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Results of the International Research Study

August 2009

CCETE Project

Concepts and Contexts in Engineering and Technology Education

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Preface

This report is the outcome of a cooperative study undertaken by two institutions: Hofstra University (New York, U.S.) and Delft University of Technology, Delft, Netherlands). Michael Hacker (Hofstra) and Marc de Vries (Delft) have known each other for many years and have cooperated on previous projects (e.g., international conferences on technology education in the context of the NATO Scientific Affairs Program). Ammeret Rossouw is a student in the Science Education and Communication Masters Program that is offered at Delft. Ammeret has done most of the practical work, and Mike and Marc have provided guidance in developing the concepts and contexts, processing the incoming data, and making sense of the data against the background of engineering and technology education, the field in which they have been involved for more than two decades. For all three of us, working together on this research study has been a rewarding and enjoyable experience.

We would like to thank NSF for providing the necessary funding for this study. We believe the study is highly relevant to the development of engineering and technology education, as it is related to the fundamental issue of establishing a sound conceptual basis for this education.

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Executive Summary

The CCETE Project conducted an international research study from June to August 2009 to identify the most important unifying concepts and disciplinary contexts in engineering and technology (ETE). The purpose of the study was to provide a framework for developing contemporary secondary school ETE curricula. Project results have the potential to inform preservice engineering and technology teacher education curriculum design as well.

The study draws upon the expertise of 30 individuals from nine countries with a broad range of experience in ETE-related domains. These experts included philosophers and historians of technology, journalists, technology teacher educators, and engineering educators.

The set of core unifying concepts that has emerged from this Project includes those that are transferable (generalizable) over a wide range of technological fields of study, subsume and synthesize a body of related subconcepts, and give insight into the nature of engineering as a holistic endeavor. The concepts and subconcepts include Design (optimization, trade-offs, specifications, technology assessment, invention); Modeling; Systems (artifacts, function, structure); Resources (materials, energy, information), and Human Values (sustainability, innovation, risk, failure, social interaction).

The panel developed a list of contexts that reflected how ETE endeavors address personal, societal, and global concerns. Contexts include: food, shelter (our translation of the context that was originally called ‘Construction’), water, energy, mobility (originally called ‘Transportation’), production, health (the former ‘medical technologies’ context), security, and communication. The panel decided to add the recommendation that when developing a curriculum, the contexts should be elaborated in two directions: in a ‘personal concern’ (or ‘daily life practice’) direction and in a ‘global concern’ direction.

The research methodology of this study is a modified version of the Delphi survey.The project is a component the U.S. National Science Foundation (NSF) –funded *MSTP Project* (Mathematics, Science, and Technology Partnership, #DUE 0314910.) that is conducting research on how contextual learning improves student understanding.

1 Introduction

One of the main issues in the development of engineering and technology education is the search for a sound conceptual basis for the curriculum in the U.S. and other countries worldwide. This search has become relevant as the nature of technology education has changed: it has gradually evolved from focusing on skills to focusing on technological literacy. This literacy implies that pupils and students have developed a realistic image of engineering and technology. What is a realistic image of engineering and technology? The answer is derived from several sources; among them are the academic disciplines that study the nature of engineering and technology, such as the philosophy of technology, the history and sociology of technology, and design methodology. A different approach is to ask experts for their opinions on this matter, and that is the route we have taken to find broad concepts that offer a basis for developing engineering and technology education.

We need to be explicit about what we mean by engineering and technology. Technology, the broader of the two disciplines, encompasses the way humans develop, realize, and use (and evaluate) all sorts of artifacts, systems, and processes to improve the quality of life. Technological literacy is what people need to live in, and control, the technological environment that surrounds us. This literacy comprises practical knowledge, reasoning skills, and attitudes. Engineering is more limited. It encompasses the professions that are concerned with the development and realization of such artifacts, systems, and processes.

