University of Rotterdam (Viruskenner). In this project, young virologists engage in secondary education. The project aims to teach pupils about certain infectious diseases and how they can be prevented. Pupils participating in this project are asked to become 'experts' on a certain disease and subsequently design a campaign to bring about awareness about this particular disease among their peers. The virologists who set up this project did so from an idealistic motive; they felt it was important to raise awareness about infectious diseases among young people.

Last, a motive for engineers to engage in secondary education can be to earn (extra) money. Many universities have outreach-activities in which engineering students are employed. Although these students are not yet real engineers, they will likely become engineers when they graduate. For them to be involved in secondary education during their own education might lead to more or easier involvement in pre-university education once they are employed as engineers. For the pupils in secondary education, the engineering students are already a big step closer to becoming an engineer than they are themselves. Engineering students who participate in education for secondary school pupils are likely to have a personal interest in education. Or at least they prefer educating pupils over cleaning, waitressing, or other common side-jobs for students. However, it is unlikely that they would spend as much time on educating pupils if they would not get paid for it. Although earning money is probably not the only incentive to participate in education, it is probably the most important. An example of a project in which engineering students are engaged in secondary education is the *traveling DNA-labs.* In this projects, students from various engineering programs travel to secondary schools with equipment, materials and knowledge of technologies that are usually not available in secondary schools, such as PCR-machines, enzymes and information about cutting edge DNA-technologies. The students explain the necessary theory and guide the pupils through a two-hour practical.

4. CHALLENGES REGARDING THE INVOLVEMENT OF ENGINEERS IN PRE-UNIVERSITY EDUCATION?

There are several challenges concerning the involvement of engineers in pre-university education. These challenges may inhibit the positive effects from engineers getting involved in pre-university education described in Section 2. First, there are certain obstacles for engineers to get involved. Second, once involved, there are several possible issues that can prevent positive effects or even lead to unintended negative effects. We will first describe the obstacles preventing the engineers from getting involved and then move onto issues preventing reaching the full potential of the involvement of engineers in pre-university education.

4.1 Obstacles to Get Involved

Obstacles for getting involved in pre-university education may differ between academia and companies. Academics are increasingly encouraged to participate in public outreach activities (Neresini & Bucchi, 2011). Within educational reform a lot of emphasis is put on the inquiry-based learning process. Academic's deep experience with the nature of scientific research is potentially of enormous value in support of this process.

Although working in academia can mean one has more freedom to schedule activities according to personal preferences, the pressure to publish results in peer-reviewed journals can prevent engineers from taking on anything besides their main research. Especially PhD-students, considered as employees in The Netherlands, are encouraged to publish their work in peer-reviewed journals and graduate in their PhD in four years. Graduate students are expected to focus on their disciplinary research and are offered few opportunities to formally explore issues of teaching and learning (Weimer, 1990). This is a pity, especially because they are young and can still relate to the everyday life of pre-university pupils and since they can be appealing role models for pupils.

For post-docs, there is equal or even more pressure to publish. Furthermore, most post-docs need to apply for grants and are seldom employed longer than two years. It is often not before an engineer has landed a permanent position in academia that he or she can really enjoy a higher level of freedom to engage in outreach activities. Until then, engineers can only get involved in pre-university education if their supervisor thinks outreach activities are important. In addition to this, there is a lack of reward systems for engineers in academia who engage in pre-university education. Reward systems are still exclusively for scientific publishing. This makes that involvement in actual outreach activities is not always seen as a priority, or even acknowledged as part of regular tasks, within research institutes and is sometimes even unofficially discouraged by colleagues and superiors. On a more institutional level there seems to be a lack of (formal) guidelines to support and encourage the social responsibilities of academics as required in the official policy of many government-funded research.

On the other hand, some supervisors *do* feel that outreach activities are an important part of a PhD's or post-docs daily work. They might urge their PhD-students or post-docs to engage in pre-university education, often without formal training in interaction with pre-university pupils. This may lead to unsuccessful interaction, which will be discussed later in this chapter.

An example of a more senior employee in academia who enjoys the freedom to participate in outreach activities is an assistant professor who participated in the Imagine competition. In the study by (Masson et al., in process). He indicated that he had much more freedom to spend his time as he pleased than he did when he was working in industry. He also indicated that he thought his supervisor, the professor in the group, found public outreach important, but that they seldom discussed this. He had not discussed his participation in the Imagine competition either.

All in all it seems that public outreach still has not established a foothold with in research institutions themselves (Neresini & Bucchi, 2010), and the 'responsibilities' are more than often seen as voluntarily (positive) or as a burden (negative), but are seldom an integrated part of the core activities of engineers (Bauer, Allum, & Miller, 2007; Neresini & Bucchi, 2010).

In companies, getting involved in pre-university education is most often a top-down decision. Most employees do not enjoy the freedom to spend large amounts of time on projects outside the company's core business. Public outreach activities are usually initiated by the department concerned with social responsibility; often the HR- or communications-department. Employees are than asked to participate in outreach activities, such as pre-university education. Most companies will schedule time away from the usual responsibilities to enable employees to participate in outreach activities. Depending on the company, employees are to a more or lesser extent coached to participate in outreach activities and receive some sort of training to interact with pre-university pupils.

An example of a company in which the involvement in pre-university education is more or less institutionalised is Shell. One of the projects with which they are involved in pre-university education is the Chocolate Challenge, already described in Section 2. The engineers involved participate in a course before they start participating and get a yearly update training as long as they are involved.

For single employees in companies it can be difficult to get involved in pre-university education when there is no support at a management level. Even for the departments involved in outreach activities it can be difficult to secure budgets and to keep outreach activities on the agenda. When a company faces financial difficulties, these activities are often the first to be cut in their budgets.

Summarizing the above: both in academia and in industry it can be difficult for an individual to get involved in pre-university education. However, in companies it is more common to engage in pre-university education on an institutional level, whereas in academia it is often a personal preference of a senior member of staff.

4.2 Challenges During the Involvement of Engineers in Pre-university Education

When engineers have overcome the obstacles described in the previous section and get involved in pre-university education, there is still no guarantee that the positive effects described in Section 2 will arise. There are several factors that may hinder these positive effects.

There is ample literature on the effectiveness of field-trips or visits to science centres. Post and van der Molen (2014) studied whether similar guidelines to the seven *field day components* (Heimlich, Carlson, & Storksdieck, 2011) can be identified for company-visits to be effective in changing primary-school pupils' attitudes toward engineering and technology. They found a lack of those conditions in the studied visits. In the study conducted by Post and van der Molen (2014), it was found that the potential benefits of the company visits in changing children's attitudes towards technology were not reached. The authors identified certain conditions that hindered a fully effective company visit. First of all, a lack of pre-orientation before the company visit. Studies have shown that when pupils are not familiarized with the environment they are going to visit, they can be overwhelmed by the novelties of this environment (Martin, Falk, & Balling, 1981; Falk & Balling, 1982; Kubota & Olstad, 1991; Anderson & Lucas, 1997). This then hinders them from taking up the information offered to them on-site. The same may hold for visits by engineers to the classroom, especially when the visit includes some sort of hands-on activity. Pupils can be distracted by the novelty of having a 'stranger' in the classroom, or the brought-in equipment.

Second, a lack of connection to the curriculum makes it difficult for pupils to master the concepts necessary to gain the knowledge offered to them during visits to the workplace or visits by the engineer. Besides preparing pupils for the visit by offering them concepts that help them understand the activities, connecting the visit to their curriculum afterwards is essential for their long-term memory formation (Knapp, 2000; Kolb, 2014). When there is a lack of connection to the curriculum, the visit is unlikely to be integrated into the pupils ideas and understanding of technology and engineering and more likely to be remembered as a stand-alone activity.

Third, a lack of teacher-participation hindered the effectiveness of the company visits. Teachers seemed unable to formulate specific learning goals for the visits, and were mostly concerned to the logistics of the visits, whereas to maximize the beneficial effects, teachers should actively engage and participate during visits (Price & Hein, 1991; Jarvis & Pell, 2005; Anderson, Kisiel, & Storksdieck, 2006). Although there are certain differences concerning this point between company-visits and activities where the engineer visits the pupils at school, there are also important similarities. An engineer, however well-instructed or experienced, does not have the years of didactical and pedagogical training and experience the teacher has. A teacher should therefore always participate in activities where engineers are involved in pre-university education, to help pupils pursue their interests and curiosity and to actively establish connections to their prior knowledge.

Last, Post and van der Molen (2014) identify a lack of involvement of the parents of the pupils. Since parents are important role models for pupils and have significant influence on their children's choices concerning their careers, they should not be forgotten. When parents hold certain stereotypes about engineering and technology, they are likely to transfer these to their children. The encounters with engineers are unlikely to change pupils' views and attitudes when they already hold strong stereotypes stemming from conversations at home (Ormerod, Rutherford, & Wood, 1989).

Apart from the factors described above, which mostly concern the circumstances under which the contact between pupils and engineers takes place, there also are factors within the interaction that may hinder full effectiveness. These mostly arise when pupils are asked to interact with an engineer over a longer period of time. Contact between pupils and engineers then may not involve the teacher and is more personal. Masson et al. (2014) describe such challenges in their qualitative assessment of the pupils' experiences in the Imagine competition, they find that when such interaction between pre-university pupils and engineers does not run smooth, pupils can end up disappointed and hold a negative sentiment to the activity as a whole. The pupils are mostly disappointed when the engineer involved is not easily reachable, or unable to answer their questions. Most issues hindering the interaction between engineers and pre-university pupils can be traced back to differences in expectations on both sides. Pupils often expect that the engineer, being the professional, will be an absolute expert on the subject they are working on. Furthermore, they may be hesitant to 'bother' the engineer when he or she does not promptly respond to e-mails. On the other hand, the engineer may expect the pupils to have a certain level of knowledge or to be able to read and understand complicated texts that they themselves use as reference material. Engineers may also expect more assertiveness from pupils when it comes to asking questions or asking for further explanation when they do not understand certain concepts.

5. POSSIBLE SOLUTIONS

5.1 Getting Involved

The reported gain of sophisticated chemistry knowledge in the study by Ritchie and Rigano (1996) was presumably due to the pupils being fully immersed in the culture of the laboratory for quite some time. If this strategy is effective in educating and enthusing pre-university pupils, why then is it not employed more often? The answer is simple: hosting pre-university pupils in an operational laboratory, or any other operational working environment, is a time- and resources-consuming activity for any company or institution. It is hardly feasible to host more than a handful of pupils at a time. Furthermore, the investment of time and resources cannot be equalled by a profit for the company. Even if and when the pupils do choose a career in engineering, chances are that they will not end up working for the company or institution at which they did a project during their pre-university years.

For both industry and academia, the answers to getting more engineers involved in pre-university education are time, money, acknowledgement and training. Enabling employees to take time off their usual tasks to invest in pre-university education will cost the organization money. It is therefore a question for any organization whether one values the involvement of engineers in pre-university education enough to invest. Acknowledging employees who are involved in pre-university education is also important. An example of a project where participating engineers are acknowledged by their company is the *Chocolate Challenge.* Engineers who participate in this project are mentioned by higher management to their direct managers, so that they will take it into account in their annual evaluation of the engineers. Furthermore, the engineers can actively participate in shaping the project, by providing feedback during an evaluation meeting. During this meeting they can exchange experiences with other engineers and suggest changes in the project to the ones managing the project. Providing training to employees (getting) involved in pre-university education is not only a form of acknowledgement, but also helps reaching the potential benefits.

For individual engineers, whether employed in industry or academia, there may not be much that can be done to overcome the limits of time and resources to get involved in pre-university education. Voicing the wish to become involved in pre-university education is not always well-received. For engineers who already are involved in pre-university education it is important to inform co-workers and management about their activities. This may contribute to creating an environment where involvement in pre-university education is valued and stimulated.

A way to create support for participating in pre-university education can be by carrying out systematic evaluation of the activities in which the engineers are involved. Not only can the quality of activities in which engineers are involved be secured and, if needed, improved, evaluations can also show the benefits from the involvement of engineers in pre-university educations. Nevertheless, evaluations may show benefits of the involvement of engineers in pre-university educations in general or in the long term and these benefits may not seem directly relevant to the engineers' employers. For example, pre- and post-questionnaires show that after the Chocolate Challenge, the number of pupils expressing an interest in becoming a process operator has increased. However, these pupils are still in secondary school, so it is not sure they will indeed proceed to tertiary education to actually become a process operator and even if they do, there is no certainty that they will seek employment with the oil company that facilitated the Chocolate Challenge. This exemplifies why evaluations of the effect of the activities in which the engineers are involved, however positive, can still be insufficient to convince a company or institution to permit or facilitate their engineers involvement in pre-university education.

There are several programs that create partnerships between engineering-students in universities and primary or secondary schools, see for instance DeGrazia, Sullivan, Carlson and Carlson (2001). This can be very useful in two ways. First, these activities establish a form of interaction between pupils and engineers. As mentioned in Section 3, engineering students are not yet engineers, but to pupils they are a big step closer to being an engineer than the pupils themselves. Second, the students who have participated in activities with pupils during their own education may be more inclined to perpetuate these kind of activities once they are working as engineers themselves.

5.2 Being Effective

When engineers are involved in pre-university education, the issues described in Section 4.2 may hinder effective involvement. To optimize the effect of the engineer's involvement, circumstances should be created by school-boards and teachers to meet the conditions described by Post and van der Molen (2014). Since reality may not always adhere to these ideal circumstances, engineers themselves should at least be aware of these conditions. They can then try to assess whether these conditions have been met. We will discuss both what teachers can do to optimize the circumstances, and what engineers can do to deal with less-than-ideal circumstances.

For teachers, it is important to prepare pupils for the classroom-activity in which the engineer is involved. In the case of a company-visit this can be done by showing pictures of the company and explaining the core business of the company. In the case of a visit by the engineer to the school, the pupils may be prepared by telling them something about who will be coming to visit, what company they work with and what (if any) hands-on activities will be involved. Ideally, teachers would spend time in the weeks previous to the visit to prepare their pupils. In practice, this is not always done (Post & van der Molen, 2014). For example, in the case of the *Viruskenner*, discussed in Section 3, some pupils had received no information on the project before meeting the virologists. Some pupils assumed that the project was about computer viruses and needed to adjust their expectations during the first meeting of the project. In the case of the *travelling DNA-labs*, described in Section 3, teachers are asked to dedicate one regular lesson to the upcoming activity, prior to the actual visit of engineering students to the classroom. Some teachers comply, while others don't. Knowing whether or not pupils are informed about and prepared for the activity at hand is essential for an engineer involved in pre-university education. An engineer may start the visit by asking about the pupils' preparation and expectations. When it becomes clear that the pupils were not prepared by their teacher for the visit, the engineer might take some time to set the expectations straight, or spend more time introducing the environment, the company and him- or herself. At least, the engineer may be aware of the fact that the pupils may be overwhelmed by all new impressions and take a slower pace in explaining what is expected of them.

To connect the visit to the curriculum, teachers can consciously plan visits to optimally fit into the curriculum. In any case, visits should not be planned at the end of the schoolyear, since this leaves no time to reflect on the visit (Post & van der Molen, 2014). Yet the end of the schoolyear is often the period when there is more time for extracurricular activities. Planning far ahead can prevent the postponing of activities until after the required curriculum has been completed. For companies it can be challenging to deal with the rigidity of a school's timetable, in which activities for a whole schoolyear are determined months before the actual start of school in September. When it is not possible to plan the visit to optimally fit into the curriculum, teachers can refer to concepts the pupils have studied earlier, or reflect on the visit once the related concepts are discussed in the curriculum. The engineer can try to find out what is in the pupils curriculum. This will give the engineer a rough idea about the level of knowledge that can be expected and help determine which concepts can be assumed common knowledge among the pupils. The engineer should avoid using jargon that is too specific unfamiliar to the pupils.

Whether visiting an engineer at his or her working venue, or having an engineer visit the pupils at school, the teacher should never disengage from teaching. To optimize the effects of the visit, teachers can monitor whether pupils are still 'on-board', or whether they are losing track. If the latter is happening, the teacher may ask additional questions to help pupils catch up. For an engineer planning a visit, it is helpful to try and discuss the level of involvement from the teacher and discuss the goals of the visit.

Another recommendation by Post and van der Molen (2014) is to get parents involved. A teacher or rather a schoolboard can do this by organizing evenings where parents are invited to learn about their children's career possibilities. By offering a diverse spectrum of possibilities, parents can learn about the perspectives for their children and have better informed conversations at home. An engineer can address parents' influence by asking pupils during the visit what their parents think about technology and engineering, or asking whether there are pupils who have relatives working as engineers. In the case of company visits, parents would ideally accompany their children. An example of an activity in which this is done are the *Lab Experience Days,* by the C3 foundation. In this project, pupils visit an industrial laboratory with their parents. During most of the visit, parents and their children follow separate programs. The pupils carry out hands-on experiments under the supervision of company engineers, while the parents are educated about career possibilities and educational tracts.

Though direct interaction between pupils and engineers may result in a disappointing experience when it does not run smoothly, research by (Masson et al., in process) shows that with a relatively simple intervention such interaction can reach the potential benefits. In this study, engineers were coached in their interaction with the pupils. They were told about the expectations the pupils were likely to hold and were assisted in determining the accurate level of knowledge among the pupils. Furthermore, their digital communication with the pupils was monitored. When needed, the engineers were reminded to respond to e-mails, or the pupils were asked whether their questions had been sufficiently answered. This intervention proved to be successful in aiding to reach the goals of leaving the pupils with a positive experience and reaching a deeper understanding of concepts than the pupils would have gained through the regular curriculum.

6. CONCLUDING REMARKS

To conclude this chapter, we would like to state that yes, getting engineers involved in pre-university technology education can be beneficial. Given the increasing interest in social responsibility and transparency and the need for future engineers, outreach is increasingly seen as important by both academia and industry. If we want to educate young people to be literate citizens, and have an accurate idea about career possibilities, we simply cannot ignore the role technology plays in our everyday life (Miaoulis, 2010). And in acknowledging the role of technology, we should acknowledge the role of engineers. The involvement of engineers in pre-university education is one way of shaping outreach activities. This involvement can provide the following benefits for pupils:

- Adding a professional or authentic context for textbook concepts,
- Challenging and motivating pupils more than regular technology education in school,
- Increasing conceptual understanding of technology,
- Helping pupils envision the possibilities of a career in technology.

Although there are challenges to be faced and obstacles to be overcome, the potential benefits justify the call for more involvement of engineers in pre-university education, provided that guidelines are followed to make the interaction as optimal as possible.

Furthermore, we would like to stress that getting engineers involved in pre-university education is a joint effort of teachers, school boards, managers, engineering educators and engineers. They all need to be involved in their own way to enable pupils to encounter the world of the engineer. School boards need to acknowledge the importance of offering a variety of career perspective to the pupils and their parents, and enable teachers to plan and embed visits and activities. Teachers should do their part in preparing pupils for the activities, linking the activities to the curriculum, and stimulating the pupils during the activities. To monitor the quality of activities and ensure that the above mentioned benefits are being reached to ensure that these benefits are indeed reached, evaluation of activities is essential.

Managers, whether in academia (professors) or in industry, need to recognize the importance of public outreach. If they are willing to invest time and money in getting their employees (or PhD-students) into the classroom, they can find engineers willing to do so. A simple evaluation tool can aid in creating support on a company or institutional level for the involvement of engineers in pre-university education. When engineers already encounter the possibilities to engage in pre-university education during their own training, they may be more inclined to engage in such activities later on. Here lies an opportunity for engineering educators, to show their students the possibilities and preparing them not only to discuss their work with peers, but with non-peers as well. And finally, engineers need to realise the potential benefits in engaging in pre-university education. Not only the benefits for the pupils and society, but for themselves as well, to broaden their scope and ensure the supply of future co-workers.

NOTES

1 *Stichting C3* is a Dutch foundation that works together with partners in industry or academia to show pupils aged 4–18 the possibilities of chemistry and chemistry-related education and careers.

2 *Technasium* is a variation on the Dutch word *gymnasium. Gymnasium* is the term used for the highest level of secondary education (6 years) when it includes the subjects of Latin and ancient Greek.

3 *Viruskenner* is a wordplay to the words 'virus scanner'. *Viruskenner* and 'virus scanner' are pronounced the same in Dutch. A translation of *Viruskenner* would be 'knower of viruses'.

REFERENCES

Abraham, L. M. (2002). What do high school science students gain from field-based research apprenticeship programs? *The Clearing House, 75*(5), 229–232.

Anderson, D., Kisiel, J., & Storksdieck, M. (2006). Understanding teachers' perspectives on field trips: Discovering common ground in three countries. *Curator: The Museum Journal, 49*(3), 365–386.