Engineering and technology education has long been delivered in two ways: through general education and through vocational education. In general education, the focus historically has been on practical (craft) skills. However, this emphasis has changed in most countries, including the U.S.; traditional school subjects have been replaced by what is generally called "technology education." The main purpose of technology education is developing technological literacy, but in some cases a vocational element remains. In vocational education the focus has been on preparing for a career in the trades or in technical areas. This kind of teaching has focused on specific knowledge and skills. The latest development is that engineering has been accorded a more substantial place in general (technology) education. This shift is combined with the integration of science and math and leads to what is known as science, technology, engineering, and mathematics (STEM) education. Our use of the term *engineering and technology education* (ETE) relates to these contemporary developments and characterizes ETE as important and valuable for *all* students. Traditionally, curricula for engineering and technology education are structured according to either engineering disciplines (e.g., mechanical engineering, electrical engineering, construction engineering) or application fields (e.g., transportation, communication). These structures do not offer much insight into the nature of engineering and technology. A better approach for developing insights is to search for basic concepts that are broadly applicable in engineering and technology and cut through different engineering domains and application fields. An example of such a concept is the systems concept. In the 1970s, the Man-Made World project focused on developing a curriculum based on such concepts. Since then, little work has been done in this area, although useful work has been done on identifying usable concepts.

The various efforts to develop a sound conceptual basis for teaching engineering and technology have led to the development of important insights and ideas. A major accomplishment was the development of the Standards for Technological Literacy in the U.S. In these standards there are many concepts related to engineering and technology. In addition, the academic disciplines of the philosophy of technology, the history and sociology of technology, and design methodology have also developed new insights that have not yet been integrated into the standards. Although eminently useful as focal points for learning, standards typically define what students should know and be able to do in specific content or programmatic areas. In some cases, competencies defined by standards are quite broad; in other cases, the competencies are atomistic.

To enhance standards-driven curriculum by helping learners understand relationships among technological domains, this study has identified a set of overarching, unifying concepts that cut across domains and thus give insight into the holistic nature of engineering and technology. These broad, unifying concepts can be used to develop curriculum and learning experiences in engineering and technology education. Some opportunities exist to make this study different from previous ones. We will mention three of the study's components in particular:

(1) We have consulted experts from a variety of disciplines concerned with basic concepts related to engineering and technology. The disciplines are technology education (as a component of general education at the secondary level, technololgy teacher education and educational research); engineering education (at the tertiary level) and engineernig organizations; philosophy and history of technology; design methodology; and science and technology communication. This last discipline is concerned with communicating about science, engineering, and technology, and it too is faced with the need to work with clear and broadly applicable concepts related to engineering and technology.

(2) We have consulted experts from a variety of countries. The Standards for Technological Literacy were primarily an effort involving experts in the U.S.

(3) We have asked not only for concepts but also for contexts in which the concepts can be taught. This should be seen against the background of recent developments in educational research. Such research has led to the insight that concepts are not learned easily in a top-down approach (i.e., learning the concepts at a general, abstract level first and then applying them to different contexts). Even an approach in which concepts are first learned in a specific context and then transferred to a different context has proved unfruitful. The most recent insights developed reveal that concepts should be learned in a variety of contexts so that generic insights can grow gradually. This growth leads to the ability to apply the concepts in new contexts. In this approach, it is important to identify the concepts that should be learned as well as the contexts that are suitable for learning those concepts.

In summary, this report describes a study that has identified basic and broad themes related to engineering and technology, as well as the contexts that are suitable for learning about those themes. We have asked an international group of experts in a variety of disciplines for their input. What we have looked for are overarching concepts and themes that are both basic and broad: they must be transferable over a wide range of engineering and technological fields of study, and subsume and synthesize a body of related subconcepts. The contexts should be broad enough to provide an understanding of the impact of engineering and technology on society, culture, and the economy, but narrow enough to relate to pupils' and students' own experiences.

2 Research methodology

2.1 Delphi study

One way to ascertain the opinion of a group of experts is to conduct a Delphi study. This research method, aimed at establishing a consensus of experts' opinions, has both strengths and weaknesses. The main strength is that one can use statistical means to establish whether or not a consensus exists, and this lends a certain objectivity to the study (even though the choice for the criteria and criterion values remains a matter of preference). The main weakness is that one depends totally on opinions rather than facts. This makes the quality of the study dependent on the choice of experts for the Delphi panel. An advantage of a Delphi study over a panel meeting is that no single expert can dominate the consensus. The disadvantage is that it is not possible to discuss the results of previous rounds with the experts. In our case we have combined the Delphi study and the panel meeting. This report presents the outcomes of the Delphi study and was used as input for a panel discussion on August 5–6, 2009, at Hofstra University. Thus we hoped to combine the advantages of the Delphi study and the panel meeting.

The reputation of Delphi studies has changed. There was a time when Delphi studies were used frequently in the U.S. However, a growing awareness of the limitations of the Delphi method led to a decline in the method's popularity, evidenced by the fact that fewer Delphi studies were accepted for publication in scholarly journals. Although the number of Delphi studies is still not high, the method has once again been accepted as a serious research design. A Delphi study was conducted by Jonathan Osborne, Sue Collins, Mary Ratcliffe, Robin Millar, and Rick Dutchl, a group of well-respected science education researchers, and published in a high-quality academic journal, the *Journal of Research in Science Teaching*, in 2003. This study was relevant not only because it justified our choice of the Delphi method, but also because it had a goal that was very similar to our own: to establish a list of basic and broad concepts related to science for use in the development of science education curricula.

2.2 Research design

Our research design, similar to the one Osborne et al. used, is typical for Delphi studies. A group of experts were invited by e-mail to participate in the study. In a first round, the 34 experts who agreed to participate were asked to generate concepts (in Osborne et al.'s case for science and in our case for engineering and technology) and rate each one for importance. The number of experts involved is well over the 20–25 usually involved in a Delphi study (Osborne et al. had 23). In our research we have adapted this first round: we provided the experts with a draft list of concepts to rate on a 1–5 Likert scale. We did this because we wanted to clarify the level of generality we were looking for. In other words, by suggesting such concepts as "systems" and "optimization," we wanted to prevent experts suggesting concepts that were substantially less transferable. Another adaptation is that we added draft definitions to the concepts and asked the experts to comment on these and to indicate whether or not they found the defined concepts suitable or not. The following rounds were more standard. In the second round the experts were presented with the broad concepts, their amended definitions, and their scores resulting from the first round. They were asked to give scores of importance again, based on their own opinion as well as on the information related to the total average score of the whole group. No more concepts or contexts could be added. We emphasized that our aim was not to reach exact definitions of the concepts. Instead, we hoped to convey the essence of each concept, so that the experts would not need to respond again to the definitions but only rate the concepts. Also, we asked the experts to be sparing with high scores so that only the most important concepts would stand out. We pointed out that aiming for a short list was also the reason why we did not include each concept that the experts had suggested in the first round.

We did something similar for the contexts part, but allowed for more variety in the levels of generality here. In the second and third rounds we therefore included suggestions for contexts of different levels of generality, thereby leaving it to the experts to indicate whether they favored high-level generality contexts or lower-level contexts. In the second round we also mentioned more criteria for ranking the contexts. Usually this second round does not lead to sufficient consensus so a third round is needed. The third round is also needed to check for stability in the anwers. To stimulate consensus in the third round, the experts are asked to account for deviating substantially from the average score. In case this still fails to result in consensus, one can search for subgroups in which consensus can be established (in our case this could, for instance, be the engineering education experts). To make this possible, we have asked the experts to provide some personal background data (age, gender, nationality, educational background, and professional area). The study was conducted during May and July of 2009. In order to stay within the available time, the experts were asked to return their responses in about a week. Several experts were on summer leave, so we have not been able to include all responses for every round. For each round, we waited until at least 30 of the 34 experts sent their responses.