Anderson, D., & Lucas, K. (1997). The effectiveness of orienting students to the physical features of a science museum prior to visitation. *Research in Science Education, 27*(4), 485–495.

Bauer, M., Allum, N., & Miller, S. (2007). What can we learn from 25 years of PUS survey research? Liberating and expanding the agenda. *Public Understanding of Science, 16*(1), 79–95.

Bleicher, R. E. (1996). High school students learning science in university research laboratories. *Journal of Research in Science Teaching, 33*(10), 1115–1133.

Bøe, M. V., Henriksen, E. K., Lyons, T., & Schreiner, C. (2011). Participation in science and technology: Young people's achievementrelated choices in late-modern societies. *Studies in Science Education, 47*(1), 37–72.

Braund, M., & Reiss, M. (2006). Towards a more authentic science curriculum: The contribution of out-of-school learning. *International Journal of Science Education, 28*(12), 1373–1388.

Cobb, P. (1994). Where is the mind? Constructivist and sociocultural perspectives on mathematical development. *Educational Researcher, 23*(7), 13–20.

Cooley, W. W., & Bassett, R. D. (1961). Evaluation and follow-up study of a summer science and mathematics program for talented secondary school students. *Science Education, 45*(3), 209–216.

Davis, D. D. (1999). The research apprenticeship program: Promoting careers in biomedical sciences and the health professions for minority populations.

DeGrazia, J. L., Sullivan, J. F., Carlson, L. E., & Carlson, D. W. (2001). A K-12/university partnership: Creating tomorrow's engineers*. *Journal of Engineering Education, 90*(4), 557–563.

Eccles, J. S., & Wigfield, A. (2002). Motivational beliefs, values, and goals. *Annual Review of Psychology, 53*, 109–132.

Falk, J. H., & Balling, J. D. (1982). The field trip milieu: Learning and behavior as a function of contextual events. *The Journal of Educational Research, 76*(1), 22–28.

Greeno, J. G., Moore, J. L., & Smith, D. R. (1993). Transfer of situated learning. In D. K. Detterman & R. J. Sternberg (Eds.), *Transfer on trial: Intelligence, cognition, and instruction* (pp. 99–167). Norwood, NJ, Ablex Publishing.

Heimlich, J. E., Carlson, S.P., & Storksdieck, M. (2011). Building face, construct, and content validity through use of a modified Delphi: Adapting grounded theory to build an environmental field days observation tool. *Environmental Education Research, 17*(3), 287–305.

Jarvis, T., & Pell, A. (2005). Factors influencing elementary school children's attitudes toward science before, during, and after a visit to the UK National Space Centre. *Journal of Research in Science Teaching, 42*(1), 53–83.

Jenkins, E., Jensen, F., & Henriksen, E. K. (2010). IRIS Working document No. 5.1: Recruitment initiatives and choice of STEM higher education: Review of theoretical perspectives and empirical findings regarding recruitment initiatives inside and outside school 59.

Jet-Net 10 years of Jet-Net, Jet-Net.

Johansson, L. (2009). *Mathematics, science & technology education report: The case for a European coordinating body*. Brussels: European Round Table of Industrialists.

Knapp, D. (2000). Memorable experiences of a science field trip. *School Science and Mathematics, 100*(2), 65–72.

Koeman, D., & Meijer, M. (unpublished). *Jaarverslag 2015 Stichting C3*. Den Haag, Stichting C3.

Kolb, D. A. (2014). *Experiential learning: Experience as the source of learning and development*. Englewood Cliffs, NJ: Pearson Education.

Kubota, C. A., & Olstad, R. G. (1991). Effects of novelty-reducing preparation on exploratory behavior and cognitive learning in a science museum setting. *Journal of Research in Science Teaching, 28*(3), 225–234.

Martin, W. W., Falk, J. H., & Balling, J. D. (1981). Environmental effects on learning: The outdoor field trip. *Science Education, 65*(3), 301–309.

Masson, A.-L., Klop, T., & Osseweijer, P. (2014). An analysis of the impact of student–scientist interaction in a technology design activity, using the expectancy-value model of achievement related choice. *International Journal of Technology and Design Education*, *26*(1), 81–104.

Masson, A.-L., Klop, T., & Osseweijer, P. (in process). Improving interaction between secondary school students and scientists.

Miaoulis, I. (2010). K-12 Engineering – The missing core discipline. In D. Grasso & M. Burkins (Eds.), *Holistic engineering education* (pp. 37–51). New York, NY: Springer.

Neresini, F., & Bucchi, M. (2010). Which indicators for the new public engagement activities? An exploratory study of European research institutions. *Public Understanding of Science, 20*(1), 64–79.

OECD. (2008). Encouraging student interest in science and technology studies. *OECD*, 134.

Ormerod, M. B., Rutherford, M., & Wood, C. (1989). Relationships between attitudes to science and television viewing among pupils aged 10 to 13 +. *Research in Science & Technological Education, 7*(1), 75–84.

Post, T., & van der Molen, J. H. W. (2014). Effects of company visits on Dutch primary school children's attitudes toward technical professions. *International Journal of Technology and Design Education, 24*(4), 349–373.

Price, S., & Hein, G. E. (1991). More than a field trip: Science programmes for elementary school groups at museums. *International Journal of Science Education, 13*(5), 505–519.

Ritchie, S. M., & Rigano, D. L. (1996). Laboratory apprenticeship through a student research project. *Journal of Research in Science Teaching, 33*(7), 799–815.

Rossouw, A., Hacker, M., & de Vries, M. (2011). Concepts and contexts in engineering and technology education: An international and interdisciplinary Delphi study. *International Journal of Technology and Design Education, 21*(4), 409–424.

Sadler, T. D., Burgin, S., McKinney, L., & Ponjuan, L. (2010). Learning science through research apprenticeships: A critical review of the literature. *Journal of Research in Science Teaching, 47*(3), 235–256.

United Nations Educational Scientific and Cultural Organization. (2010). *Engineering: Issues challenges and opportunities for development*. Paris: Author.

Viruskenner. Retrieved November 2015, from http://viruskenner.nl/?lang=en.

Vries, M. D. (2012). Teaching for scientific and technological literacy: An international comparison. In U. a. R. O. H. Pfenning (Ed.), *Wissenschafts-und Technikbildung auf dem Prüfstand* (pp. 93–110). Baden-Baden: Nomos Verlag.

Weimer, M. (1990). The teaching professor. Volume 4. Numbers 1–10, January 1990–December 1990. *The Teaching Professor, 4*, n1–n10.

Anne-Lotte Masson
Faculty of Applied Sciences, Department of Biotechnology
Section Biotechnology & Society
Delft University of Technology
The Netherlands

Tanja Klop
Science Center
Delft University of Technology
The Netherlands

Patricia Osseweijer
Faculty of Applied Sciences, Department of Biotechnology
Section Biotechnology & Society
Delft University of Technology
The Netherlands

Marc J. de Vries
Delft University of Technology/Royal Institute of Technology
The Netherlands/Sweden

LENA GUMAELIUS AND INGA-BRITT SKOGH

14. PRE-UNIVERSITY ENGINEERING EDUCATION RESEARCH AT A UNIVERSITY OF TECHNOLOGY

A Case Study of the Pre-university Engineering Initiatives at KTH

1. INTRODUCTION

In recent years, the issue of students' knowledge and interest in science and technology has attracted the attention of several international studies (e.g., PISA/OECD, ROSE, TIMMS). Findings from these studies have influenced debates about education in general and about STEM subjects in particular (Science, Technology, Engineering, and Mathematics). In for example Sweden the deteriorated test scores has resulted in an intense debate about the reasons behind both the test results and the decreasing interest in STEM subjects among parts of the young population. Policymakers in Sweden and other concerned countries demand rapid and preferably inexpensive solutions. A number of players have taken on the task of initiating projects to strengthen the teaching of STEM subjects. Industry and branch organisations are players that have been very active, which is of great importance. The question of why young people's lack of interest in and knowledge about STEM subjects is not, however, automatically answered by increasing the number of subject-oriented activities. Long-term solutions require serious educational studies in combination with collaboration between different societal actors.

In Sweden, as well as internationally, universities have made efforts to resolve the problem, which has resulted in many initiatives aimed at taking on these challenges. What could be described as universities' 'triple role' when it comes to improvement of pre-university engineering education in society has emerged. First, universities play an important role of performing pre-university engineering *education*, which may take the form of teacher education programs and/or in-service courses of different kinds (subject content and/or pedagogically oriented courses at various levels). Second, in addition to initiatives aimed directly at schoolteachers' education, many universities offer *outreach activities* in many different ways that seek to target students and/or the general public. Third, universities have the capacity to initiate and perform *educational research in the area pre-university engineering education.* Education and outreach activities need to be well balanced in both content and form. But what does that mean, exactly? *What* should be taught, and *how* and *when* should it be taught? Research is definitely required to address these questions.

M. J. de Vries et al. (Eds.), Pre-university Engineering Education, 237–260.

In particular, universities of science and technology have taken on the role of inspiring young people to choose a career in science and engineering. Universities' position 'between' schools and the business community is, in this context, strategic. If performed wisely, the activities of universities increase teachers' and students' awareness of the latest high-quality subject knowledge and skills in technology-relevant disciplines, as well as their applications in industry. Universities' potential for serving as information drivers between the business community and young people should not be underestimated. The combination of commitments presented above enables universities to develop science-based, pre-university engineering education with the potential to enhance both students' technological knowledge and their interest in careers in the fields of science and technology. Opening up the resources of technical universities, either directly to young students or indirectly via their teachers and or the general public, allows opportunities for the next generation of citizens to meet future technological challenges, not as bystanders but as confident and knowledgeable actors.

In this chapter, attention is paid to the development of pre-university engineering education activities and related educational research at the Royal Institute of Technology (KTH). Our 'KTH case' should be seen as an example of how pre-university engineering education and research have been developed at one specific technical university. The presentation should not be taken as normative. This is not an example of 'how it should be done'. Our aim is rather to give an example of how circumstances and conditions surrounding a technical university influence the space for educational research-oriented activities and initiatives. With the hope that experiences gained at KTH will be perceived as transferable to other technical universities with similar objectives, we are ready to present our 'case'.

The chapter is structured as follows: (1) this introductory text; (2) a background of the challenges of educational research and how pre-engineering educational research has developed internationally and nationally; (3) a description of the selected theoretical framework; (4) a presentation of the emergence of the pre-university engineering education, outreach, and related research environment at KTH; (5) examples of KTH research supporting pre-university engineering education and outreach activities; (6) an analysis of the outcome of presented research activities in line with the chosen theoretical framework; and (7) concluding remarks.