2.3 Transition round 1 to round 2

The most difficult transition is the one from the first round to the second. The first round results in a great variety of comments and suggestions, and from these the researchers have to derive a common denominator that can be presented to the experts in the second round. In our case, the problem was that including all concepts suggested by the experts would have resulted in a very long list with many overlapping concepts and different levels of generality. Therefore, this round needs particular accounting as to the decisions we have made. Concerning the concepts, we have included any concept that was mentioned by more than one expert. However, we have sometimes renamed a concept if two experts were thinking of the same concept but used a different term for it. The definitions given ensured that this was really a matter of different words and not of different concepts. Concepts that were mentioned by one expert only have been added because they were new and on the same level of generality as the concepts in our draft list. Concepts mentioned by one expert of a lower level of generality were mentioned explicitly as examples of subconcepts in the explication (definition) of the concept under which it could be subsumed. All suggestions for amending the definitions have been worked into the text for the second round, unless it was clear that there was a misunderstanding between the expert and us concerning the meaning of the concept. In such cases we have tried to amend the definition so that the misunderstanding was avoided. Regarding the contexts, we followed practically the same recipe. However we were far less strict relative to the level of abstraction, than we were with the concepts. In general, we believe that we have been able to do justice to all comments provided by the experts in the first round. In some exceptional cases, the experts' remarks were too fundamental to be worked into the list of concepts and contexts, and those remarks have been included in our analysis of the various rounds in chapter 3. The remarks give rise to some important questions of a more general nature about the use of concepts and contexts in engineering and technology education. They do not devalue the outcomes of the Delphi study, but do provide clues as to what the role of such a study can be and what its limitations are. Such questions deal, for instance, with the question of whether or not one can separate concepts and contexts into two different lists, and whether or not contexts should be practices in which students themselves are involved (rather than broad areas of application). This question is directly related to the level of generality of these contexts; for instance, is "transportation" a suitable context, or should one think in terms of "taking part in traffic by riding from home to school"? Another fundamental issue is whether or not it is possible to use one list for both engineering and technology education or for both general and vocational teaching about engineering and technology. In the chapters that follow, we will come back to these and other issues when we discuss the outcomes of the study.

The final list of concepts and contexts consists of those concepts for which we found stable agreement—that is, those that were given high scores in at least the two last rounds, and for which the standard deviation of the average score was low. In practice, after the third round we have ordered the concepts according to their scores, starting with the highest score, and we went down the list until either the stability criterion or the agreement criterion failed, or both.

3 Data collection, analysis and results of the three-round Delphi study

3.1 Analysis round 1

Table 1: Respondent Totals Round 1

Philosophy/History and Communication of Technology:	5
Engineering Educator	8 (Of which one didn't agree with the study, and didn't rate)
Technology (Teacher) Educator	20
Total respondents	33

3.1.1 Two parts:

We divided all three rounds' questionnaires into two parts, part one dealing with concepts and part two with contexts.

The first round of the Delphi consisted of an open-ended brainstorm on what the core concepts characterizing engineering and technology are and what the most suitable contexts for teaching them are. As stated in the previous chapter, the brainstorm did not start out completely blank. Rather, we provided the experts with two draft lists of concepts and contexts to rate and invited them to add their own concepts and contexts. We asked them to add only concepts and contexts that they themselves would rate with a 3 ("important") or higher on our Likert scale, so as to limit the lists to, and encourage careful thought on and consideration of, new concepts and contexts. We also asked them to rate the items on the draft lists, to activate their minds for the brainstorm and get them thinking at the approximately correct level of generality we were aiming for. Also, we wanted to get an idea of how they would evaluate the provided concepts and contexts. Considerations for rating the concepts were as follows. The concepts had to be:

- core to both engineering and technology, characterizing their essence.
- unifying—cutting across the various engineering and technological domains and thus giving insight into the nature of engineering as a holistic endeavor. They had to include big ideas that are generalizable over a wide range of technological fields of study.

- broad enough to subsume and synthesize a body of related subconcepts.
- suitable as themes to be woven through different secondary school courses at different grade levels, allowing all students[1] to have a better understanding of the nature of the human-made world; and engineering and technology as holistic and ubiquitous endeavors.

Considerations for rating the contexts were less strict, as we wanted to allow the experts freedom in providing and rating contexts. In providing a draft list of possible contexts, we took on the approach that contexts are endeavors that people can be involved in, either now (as students) or later in their lives (as workers and knowledgeable citizens). We explicitly stated that our list served only as an example to reflect the breadth of contexts that we are soliciting from them. Our goal was for these examples to lead to new suggestions that are of the same nature, but participants were completely free to choose their own approach in suggesting contexts.

Furthermore, brainstorming over suitable contexts for teaching technological concepts is a novelty in technology education research. What the relevant considerations are for a context to be suitable is therefore still a point of discussion. Nevertheless, we gave a general description as to what would make a context suitable. We stated that the contexts should:

> "enable the teaching and learning of the concepts that have been identified in the first part of the study. The contexts should be broad enough to provide an understanding of the human-made world and the impact of engineering and technology on society, culture, and the economy."

Additionally we invited the experts to comment on any of the concepts or contexts on the provided list or their draft definitions.

This first round resulted in an extensive list of suggested concepts and contexts and much commenting on the draft descriptions and the study in general. As described in chapter 2, we used several criteria to do justice to all of the comments and suggestions, working them into the round 2 questionnaire while limiting its length so as not to overwhelm participants in further rounds. Discussion among the three members of the research team resulted in agreement on the content of round 2. The process is illustrated on the next page.

[1] not only those with technological career aspirations

3.1.2 Illustrations of concept analysis:

A) Example of how we modified an existing concept

Round 1

Concept: "*Social Impact*"

Description: "The effect of an activity on society and culture"

Comments on context[2]

- (partly) included in new item description:

(R1)[3]: *How about the reverse—what effects do societal or cultural rules have on "doing" engineering?*

(R6): *It should be: "The effect of an activity on individuals, society, and culture.*"

(R8): *This goes both ways. Engineering impacts society and culture and is impacted by society and culture.*

(R9): *Absolutely should not be "impact." This suggests a linear model of technological invention, followed by social "impacts," which is historically inaccurate. "Interaction" would be better.*

(R14): *Not just an activity—maybe a product.*

(R16): *Do you consider social impact the same as societal impact? Or is social one of many societal impacts, along with ethical, legal, etc. impacts?*

(R19): "*Impacts" sets technology too far apart from society.*

(R20): *Don't confuse society and culture.*

(R23): *How about "societal impacts" or "sociocultural," though I like "societal" better because there are also economic, political, etc. impacts. So "societal" covers them all. I suggest it be broader than "activity."*

(R26): *Not sure about use of "culture" here, if culture is viewed as a set of values, beliefs, and ways of being of a particular group within society as used in this sentence, or of a society if you are focusing on a culturally bounded grouping. But this is not the case here, where I think the use of "society" is more generalized. Therefore, I think it should read more like "the effect of an activity on society including the effects on different cultural groups within that society." Alternatively, you could just say "the effect of activity on society" and allow culture to sit beneath the term as one social structure of society.*

(R30): *The effect of information, invention, innovation, or another activity on society and culture.*

(R33): Add: " ... on the individual, society, and culture."

[2] Some comments have been adapted or summarized to make them more clear and concise.
[3] The coding refers to real respondents, but is not linked to the order in which they are listed.

- (partly) not taken into account for new description:

(R17): Belongs to conditions

Reason not included: We felt this more concrete concept was important enough to mention separately, and the reactions of most respondents affirmed that. Also, the concept "conditions" was in our opinion on a too high level of generality (and of quite a different nature) compared to the other concepts in the list.