2. PRE-UNIVERSITY ENGINEERING EDUCATIONAL RESEARCH (K–12)

Educational Research and Proven Experience

In most (Western) countries, policymakers and stakeholders within the educational sector increasingly stress the importance of research-based education in schools (Prop, 1999/2000: 81; Andræ Thelin, 2009). The move from ambition to reality, is however, much easier to talk about than to actually conduct. A common strategy for teachers in need of assistance and guidance is to adjust the teaching to proven experience. Proven experience is based on teaching traditions developed by skilled professionals during many hours of practice. To use teaching methods that colleagues and mentors have developed, tested, and judged as effective is both natural and sensible. The snag is that experience-based solutions are not always transferable 'straight off,' and not tools that, by themselves, lead to educational development. There is an evident need also for scientifically based guidance.

Educational Research and School Practice

School authorities, researchers, and politicians in most countries have continually discussed to what extent teachers and teaching are influenced by new educational research (OECD, 2015). Research findings seem neither to reach nor to involve practicing teachers to the extent desired. It seems as if there were a considerable gap between educational research and teachers' practice. The importance of a dialogue between research, training, and the educational sector has been emphasised on both 'parties'. The requirement that teacher education should be based on research is stated in governmental directives (e.g., SOU, 2008: 109). In order to consider training to be research based, the scientific basis of teaching must be made clear to students. This includes offering students opportunities to integrate research findings in their learning, and to constructively reflect on the scientific basis of teaching in relation to their own experiences and insights acquired during their work-based 'clinical' training (Wahlström & Alvinger, 2015).

Educational research in Sweden sometimes referred to as 'improving teaching practice research, should support both teachers teaching and students' learning. To do so, the object of study should relate and connect to authentic 'real-life' experiences of teachers and students (cf. Skogh, 2001; Bjurulf, 2008; Teknikdelegationen, 2010). In Sweden, the aim and goal of pre-university engineering education is defined in the national curricula under the heading of technology, mathematics, physics, biology and chemistry (Skolverket, 2011). There are indeed regulations stipulating what must be addressed within the framework of these subjects. However, as the wording of these syllabuses suggests a broad rather than deep appropriation of subject matter, there is considerable room for different interpretations regarding *what* to teach, *how* to teach, and *when* and *why* to teach. Once again, the need for scientifically based decisions on these matters is great.

Trends and Lines of Development in Pre-Engineering Education

First, this presentation is undoubtedly inked by its Swedish context. This "coloration" is most likely reflected in our use of the concepts of 'pre-university engineering education' and 'technology education'. In earlier chapters of this book (de Vries and Norström), both concepts and the relation between them have been discussed from primarily a theoretical philosophical perspective. In this present chapter 'real life' educational activities and related research activities are presented. This move from reasoning to practice put the issue of conceptual use into 'sharp mood'. Our starting point is that educational activities and related research presented in this chapter, to a greater or lesser degree, include engineering elements in line with the reasoning of de Vries and Norström (chapters in this book). Practitioners and concerned educational researchers in different countries do however not always agree on what counts as pre-university engineering education and what does not. The focus of the national curricula varies and so do teaching traditions. In Sweden the use of the concepts of pre-university engineering and technology education by some are used interchangeable, while others never would choose any other heading than 'technology education' for the representation of this/their teaching or research. To us, the heading pre-university engineering education is a logical consequence of our vision of subject depth and continuity in education in engineering sciences – from kindergarten to university. With that being said, it is now time for a brief presentation of the development of pre-engineering educational research in Sweden.

International Development

Pre-university engineering education is a comparatively 'young' field of research. Even though research (on a limited scale) was conducted before 1980, the start of the so-called PATT project, Pupils' Attitudes Towards Technology, in the 1980s (de Vries, 1988) could be seen as a starting point for both Swedish and international pre-university engineering educational studies. A recent review of research (Williams, 2013) revealed interesting patterns regarding the development of the field. In regard to the choice of study focus, Jones and de Vries (2009) identified a number of common areas of research as key areas: 'technology and science', 'learning and teaching', 'the nature of technology', 'perceptions of technology', 'assessment', 'teacher education', and 'theoretical and practical approaches'. Middleton (2008) drew attention to the many different 'types' of research performed internationally. His description of methods includes 'traditional' methods like (video) observations, interviews, verbal protocol analyses and surveys, but also the use of more untraditional analytical tools such as repertory grids. In his review of research, Williams also mentioned a Delphi study involving 20 experts in different countries performed by Ritz and Martin (2013). Findings of this study reveal that further research, is particularly needed in the areas of curriculum studies, studies focusing on sustainability and global citizenship, epistemological studies, and pedagogical studies regarding student learning of technology. To provide additional perspectives on the research field, Williams (2013) analysed research being published in journals and/or presented at international conferences between 2006 and 2013. According to Williams, the interest in Design and Curriculum has continued through the years. Research in the area of STEM is, according to Williams, likely to grow. Research on the educational use of ICT, including computing and mobile learning, was also mentioned as possible areas of increased interest. The difficulties of predicting which areas will increase or decrease in interest are, according to Williams, considerable.

> The future trends for research in technology education will continue to be diverse, and increasingly so, in order to address the needs of this developing profession. (Ibid.: 148)

Even though outreach activities have been a common phenomenon in society since the 90s, not much research has been conducted in this area, especially not when it comes to the efficiency or outcome of an outreach activity. In Sweden, researchers like Fors (2006, 2013), Ljung (2009), and Gumaelius et al. (2016) constitute welcome exceptions. The existing research is otherwise conducted predominantly in the US (e.g., Moskal et al., 2007). The US literature also details how universities deal with outreach activities regarding aims and performances (Jeffers et al., 2004).

National Development

Swedish pre-engineering educational research follows, in principle, the same pattern as the above-described international development. From the 1980s to early 2000s, the *what* issue, that is, course structure and subject content, largely dominated research carried out in Sweden (cf. Gustafsson, 1984; Elgström & Riis, 1990). Although research focusing on the *what* question remains dominating also during the early years of 2000s. (cf. Westlin, 2000; Gyberg, 2003), a number of *how* studies (focusing on K–12 compulsory school teaching of technology), are presented during this period. Mattsson (2002) highlighted teachers teaching, whereas Skogh (2001) and Lindahl (2003) studied pupils' encounters with and attitudes towards pre-engineering/technology education. The start of the first teacher graduate school oriented towards educational research in mathematics, science, and technology (FONTD) in the same period (2003) contributed strongly to an increase in the number of active researchers and pre-engineering education-oriented projects in the STEM field. Since then, a number of initiatives allowing STEM teachers to perform research have been launched around Sweden (teacher graduate schools/programmes). Until today, only two graduate schools/programmes have had a specific focus on the technology subject. Both Technology Education for the Future (TUFF) and Quality, Effectiveness and Status in Technology Education Graduate School (QUEST) were/are hosted by KTH's Department of Learning.

With respect to the Swedish pre-engineering educational research, the period from the mid-2000s until today could be summarised by the words growth and development. Since 2005, 15–20 theses (doctorate and licentiate) have been produced, professors and lecturers have been appointed at several universities and cooperation projects between researchers at institutions around Sweden, and collaborations with international researchers/research environments have been established. During the period, research has increasingly focused on compulsory school teaching and learning technology. The starting point is often taken from a teacher's perspective of how the *how* issues relate to teachers' attitudes and choice of teaching methods (Blomdahl, 2007; Bjurulf, 2008). Also the *what* issue is frequently addressed. Compared to the *what* studies of the 1980–1990s, a shift in focus can be seen. Studies of policy documents and curricula, as they were currently written or practiced, have given way to *what* studies of practitioners' use, interpretations, and transformation of the policy documents. This category includes studies by Klasander (2010), Svensson (2011), Hartell (2015), Norström (2014), and Rolandsson (2015). Although a majority of pre-engineering educational research in Sweden has been (and still is) primarily of a qualitative nature, there are currently a few projects where the approach is either 'purely' quantitative (Svärdh, 2013) or a mix of quantitative and qualitative methods (Gumaelius, Hartell, & Svärdh, submitted).

3. A FRAME FACTOR THEORY APPROACH

Every exposition of an event or series of events will, in different ways, reflect the narrators' views and experiences. This presentation is no exception. We, the authors, have in different ways been part of the development described. A way for us to distance ourselves from our own preconceptions is to contemplate the presented chains of events and experiences by using the frame factor theory (Dahllöf, 1967) as a 'lens'.

Frame factor theory was developed during the 1960s. The basic framework-process model is of a paradigmatic nature that, in general terms, underlines the need to study how a frame, or a combination of frames, affects the pedagogical processes that leads to outcomes in different dimensions. Frame factor theory provides a model for thinking about initiatives and activities (education, research, outreach), not in terms of their effect as interventions, but as opportunities within established limits. Insight about environmental conditions that, to a larger or smaller extent, can be controlled administratively or politically increases the possibility to draw well-founded, action-oriented and theoretical conclusions (Gustafsson, 1999). Depending on what problem or perspective a researcher is interested in, issues regarding the framework, processes, and outcomes can be set in very different ways. Frame factor theory is sometimes criticised because it omits the acts of involved actors/individuals. This is true. Frame factor theory is *descriptive.* It is suitable when the aim is to explore and describe a framework, related processes, and their outcomes at an organisational level. An explanatory approach aiming at a deeper understanding of why 'what happens happen' would demand a supplementary theoretical framework that would, to a greater extent, draw attention to involved individuals, their actions, and influencing factors (von Wright, 1983; Lindblad et al., 1999; Skogh, 2001).

In line with frame factor theory (Dahllöf, 1999), the starting point for our 'case' is an interest in understanding the possibilities and limitations of the framework surrounding pre-university engineering education and related educational research at KTH. According to the model, it is useful to first (1) consider the organisational frames (here, the academic development of the department/organisation); (2) select a dimension for the intended outcome (here, research activities relevant to pre-university engineering education and outreach activities); and (3) ask what kind of process/es become necessary to analyse (here, analyses of the outcome of research activities/processes, in order to identify obstacles, limiting factors, and ways of optimising the impact of/from the research activities/findings).

4. PRE-UNIVERSITY ENGINEERING AT KTH – FRAMES AND ACTIVITIES

KTH is the leading technical university in Sweden, whose core activity is engineering education. The rapid technological development in society implies the need for engineers with skills to act as knowledge brokers and knowledge developers within industry, government, and academia. Insights about the importance of opening up the field of engineering to broader groups of students have resulted in a number of initiatives and efforts at KTH, as well as at other technical universities, in order to spark interest in science and technology among young people.

It takes time to 'build' an engineer. The question of how, when, and what young people are introduced to regarding the STEM subjects is no longer a matter only for schools but also for universities and society as a whole.

In 2010, a new department at KTH, the Department of Learning (DoL), was assigned the task of developing teacher education programmes, faculty training, and outreach activities. At this point, these activities were spread throughout the organisation.

The assignment was to build a comprehensive academic environment for all activities at the university belonging to the competence field of learning in engineering, including both university engineering education and pre-university engineering education (K–12) and its related research. Organising these activities together resulted in the building of a unique environment where teachers who are training at all levels (preschool to university) can interact and learn from each other. An important incentive for creating this department was also the ambition to develop a research environment around these activities in order to increase visibility and improve both pre-university engineering and engineering education in a Swedish context.

Building an academic environment around pre-university engineering education requires long-term investments and dedication from both the management and staff of various departments and disciplines. A range of experts must cooperate with one another, and various means must be coordinated. This presentation describes the circumstances surrounding the execution of pre-university engineering education activities and related research at KTH/DoL. The focus is laid on pre-university engineering education and outreach activities at DoL. We will, however, return to the impact arising from the fact that the DoL is part of a technical university whose core interest lies in higher education with a specialisation in the engineering profession.

Pre-university Engineering Teacher Education Programmes

The management of the university has repeatedly expressed its ambition to take social responsibility and to secure high technology competence among Sweden's youth. The first initiative to broaden the education and training at KTH to also include pre-university engineering education was taken in the early years of the 2000s, nearly ten years prior to the establishment of the DoL. In 2002, a *combined education in both engineering and education* leading to a master's of science and a teaching degree started at KTH in collaboration with Stockholm University. Students can choose specialisation in any of the subject combinations, such as mathematics/physics, mathematics/IT-data, mathematics/energy and environment, and mathematics/chemistry. The programme provides skills to work as an engineer as well as a teacher, predominantly in secondary school and adult education. The programme has been a success and attracts many applicants. Sixty students start the programme each year. Since then, pre-university engineering activities have been increasingly emphasised as an important field of interest at KTH as a whole.

The mandate to expand the educational training to include also pre-school, primary, and secondary school levels arose in conjunction with the founding of the DoL in 2010. Commissioned by Stockholm University, the DoL has since then provided *pre-engineering (technology) courses in teacher programmes* for pre-school teachers up to the sixth grade in the teacher training programmes led by Stockholm University.

Pre-engineering/technology courses for in-service teachers are also given on a regular basis. The range of courses includes both continuous training and courses for teachers working as unqualified teachers, who need credits to be able to obtain a teaching degree.

In 2013, KTH/DoL started another educational initiative together with Stockholm University, *a technology teacher programme* for teachers teaching technology (pre-university engineering) in grades 7–9 in compulsory school (12–15-year-old students). These students earn a teaching degree in three subjects, two of which are technology and mathematics; the third subject can be either chemistry or physics. Unfortunately, teacher education is not considered an attractive educational programme among young people in Sweden, which has resulted in very few applicants to this programme (and similar programmes all over Sweden). So far, about 10–15 students participate in the programme, and the first teachers will be examined in 2018.

In 2016, a third programme will begin. This training programme will last just over a year; taught partly as distance education, it is called *Complementary Pedagogic Training (CPU).* This programme will give people who already have the requested subject competence the possibility to obtain a teacher's degree by only taking the educational part of the teacher programme. As this 'quick route' to the teaching profession is very popular in Sweden, we expect many students will soon apply for admittance.

Outreach Activities at DoL

KTH has initiated and been part of outreach initiatives since long before the initiative to initiate the DoL. In the 1990s, *science courses for kids* were held on weekends, an initiative that was launched by a dedicated professor. During subsequent years, a number of smaller initiatives were started at KTH. The first broader initiative were introduced in 1993 when some of the technical universities in Sweden initiated a schoolchildren's *technology tournament called Teknikåttan* in which KTH/DoL has take an active part.

In 2002 a unified organisation for outreach activities, called Vetenskapens Hus, was established. Vetenskapens Hus is an organisation that works as an umbrella for the diverse set of outreach activities held at KTH/DoL and Stockholm University. It is owned by the two universities, and has operated in close collaboration with the municipality of Stockholm. The initial activities, begun in the early 1990s, are still offered at Vetenskapens Hus, but the core activities of today mainly focus on offering experimental programmes to school classes. Today, approximately 100 different programmes are offered in the disciplines of physics, chemistry, biology, technology, or mathematics (STEM), thereby targeting students from preschool to upper secondary school (K–12). Each programme last for about one and a half hours, and usually include an introduction and a hands-on activity; the programmes all fill a portion of the school's objectives and curriculum content. Examples of programme themes include electron diffraction, encryption, rocket fuel, solar cells, digital waste sorting systems, and plants for business and pleasure. Tutors who are students at KTH or Stockholm University lead the programmes. The university students act as role models and 'experts' in the discipline of interest. Teachers join their classes during all school visits, so the activities offer involved teachers both a learning opportunity and the possibility to observe and assess her or his students.

Besides these core activities, Vetenskapens Hus is also involved in many different events and projects for K–12 students, teachers, and, to some extent, the general public. Examples of such events and projects are *Researchers' Night*, a European project that aims to make researchers visible to the public in a positive way, *Teknikåttan, First Lego League, Amusement Park Physics,* and *Science on Stage*. In total, about 60,000 K–12 students and teachers participate in activities arranged by Vetenskapens Hus each year (Gumaelius et al., 2016).

Building a Sustainable Research Environment Requires Funding …

Successful and effective research environments need to meet a number of requirements and preconditions. Resources in the form of people and funding need to be in place and used wisely in order to fully support involved individuals and institutions. At DoL, this is on-going work. Today KTH allocates about 50% of the funding for the educational research done at KTH, where most of the internal funding is used for engineering education at the university level. The other half consists of external funding from the Swedish Research Council, various foundations, municipalities and business partners. Finding external funding is necessary. Since the area of education in general, and in pre-university engineering education in particular, is known to receive only small amounts of funding compared to nearby fields (such as engineering), the difficulties in finding external funding is the most limiting factor for growth in the KTH group. However, today stakeholders have increasingly paid attention to the challenges of the field, which, in the long run, could improve access to funding.

… and Staff

Creating a dynamic social and academic community continues to be a prioritised task, and has proven to be somewhat more challenging than expected. This might be due to the fact that research in engineering education and pre-engineering education are both relatively new fields. Commonly active researchers originate from many different research areas. Aspects of these activities have traditionally belonged to the central administration (where the personnel may lack research experience/background) rather than to an academic department, which has created additional challenges. Consideration must be taken of the different cultures and traditions that the various activities carry with them.

Since 2010, the head of the DoL and a handful of full-time *professors* and *associate professors*, together with a growing group of *PhD students* – in total around 15–20 persons – have shaped and built up the on-going pre-university engineering educational research at KTH. In the start-up phase, DoL gave some of the *non-academic staff* the opportunity to receive continuous training in order to earn a doctoral degree. In order to enhance the understanding of the research procedure among staff that do not have a doctorate and/or conduct research in their position, all staff have also been given the opportunity to apply for part-time funding for a *practice-oriented research-project* in which their own practice can be researched.

In order to strengthen the field of engineering education at KTH as a whole, *senior researchers* from other parts of the university have continually been offered the opportunity to apply for *part-time funding* (20% for one or two years) for educational research projects at DoL. Several of these projects have been found to be relevant also to pre-university engineering education. In addition, new staff with an engineering education research background has been hired to complement the pre-engineering education-oriented researchers. These measures have resulted in DoL now having a stable academic structure, enabling involved researchers to conduct both pre-engineering education and engineering education in line with the research vision. Within the frames of the research environment at KTH/DoL, research focusing on engineering education at *all* educational levels is now performed. This includes studies of educational progression (subject content as well as skills) over different educational levels/stages. These conditions provide DoL with a unique opportunity for exploring and understanding engineering education as a whole.

Ensuring the recruitment of new researchers is a priority for any research-oriented university. To promote and support practice-oriented educational research, *teaching-graduate programmes* were introduced by the Swedish government (Prop, 2000/2001: 3) in the early 2000s. This initiative was directed towards practicing teachers who, if admitted, would be able to carry on educational research part-time and work as a teacher part-time. In 2008 and 2014, a KTH/DoL research group received funding for two such teaching-graduate schools (TUFF and QUEST). Currently, a total of 14 teaching-graduate school students have been admitted to DoL within the frames of these graduate schools (doctoral studies to the level of licentiate, or 'half a PhD'). The possibility of admitting students with funding from industry is an as-yet untapped opportunity that hopefully will become a reality in the future.

Building a sustainable research community also involves social interaction. Every second week, *higher seminars* with presentations by members of the research group (senior researchers and/or PhD students) or invited internal or external researchers and experts are held. Every sixth week, an invitation to the so-called *researcher's lunch* is sent to those in our staff interested in discussing pre-university (and also university) engineering educational research. Here, the PhD students are responsible for invitations, arrangements, and discussions. These lunches are much appreciated by all concerned.

A dynamic social and academic community also offers the opportunity to communicate and cooperate with researchers at other (national and international) universities. The research group's focus is on being represented at *conferences* in the area and, of course, the aim is to *publish articles* in both high-ranked journals and journals that have a high impact on the teaching practice, as well as national and international journals.

5. SELECTED EXAMPLES OF RESEARCH IN PRE-ENGINEERING EDUCATION

The educational research at KTH has a clear purpose. The ambition is to contribute to the development of the research field and to provide a new and deeper understanding of teaching and learning engineering/technology. Research is based on the assumption that in-depth knowledge of pre-university engineering teaching activities (school based and extramural) will contribute to improved teaching and thus facilitate student learning. It may be noted that even when performing research focusing on pre-engineering education, there is an implied expectation that research findings can and will be useful also in engineering education.

DoL is one of the leading pre-engineering educational research environments in Sweden, and the development of research in many ways reflects the development of research in Sweden as a whole. Even though the research projects at DoL cover a number of research questions/areas, most of our research projects can be housed in one or more of the thematic areas indicated in Figure 1. It is also shown that the research, in one way or another, is related to the question of content and content knowledge.