(R16): *Do you consider social impact the same as societal impact? Or is social one of many societal impacts next to ethical, legal, etc. impacts?*

(R23): *How about "societal impacts" or "sociocultural," though I like "societal" better because there are also economic, political, etc. impacts. So "societal" covers them all. I suggest it be broader than "activity."*

Reason not included: We did not change the term *social* into *societal* as most respondents did not have comments on this part of the phrasing, and we already used the term *society* in the description.

Examples of suggestions for new concepts (partly) included in this concept:

(R14): Human factors/ergonomics: *Analysis of interactions between humans and other elements of a system to maximize human well-being and system performance.* (Included as "man-machine interaction.")

(R15): Understanding users: *Intended audience for which the design is intended.* (Included as "man-machine interaction.")

(R18): Sociocultural influence: *The influence of social and cultural contexts on the activity.*

R19: Technology & Culture: *The ways culture influences forms of innovation and how innovation influences development of culture.*

Result for Round 2:

New concept phrasing: Social Interaction.

Amended description: The effect of technology and engineering on individuals and society and vice versa. (Includes human-machine.)

B) Example of how we combined suggestions for a new concept

Round 1:

Concept suggestions phrasing:

R2: Modularity

R20: Interchangeability

Concept suggestions description:

R2 (Modularity): *The approach to design and construction that recognizes the boundaries of partially independent subsystems in terms of their input/output characteristics, and therefore their separability. This allows for degrees of specialization among workers, reuse of products from earlier designs, and simplification during testing and debugging.*

R20 (Interchangeability): *No description*

Result for Round 2:

New concept's phrasing: Modularity

New concept description: *The approach to design and construction that recognizes the boundaries of partially independent subsystems in terms of their input/output characteristics.*

C) Example of how we included suggestions for new concepts in an existing concept

Round 1:

Concept suggestions phrasing:

R18: Appropriateness

R28: Customization

Concept suggestions description:

R18 (Appropriateness): *Designed with special consideration to the environmental, ethical, cultural, social, and economical aspects of the individuals/ community it is intended for.*

R28 (Customization): *This could be another way of thinking of constraints that is included above.*

Round 1 Concept to include it in:

Design (as a verb): *"The process of originating and developing a plan for a product, structure, system, process, or component with intention."*

Result for Round 2:

Concept phrasing: Design (as a verb)

New subconcept phrasing: "customization"

New concept description: *"The process of originating and developing a plan for a product, structure, system, process, or component with intention. (Includes problem recognition, analysis, experimentation, testing, teamwork, communication, customization, and design cycle)."*

D) Example of new concept suggestions not used because they are of a too different nature:

Round 1:

(R2): Reverse engineering: *Working backward from preexisting products or processes that are desirable to a set of principles and that are often then used to mass-produce or widely disseminate the product.*

(R4): Know-how : *Skills necessary to make or use something.*

(R5): Normative aspects: *Serious consideration, by way of consultation, needs to be given to the "should we" aspect as opposed to the "we have the technology" aspect.*

(R9): Human systems: *Arrangements, policies, and procedures that involve humans as individuals and as formal or semiformal groups.*

(R13): Mechatronics: *This concept brings up some interchanges for material, energy, and information by focusing on mechanical elements.* (This is not a general technological or engineering concept. For example, software engineering or informatics doesn't involve mechatronics.)

(R16): Technology: *No description*

(R19): Exemplar: *A problem whose solution embodies the essential concepts and principles of a particular, paradigmatic engineering science.*

(R22): Technological Processes: *Structure material, energy, and information processes*

(R23): The nature of technology: *No description*

(R23): The nature of engineering: *No description*

(R23): Systems model: *No description*

E) Example of new concept suggestions not used because they're already covered.