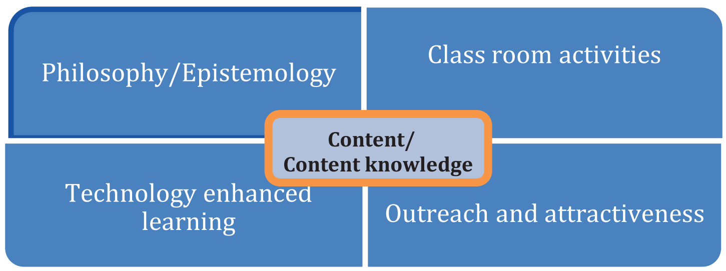

Figure 1. Schematic overview of current research themes addressed at KTH

Regarding the choice of research focus, some research projects relate to activities within the department (courses, outreach activities), while others emanate from involved researchers' search for knowledge and understanding of events and contexts (e.g., on-going licentiate projects include pre-school technology education, students' use of mobile phones, or compulsory school teachers' choice of subject content and related work methods). Below is a selection of research projects performed at the DoL. The examples are selected as being representative of the variety of projects performed at our unit. In line with the chosen theoretical perspective, the presentation of each research block/theme ends with a comment regarding the outcome of the research.

The question of subject content and content knowledge is directly or indirectly at the centre of our research interest (Figure 1). Teaching and learning requires that involved actors, preferably both teachers and students, have a clear idea of what is to be taught/learned. In Sweden, the goals of teaching are set in the curricula. However, the question of how to reach these goals is left for concerned teachers to decide. A considerable space for individual interpretations is hereby opened. In searching for knowledge and understanding of teachers' choices of educational focus, our group has performed a number of *subject*-related studies.

Exploring the epistemology. Based on technology and a philosophical approach, Norström (2014) has performed epistemological as well as practice-related research projects. In a study of technology teachers' understanding of the concept of technological knowledge (Norström, 2014), teachers were asked to decide (and to justify their answers) whether some selected activities involved technological knowledge or not. The results point to a significant problem with important implications for pre-university engineering teaching. Some of the teachers in the study were not able to satisfactorily express an explicit and clear opinion regarding what counts as technological knowledge and what does not. Some of the answers in fact raise questions regarding their disciplinary competence. The studied teachers do express an interest in discussing different ways of interpreting the concept. The impression is that few of them have had such discussions previously (during teacher training or in their respective schools).

Outcome: Tangible results from these studies are their impact on the design of our K–12 courses. Today all K–12 courses include lectures and seminars focusing on epistemological issues, with lots of opportunities for the students to reflect upon and to discuss these matters.

Exploring classroom activities. In collaboration with Stockholm University, Björkholm (2015) recently presented a study highlighting primary school technology education. Björkholm is interested in children's learning of mechanisms. Two learning studies were performed during which primary school teachers and students were followed. Findings revealed a number of different ways that the students in the study assimilate or understand the teaching (what the teacher strives for regarding the students' learning). The study also revealed aspects relevant to students' acquisition of desirable specific skills and knowledge, and which are therefore important for the teacher to address.

Assessment conducted by teachers has long been, and still is, a high-profile issue for politicians, educational researchers, school leaders, and teachers in Sweden. Assessment links teachers' teaching to learners' learning. Transparency regarding criteria for success in assessment processes is challenging for most teachers. With the purpose of exploring what criteria for success teachers put forward during the act of assessment, Hartell and Skogh (2015) presented a study of primary school teachers during their assessment of Year 5 pupils' multimodal e-portfolios. Findings showed consensus among the studied teachers, focusing on the execution of the task in relation to the whole, rather than to particular pieces of student work. The results confirmed the importance of task design, where active learning in combination with active tutoring is an integral part, including provision of time and space for pupils to finish their work. In another study, Hartell and Norström (in progress) explored how tests are designed, what content they address, and for what purpose they are used. The studied tests were gathered from 12 schools in the Stockholm region. The test items were classified according to the expected response—'short answer', 'alternative response', 'performance task', etc. They were also classified according to knowledge—'remember fact', 'remember term', 'create', etc. A third classification was based on the technical abilities listed in the national curriculum. Findings revealed that the most common types of questions in the studied technology tests are of the 'short-answer' type, dealing with the name or function of a technical artefact or principle. Many questions are difficult to understand, potentially very far-reaching ('Explain the function of a steam-engine'), and/or deal with problems and concepts from natural sciences rather than technology ('Define density').

The authors concluded that the examined test questions, in general, are too narrow in scope to be suitable for testing pupils' knowledge or abilities in the interdisciplinary technology subject, and the quality of the items limit possible inference for further activities.

Outcome: The findings of Björkholm regarding possible patterns of learning are discussed during courses. Such discussions have proved to improve skills in designing lessons, as well as increased teachers'/teacher-students' awareness of the use/misuse of concepts among children.

Grading and assessment is a prioritised area of concern to students, student teachers, in-service teachers, and society. It is an official exercise of a public authority and therefore in need of being performed correctly. Assessing knowledge and skills is therefore an important element in all our courses.

Exploring outreach activities. The perhaps clearest example of pre-university engineering activities at DoL is performed within the frames of our outreach activities. Vetenskapens Hus operates from the explicit goal to increase interest in the STEM-subjects and, by extension, the interest in the field of engineering. Our affiliation at a technical university is here reflected in both the design and staffing of the activities (e.g. science and engineering students being hired as teachers/supervisors). At KTH, the outreach activities have been the focus of research only for the last few years. In a recent study (Gumaelius et al., 2016), the question of how technical universities deal with the task of outreach was explored. The study analysed eight different university strategies for outreach and showed how their strategies influence factors such as number of visitors, needed support, collaboration partners, and more. Two major strategies were found. Some universities choose a strategy that resembles the everyday activities at university, hosting fewer visitors but often lasting for a longer period than the other strategy. Other universities choose an alternative strategy less similar to everyday university activities, hosting more visitors and often performed together with other actors in society, such as municipalities and/or industries. Concerned actors all agreed on the need for better evaluation methods in order to measure the effectiveness of outreach initiatives.

Other outreach studies have examined specific initiatives aimed at increasing the interest in STEM. In an on-going study (Nymark & Gumaelius, submitted) of a competition called Teknikåttan (corresponding translation: 'Technology year eight', a technology oriented tournament for 15-year-old students) collected data from thousands of students were analysed in order to explore young people's views on/experiences of different subjects. In line with previous research, preliminary findings revealed that girls showed better results when questions were related to biology, and boys showed better results in physics.

Improvement of school based pre-university engineering education. The Boost of Technology (BoT), a regional initiative aimed at improving school technology education in the Stockholm area, was the focus of another study (Gumaelius, Hartell, & Svärdh, in progress). The study described and analysed important factors for educational change (e.g., teacher competence, available professional development, and updated steering documents).

Gumaelius and Skogh (2015) have also studied the BoT initiative. Work plans from 19 schools were collected and analysed. Two aspects in particular were studied: (1) how the work plans correlate with the national steering documents, and (2) to what extent the work plans correlate with Mitchams's (1994) four ways of describing technology/technological knowledge. Findings showed that many (most) work plans contain quotes from the curricula without specification regarding how the aspects in question should be dealt with (choice of activities and/or aims and learning goals). In the cases where actual suggestions regarding themes and activities did occur, the knowledge objectives were rarely (almost never) described. Findings revealed few traces of what, according to Mitcham, could be described as 'technical content knowledge'. Technical volition is an aspect almost invariably anticipated in the work plans. Most work plans also lacked progression in the presented themes/learning activities. It was concluded that the teachers in the study, despite having attended the BoT-program, know little about technical knowledge, and therefore are in need of further subject content education.

Outcome: The variation in pedagogical and subject-related approaches needed in extramural environments places high demands on teaching. Since outreach activities often include involvement from industry and trade organisations, various forms of participation are/can be studied and analysed. The findings from outreach research are obviously important contributions in the (re)design of future and current outreach activities. They are discussed in our teacher education courses and at research seminars.

Findings have proven to be useful in discussions about if/how (technology) philosophical theories can be used as a tool for teachers/teacher-students when designing and assessing lessons and/or longer periods of teaching activities.

Exploring technology enhanced learning research. An increasingly important educational research area at KTH and DoL is the use of digital tools/technology in schools. Under the heading of 'E-learning research', a number of studies focusing on learning supported by digital technology have been performed at our department. In a recent thesis project (Stenbom, 2015), inquiry-based, one-t-one online education was studied. The empirical case used in the thesis was the so-called Math Coach programme. This programme employs one-to-one education for K–12- students in mathematics via chat and a shared digital whiteboard. Online coaching is, according to the thesis, theoretically grounded in collaborative constructivism, critical thinking, and proximal development. It is defined as an inquiry-based learning activity through which a person receives support on a specific subject matter from a more knowledgeable person, using the Internet. The study introduced a newly developed framework/analytical tool called Relationship of Inquiry. Central for this framework are the elements of cognitive presence, teaching presence, social presence, and emotional presence. Emotional presence is, in the study, confirmed as a critical, interdependent element of the framework. Another study (Leinonen et al., 2015) explored the use of digital resources in Swedish classrooms. It addressed the question of what ways mobile phones were used to support students in a problem-solving process. With regard to their problem-solving activity (based on observations during a technology lesson), both supportive (a photograph of a bridge downloaded from the internet) and non-supportive (a mobile-photo documentation action initiated by the teacher) actions were found. With the aim of deepening our understanding of how teachers can/should structure students' use of mobile devices in problem-solving activities, these preliminary results will be further analysed and discussed.

Outcome: KTH has formulated a vision regarding its e-learning policy with the goal of making virtual learning environments as effective and natural as campus-based environments. This vision demands fundamental research that can draw attention to e-learning (and e-teaching) from different perspectives and focus on different educational levels. New insights (as in the above-mentioned studies) are important elements in our courses.

Research projects linked to university engineering education. The primary focus of most DoL research projects lies in K–12 pre-university engineering education. This, however, does not mean that research topics linked to engineering education are excluded. On the contrary, a number of such studies have been performed. In a study of what are perceived to be the main challenges associated with integrating of social sustainability in engineering education at KTH (Edvardsson, Björnberg, & Skogh, 2015), it was found that programme leaders and teachers at KTH struggle with how to understand the concept of social sustainability. The vague and value-laden nature of the concept is considered to be a challenge when operationalising educational policy goals on sustainability into effective learning outcomes and activities. Allocation of resources (assisted peer discussions, supplementary sustainability training for teachers, feedback on initiatives taken, and economic incentives) was identified by the informants as being crucial to successful integration of (social) sustainability in engineering education at KTH. In a follow-up study (Edvardsson, Björnberg, & Skogh, under review), focus was shifted to the students. Engineering students enrolled in a combined engineering and teacher education programme were asked about their understanding of the concept of sustainable development and the professional roles and responsibilities of engineers vs. teachers in contributing to this goal. Findings indicated a fairly 'balanced' view of sustainable development among the students; a clear interest in sustainability issues, particularly among the final-year students and female students; a tendency to ascribe significant but differentiated responsibilities to engineers and teachers; and a surprisingly low degree of confidence in their own ability to adequately address sustainable development issues in their future work life. A similar study (Skogh, Gumaelius, & Geschwind, 2013), focusing on sustainable development education in compulsory school (i.e., the same research question and method as Edvardsson, Björnberg, & Skogh), pointed to the same kind of experiences/attitudes among compulsory schoolteachers and headmasters. Another engineering education-related study (Rooke, 2013), highlighted initiatives taken in order to increase the number of female students in higher technology education. Findings revealed that structural actions, preferably initiated by the government, are often successful. The introduction of the Technical Preparatory Year, affirmative action, and new programmes with adjusted subject combinations are some examples of such measures. The inclusion of gender and gender-inclusive methods in policy documents is another important factor. A last example of research is taken from a project that is located between the areas of pre-engineering education and engineering education. In a recent study, Engström (2015) explored the profiles of successful female engineering students. Based on collected data (web-based questionnaire sent to 411 students), four different female student profiles were detected: the Life-experiences profile, the Engineer-capital profile, the Educational-capital profile, and the Natural-science-capital profile. Children of educated parents are provided with clear choices concerning educational and professional goals through the capital they possess. These active and successful forms of capital do not seem to come from earlier schooling, but from the students' home conditions. One important implication for pre-university engineering education is to take responsibility for making technology a subject also relevant for girls with different social backgrounds, interests, and lifestyles.

Outcome: The wide approach (which in different ways covers both compulsory school and university levels) is important to actors on 'both sides'. Linking school and university together is beneficial in relation to subject content–related issues and choice of work methods (progression in teaching/learning), as well as for reasons behind student recruitment. The gender aspects highlighted are important to engineering education at all levels. Findings have been used in seminars with in-service teachers. The dissemination of these findings to stakeholders at KTH is still limited.

6. OUTCOME ANALYSIS

In line with the chosen theoretical framework (Dahllöf, 1999), we have now described the framework in focus, that is, the academic development of the department/organisation. We have selected a dimension of the intended outcome of this framework, that is, research activities relevant to pre-university engineering education and outreach activities. Consequently, it is now time to analyse the outcome of research activities/processes in order to identify obstacles, limiting factors, and ways of optimising the impact of the research activities and findings.

Obstacles?

In thinking about possible obstacles that may hinder the development of our research, we perceive more opportunities than barriers. We do recognise that a precondition for continued development is that KTH management continues to believe that educational research is important, or rather that educational research is of equal importance as other research areas at KTH. Excellence in both scientific knowledge *and* teaching methods is clearly an important competitive advantage, which can help KTH hold onto its position as Sweden's leading technical university.

The support from the central management of KTH has been clear in regard to expressing appreciation of our research efforts. It is, however, not obvious to all KTH staff that educational research focusing on pre-university engineering education has the same dignity as other research performed at KTH. It must also be considered that, even if educational research is seen as important, the core interest lies in engineering education research. An important mission for the DoL is to clarify that there are findings from pre-university engineering educational research that are also applicable to university engineering education. What and how students learn in engineering-relevant subjects in school could be of also interest to university teachers.

The previously mentioned 'part-time funded positions', assigned to senior researchers at 'the rest' of KTH, has, this context, proven to be an important initiative. The participating part-time researchers have shown great interest in educational theory and methodology. Several have taken seminars at their 'home institutions' and thereby shared their knowledge and experiences. The need for scientifically based education models is significant, especially in times when new technology is gaining entrance into many courses.

Which Are the Limiting Factors?

We see this question as very relevant when analysing how the frame factors should be continuously followed up in order to see how well educational research is developing at KTH. Simply stated, we believe there are two main limiting factors, namely, the number of researchers and amount of resources.

There is no doubt that our department has grown substantially over the years since its inception in 2010. It is obviously something that has to be described as very positive. We are today considered to be one of the leading research environments within the field of educational pre-university engineering research in Sweden. Our researchers are represented at many national and international research contexts (conferences, publications), which give us opportunity to share findings outside the institution. However, there are challenges we need to deal with.

For a research environment to be stable, the issue of recruitment needs to be kept constantly revisited. We have learnt that it is rather difficult to recruit faculty who possess the desired competence. Very few PhDs have focused on technology education, and there are so far very few full professors, nationally and internationally, whose main focus is technology education or pre-engineering education. Surprisingly to us, we also learnt that it is difficult to recruit PhD students among practicing teachers at our research schools. This may well be a consequence of the low status of technology as a subject in school. As the number of subject-specific educated teachers increases, a change in attitudes should be expected.

The fact that not many researchers have a background in pre-engineering research creates a research environment where researchers originate from different research areas (engineers within various specialisations and teachers at different levels of the compulsory school system). Even though this is seen as an important asset, consideration must be taken of researchers' different cultures and traditions (e.g., publication strategies and/or theoretical and methodological approaches). Today several members of the staff have a mixed teacher-engineering background, which has proven to be valuable to both research and teaching activities. We must continue to make room for, and to take advantage of, the different expertise that our researching staff carries with them. Here, activities like higher seminars and research lunches constitute important forums. The fact that growth has been rapid in terms of the number of researchers does not mean that the supply of researchers is secured over the long term.

Resources are always an issue. In any organisation, there is always a need for more money. Although it must be said that there is no obvious connection between a big budget and successful research, research funding *is* important. It not only sets the frames for what is possible to explore and investigate, but also access to funding can be seen as a marker of how important research is to society and, by extension, the extent to which eminent scientists are willing and able to devote themselves to educational research. In Sweden, there is inconsistency in how the field of educational research is treated. In the public debate, educational research is pointed out as an important (even *the* most important) means to secure Sweden's future position as a leading industrial nation by improving teaching and learning in school and students' performance on international tests. Looking at how the state distributes research funding, the picture is reversed. The Swedish Research Council, which is the largest public funder of research in Sweden, is given a budget in which 160 million Skr is allocated to research in educational sciences each year, approximately one fifth of the funding allocated to natural and engineering sciences and to medicine and health. The funding to medicine and health and to natural and engineering sciences are well earned, and both areas are most likely in need of even more research funding. It is, however, interesting to point to the remarkable disproportion in funding. One might have expected that education would be classified as an equally important key area to governmental decision makers responsible for the distribution of national research funds. Dare we hope for a change reflected in the size of future research grants?

Ways of Optimising the Research Impact

Based on our analysis of the research projects accounted for in Section 4, we conclude that these studies, seen separately and together, meet the demand for useful K–12 pre-university engineering educational research. In different ways, our research is actually used in the courses and outreach activities performed at the DoL. We can also confirm that research is disseminated to both national and international K-12 teaching and research environments. It can probably be said that these are very good results for a research environment still being built up.

But we can also identify possibilities that need to be realised in order to further optimise the research impact. It is of the greatest importance to further develop networks with our stakeholders. Technology and engineering activities are not isolated from society. Including industry in pre-university engineering educational research has a potential of making pre-university engineering education research part of, and not distant from, society and the contexts where it ultimately will be of use. This connection is urgently needed in both educational and research activities. Today Vetenskapens Hus collaborates closely with both industry and the municipality, thereby playing an important role when it comes to bringing the academy and society together. These actors all share the same interest in increasing young people's interest and knowledge in STEM subjects and collaborative projects, and initiatives are in fact already on-going. This partnership gives us a unique opportunity to interact with industry in terms of outreach, education, and research. Vetenskapens Hus also has great development potential in other areas. Obviously, increasing the number of visiting students is one such potential gain. Vetenskapens Hus is filled with school classes that continually offer the same experimental programmes, which opens up many opportunities to test and evaluate educational methods and strategies. The potential of Vetenskapens Hus serving as an educational laboratory for research is evident. Already, many teacher-students conduct their thesis projects at Vetenskapens Hus (performing tests and/or developing classes/experiments), but more research can and should be conducted in these laboratories.

7. CONCLUDING REMARKS

In a research environment based on engineering education and pre-university engineering education (including technology education) it is possible to link school, university and society in a successful way, i.e. where all involved parties acts in a fruitful collaboration. This has previously been seen in the co-owned centre for outreach activities at Vetenskapens Hus. From the analyse of what is presented in this chapter this collaborative approach can and should be taken by the whole DoL, in all its research, education and outreach activities.

We can conclude that in order for pre-university engineering education and related research to reach the goal set, to increase the interest for engineering in society, both formal and informal educational environments are needed. In

Sweden pre-university engineering is taught formally mainly within the frames of the Science- and the Technology subjects and, informally at science centres, museums and educational centres such as Vetenskapens Hus.

By placing teacher-training programs for future technology teachers at a technical university it is possible to facilitates the use of in house competence in engineering knowledge and thereby future teachers' skills in engineering. Thus, in the long run, teachers teaching technology in school will have higher competence in engineering and probably this make teachers aware of the importance of pre-university engineering education in school. This insight may also be the base for an adequate progression in the school system making students well prepared for university engineering studies.

In this chapter, the frames, processes, and outcomes from educational and research activities at technical universities is presented. The presented frames are probably not exceptional or unusual. Aside from the fact that we, within the frames of our university, are able to monitor and study teaching and learning in engineering sciences, from preschool to higher education, our department most likely resembles most universities. It is all about making room for searching for new and/or deeper knowledge about teaching and learning. It is not always easy, but important.

For us, it is now possible to perform what could be described as an inversed frame factor analysis. Insight about frames, processes, and outcome opens up discussions about what factors and elements we can and should revise or develop in order to optimise the outcomes of our investment in pre-university engineering research.

A well-known phrase reads, 'No man is an island'. This idea is definitely applicable to us. Our research team is built on collaborations within and outside our university. Nationally, our partners are found at all levels of education. It may be teachers and students, schools, municipalities, government agencies, and, not least, industry and industrial organisations. At the international level, we have established cooperation with leading researchers in our fields. The prospects for the future seem good. Together with our partners, we will continue our efforts to explore the field of pre-university engineering educational research.

REFERENCES

Andræ Thelin, A. (2009). *På tröskeln till en okänd värld. Forskarutbildning och skolans vardag.* Rapport 31/2009. Oslo: Norsk institutt for studier av innovasjon, NIFU STEP.