Round 1:

(R6): Opportunities: *Identifying possibilities for achieving suitable solutions within particular contexts.*

(R11): Behavior: *Changes in the system in time*

(R12): Visualization: *The ability to conceive of an object or process in the abstract.*

(R12): Research: *Investigation or experimentation aimed at the discovery and interpretation of facts, revision of accepted theories or laws in the light of new facts, or practical application of such new or revised theories or laws.*

(R17): Conditions: *To accept the conditions makes the innovator an inventor.*

(R17): Decisions: *As a common part of the design process often compromises instead of going ahead—sometimes social competence.*

(R19): Infrastructure: *The resources—both local and global— that engineers can draw upon in their work at any point in time.*

(R21): Materials/Structures: *What both built forms and natural forms are composed of. An understanding of materials and structures assists in bridging ideas between the natural world—with natural materials and naturally occurring forms and structures—and the made world.*

(R26): Technological or engineering practice: *An iterative process of design and development for the purpose of developing a product or system to resolve an identified need or realize an opportunity.*

(R26): Ingenuity: *The human dimension of invention and innovation including knowledge creation.*

Summary general remarks on concepts:

R5 (TE[4]/PHC[5]): All concepts should take account of social and cultural determinations. This should not be treated separately.

R6 (TE): The concepts seem to be of various levels or generality and need to be organized within a schema that reflects these different levels.

R17 (TE): I miss a clear structure of the concepts. A leading idea that gives orientation. Up until now it is only a stochastic accumulation of ideas.

R20 (TE): I'm troubled by the approach that treats "engineering" and "technology" as if they were congruent. Why don't you separate them in your lists? It seems to me that there are many substantial and significant differences between the two fields.

R23 (TE): All of the ideas are relevant but many are associated with the design process which is a little worrisome to me as design is only one component of technological understanding. I'm concerned that "engineering" seems to be overpowering the list while "technology" is the broad idea that dominates our culture in the 21st century, NOT "engineering," which is simply a vocation. We shouldn't be teaching vocations. We should be teaching for literacy for all, not engineering for a few.

R28 (TE): I found myself sometimes pondering the idea of technology and engineering without the term "education" after them. Would it have made any difference if you had done this study on technological literacy and engineering? For many, technology education is the study of technological literacy.

[4] TE: Technology (Teacher) Educator
[5] PHC: Philosopher, Historian or Communicator of Technology

3.1.3 Illustration context analysis:

A) Example of how we modified an existing context

Round 1

Context: "Sports"

Description: "playing football, tennis, hiking"

Comments on context

- included in explanation of questionnaire:

(R3): *"Perhaps I am missing the point on many of these but the context should be examining how the football helmet protects the head, not playing football."*

(R21): *This will appeal to some students and certainly not others.*

– (partly) included in item description:

(R18): *"Physical and mental fitness through activities. This will include individual and team sports and outdoor activities."*

– not taken into account for description:

(R26): ...*may be better to group under categories like equipment, clothing, monitoring systems...*

Reason: Relevant consideration, but this will mean eliminating the broad context sports at this point and distributing it among three new contexts. As there were no similar suggestions and as we want to limit the list, we kept the broader context "sports." This comment can, however, be used further down the road of developing the curricula, for operationalization of this broad context "sports." In the meantime, experts who find this context too broad may indicate that by giving it a low rating.

(R17): *I prefer: "Free time" so I can add hobbies and taking part in competitions (e.g., Robocup).*

Reason: This would make the context far too general in our opinion.

(R3): *Good domain but overused in physics, in my view.*

(R6): *Contemporary interest in sports and engineering/technology opens possibilities.*

(R7): *Appeals to youth interests.*

(R9): *High interest for many students.*

(R20): *There is some technology involved in some sports, but little engineering—and quite a bit of science.*

(R22): *No relation to technology education.*

Reason: These can be considerations for giving the item higher or lower ratings, but not for changing the phrasing.

NB: Comments R3, R6, R7, and R9 confirm our wanting to keep this context, despite (R26)'s suggestion to factor it into other contexts.

Suggestions for new contexts (partly) included in this context:

(R28)*: Recreation (use of devices in sports and leisure)*

Result for Round 2:

New context phrasing: Sports and recreation.