Bjurulf, V. (2008). *Teknikämnets gestaltningar* (PhD thesis). Karlstad University, Faculty of Arts and Education, Sweden.

Björkholm E. (2015). *Konstruktioner som fungerar. En studie av teknikkunnande i de tidiga skolåren* (Doctoral thesis). Stockholms universitet, Stockholm, Sweden.

Blomdahl, E. (2007). *Teknik i skolan* (Doctoral thesis). Institute of Education, Stockholm, Sweden.

Dahllöf, U. (1967). *Skoldifferentiering och undervisningsförlopp*. *Göteborg Studies in Educational Sciences 2*. Stockholm: Almqvist & Wiksell.

Dahllöf, U. (1999). *Det tidiga ramfakteorteoretiska tänkandet. En tillbakablick. I: Pedagogisk forskning i Sverige* (Årg. 4, nr 1). Göteborg: Göteborgs universitet.

de Vries, M. (1988). *Techniek in het natuurkunde-onderwijs* (Doctoral Thesis). *Technische Universiteit Eindhoven,* Eindhoven, The Netherlands.

Engström, S. (2015). Female students who succeed within higher technical education: When and why they choose and who they are. *Procedia – Social and Behavioral Sciences, 167*(8), 161–169.

Edvardsson Björnberg, K., Skogh, I.-B., & Strömberg, E. (2015). Integrating social sustainability in engineering education at the KTH Royal Institute of Technology. *International Journal of Sustainability in Higher Education, 16*(5), 639–649.

Edvardsson Björnberg, K., & Skogh, I.-B. (submitted). KTH student perceptions of the engineer's vs. Teacher's roles and responsibilities in contributing to sustainable development.

Elgström, O., & Riis, U. (1990). *Läroplansprocesser och förhandlingsdynamik : exemplet obligatorisk teknik i grundskolan* (Linköping Studies in Arts and Science, 52). Linköping, Sweden: Tema University.

Fors V. (2006). *The missing link in learning in science centres* (Doctoral thesis). Luleå tekniska universitet, Luleå, Sweden.

Fors V. (2013). Teenagers' multisensory routes for learning in the museum: Pedagogical affordances and constraints for dwelling in the museum. *The Senses & Society, 8*(3), 268–289.

Gumaelius, L., & Skogh, I.-B. (2015). Work plans in technology. A study of technology education practice in Sweden. In M. Chatoney (Ed.), *Marjolaine Chatoney. Plurality and complementarity of approaches in design and technology education: PATT29 conference proceedings*. Marseille, France.

Gumaelius, L., Almqvist, M. , Árnadóttir, A., Axelsson, A., Conejero, J. A., García-Sabater, J. P., Klitgaard, L., Kozma, C., Maheut, J., Marin-Garcia, J., Mickos, H., Nilsson, P.-O., Norén, A., Pinho-Lopes, M., Prenzel, M., Ray, J., Roxå, T., & Voss, M. (2016) Outreach initiatives operated by universities for increasing interest in science and technology. *European Journal of Engineering Education.* Retrieved from http://dx.doi.org/10.1080/03043797.2015.1121468

Gumaelius L., Hartell E., & Svärdh J. (submitted). *Improvements in technology education during the boost of technology initiative—Evaluated by measuring changes in preconditions*.

Gustafsson, C. (1984). Utvecklingsarbetet Barn och teknik. Sju arbetsrapporter. In *Pedagogisk forskning i Uppsala 50*. Uppsala: Uppsala universitet, Pedagogiska institutionen.

Gustafsson, C. (1999). Ramfaktorer och pedagogiskt utvecklingsarbete. *Pedagogisk Forskning i Sverige, 4*(1), 43–57.

Gyberg, P. (2003). *Energi som kunskapsområde* (Doctoral thesis). Linköping University, The Tema Institute, Technology and Social Change. Linköping. Sweden. Linköping University, Faculty of Arts and Sciences.

Hartell, E. (2015). *Assidere Necesse Est. Necessities and complexities regarding teachers' assessment practices in technology education* (Doctoral thesis). KTH Royal Institute of Technology, Stockholm. Sweden.

Hartell, E., & Skogh, I.-B. (2015). Criteria for success: A study of teachers' assessment of e-portfolios. *Australasian Journal of Educational Technology,* 2.

Hartell, E., & Norström, P. (submitted). *What is it called and how does it work?*

Jeffers, A. T., Safferman, A. G., & Safferman, S. I. (2004). Understanding K–12 engineering outreach programs. *Journal of Professional Issues in Engineering Education and Practice, 130*(2), 95–108.

Jones, A., & de Vries, M. J. (2009). International handbook of research and development in technology education. *International Journal of Technology and Design Education, 22*(1), 115–122.

Klasander, C. (2010). Talet om tekniska system – förväntningar, traditioner och skolverkligheter. *Studies in Science and Technology Education* 32 (Doctoral thesis). Linköpings universitet, Linköping. Sweden.

Leinonen, T., Hrastinski, S., & Skogh, I.-B. (2015). 'Exploring Students': Multimodal mobile use as support for school assignments. *ASEE Annual Conference and Exposition, Conference Proceedings*.

Lindahl. (2003). *Lust att lära naturvetenskap och teknik? En longitudinell studie om vägen till gymnasiet* (Doctoral thesis., Göteborg Studies in Educational Sciences 196). Acta Universitatis Gothoburgensis, Göteborg. Sweden.

Lindblatt, S., Linde, G., & Naeslund, L. (1999). Ramteori och praktiskt förnuft. *Pedagogisk Forskning i Sverige, 4*(1), 93–109.

Ljung B. (2009). *Museipedagogik och erfarande*. Doktorsavhandling Stockholms universitet, Pedagogiska Institutionen.

Mattsson, G. (2002). *Teknik i ting och tanke. Skolämnet teknik i lärarutbildning och skola*. IPD-rapport 1. Göteborg: Göteborg universitet.

Middleton, H. E. (Ed.) (2008). *Researching technology education: Methods and techniques*. Rotterdam, The Netherlands: Sense Publisher.

Mitcham, C. (1994). *Thinking through technology.* Chicago, IL: The University of Chicago Press.

Moskal, B. M., Skokan, C., Kosbar, L., Dean, A., Westland, C., Barker, H., Nguyen Q. N., & Tafoya, J. (2007). K-12 outreach: Identifying the broader impacts of four outreach projects. *Journal of Engineering Education, 96*(3), 173–189.

Norström, P. (2014). How technology teachers understand technological knowledge. *International Journal of Technology and Design Education, 24*(1), 19–38.

Nymark, T., & Gumaelius, L. (in review). *The role of Teknikåttan' – A competition aimed at increasing interest in science and technology for year 8 students.*

OECD. (2015). *Improving schools in Sweden: An OECD perspective*.

OECD. (2015). *Program for International Student Assessment* (PISA). Retrieved December 2, 2015, from http://www.oecd.org

Proposition. (2000/2001). 3: *Forskning och förnyelse*. Stockholm: Utbildningsdepartementet.

Proposition. (1999/2000). 81: *Forskning fo□r framtiden – en ny organisation fo□r forskningsfinansiering*. Stockholm: Utbildningsdepartementet

Research Council. Retrieved December 02, 2015, from www.vr.se

Ritz, J., & Martin, G. (2013). Research needs for technology education: An international perspective. *International Journal of Technology and Design Education, 23*(3), 767–783.

Rolandsson, L. (2015). *Changing computer programming education: The dinosaur that survived in school: An explorative study of educational issues based on teachers' beliefs and curriculum development in secondary school* (Doctoral thesis). KTH Royal Institute of Technology, Stockholm, Sweden.

Rooke, G. (2013). *In search for gender awareness in technology education* (Licentiate thesis). KTH Royal Institute of Technology, Stockholm, Sweden.

ROSE-project (The Relevance of Science Education). Retrieved December 02, 2015, from http://roseproject.no

Skogh, I.-B. (2001). *Teknikens värld – flickors värld: en studie av yngre flickors möte med teknik i hem och skola* (PhD thesis). *Studies in Educational Sciences*, 44.

Skogh, I.-B., Gumaelius, L., & Geschwind, L. (2013, December 2–6). Education for sustainable development in compulsory school technology education: A problem inventory. In *Technology education for the future: A play on sustainability. Proceedings. PATT 27*. Christchurch: University of Waikato

Skolverket. (2011). *Curriculum for the compulsory school, preschool class and the leisure-time centre*. Retrieved from http://www.skolverket.se/publikationer?id=2687.

SOU. (2008). 109: *En hållbar lärarutbildning. Betänkande av Utredningen om en ny lärarutbildning* (HUT 09). Stockholm: Utbildningsdepartementet.

Stenbom, S. (2015). *Online coaching as a relationship of inquiry: Exploring one-to-one online education* (Doctoral thesis). KTH Royal Institute of Technology, Stockholm. Sweden.

Svärdh, J. (2013). *Measuring long-term effects of a school improvment initiative* (Licentiate thesis). KTH Royal Institute of Technology, Stockholm, Sweden.

Svensson, M. (2011). *Att urskilja tekniska system: Didaktiska dimensioner i grundskolan* (Doctoral thesis). Linköping University Electronic Press, Linköping, Sweden.

Teknikdelegationen. (2010). *Vändpunkt Sverige* (No. 2010:28 in SOU). Stockholm: Teknikdelegationen.

TIMMS (Trends in International Mathematics and Science Study). Retrieved December 2, 2015, from http://timssandpirls.bc.edu

von Wright, G. H. (1983), Determinism and the study of man. In G. H. von Wright (Ed.), *Philosophical papers of Georg Henrik von Wright. Vol. 1: Practical reason.* Ithaca, NY: Cornell University Press.

Wahlström, N., & Alvunger, D. (2015). Forsk*ningsbasering av lärarutbildningen*. *Delrapport av SKOLFORSK-projektet, Vetenskapsrådets rapporter 2015*. Stockholm: Vetenskapsrådet.

Westlin, A. (2000). *Teknik och politiskt handlande: Rationalitet och kritik i den samällsorienterande undervisningen* (PhD thesis). Acta Universitatis Upsaliensis, Uppsala.

Williams, J. P. (2013). Research in technology education: Looking back to move forward. *International Journal of Technology and Design Education*, *23*, 1–9.

Lena Gumaelius
Department of Learning, School of Education and Communication
Royal Institute of Technology
Sweden

Inga-Britt Skogh
Department of Learning, School of Education and Communication
Royal Institute of Technology
Sweden