Amended description: Includes playing football or tennis, hiking, mountain climbing, camping.

B) Example of how we combined suggestions for a new context

Round 1:

Context suggestions:

- Energy supply. *Producing and using energy.*
- Energy-dependent technologies. *This relates to power (nuclear, solar, wind, tidal) and energy-dependent technologies, such as transportation.*
- Energy. *How to generate it, use it most efficiently, transform/convert it.*
- Energy production/diversification *(Perhaps better titled under context of "sustainable living" or "future energy"....)*
- Energy efficiency—*again better situated under context of "sustainable living" or "sustainable futures."*
- Energy-dependent technologies (transportation)

Result for Round 2:

New context phrasing: Energy in society

New context description: *(Includes generation, usage, storage)*

C) Example of how we included suggestions for new concepts in an existing concept

Round 1:

New context suggestion: (R24): Web 2.0 technologies

Included in: Two-way communication: Communicating between individuals and/or groups

Round 2 description includes making phone calls, sending e-mails, Web 2.0.

D) Example of new context suggestions not used because they are of a very different nature:

(R1): Design contests (FIRST LEGO League, boat building, egg drop, etc.)

(R1): Problem solving (LEGO or other robotics kits to build a machine to do a specified job)

Reason not included: With a context we meant a societal context. These are more like approaches to education.

(R6): Information (data transmitting/receiving)

Reason not included: This is already a concept. It is not suitable for explaining the list of concepts.

(R): Motion (projectiles, celestial bodies, anatomical processes)

Reason not included: This is more science, and as described not a societal context. As societal contexts it's already partly included in transportation.

E) Example of new context suggestions not used because too-different level of generality:

Round 1:

(R4): The development of the paper clip (zipper): *As described by Petroski*

Reason not included: Although arguably an exemplar context for explaining many of the concepts, and arguably makes it through our statement filter, this is an example of a far too specific context suggestion. It is too narrow in level of generality compared to most other contexts. It can be useful for operationalization of broader contexts further down the road of developing the curricula. It may, for example, be used in the broader contexts of production and manufacturing, domestic technologies, or education.

Analysis (general) remarks on context part:

The proposals for new contexts and comments on existing ones reveal very different approaches that respondents use for suggesting and evaluating contexts. Analyzing also the general remarks on the context part, we find roughly the following approaches:

"The contexts should...":

- **Encompass the Human-Made World** (R2 EE[6] –- USA)
    - R2: *"I think major contexts are needed that include all aspects of the Human-Made World, its creation, and its development. Most of the concepts in the list are only minor aspects of it."*
    - (R11: EE – USA) *I have emphasized the contexts that are of industrial importance.*
- **Be truly relevant to students' lives** (R24 EE – USA)
    - Focus on examples from the perspective of teenage learners. (R10 PHC[7]– USA)
    - Have an element of excitement, to keep students engaged (R30: EE – USA)
- **Exemplify enduring human concerns**, situations that are grounded in the nature of being human in contrast to being prominent social phenomena that are commonly found in industrialized nations. (R31 TE[8] – USA). Rather, they should be:
    - Fundamental to human nature
    - Relevant in variety of cultures and societies

[6] EE = Engineering Educator
[7] PHC = Philosopher, Historian and or Communicator of Technology
[8] TE = Technology Educator (and/or Technology Teacher Educator)

- **Be situated around societal issues/problems** (R23 TE – USA)
  - R23: *Technology is inseparable from our culture. The world is looking at technology to solve all of the major problems that are confronting/will confront us in the 21st century. I'm fine with the "subsets" of technology STL and those you have suggested, but I think we need to think in broader contexts.*
  - The vision "making the world a better place" (R17 TE – Germany) also fits in this approach.
  - Environmental concerns should figure prominantly (R14 TE – Australia).
    - R14: "*The structures developed should be forward looking, engaging for kids and be opportunistic rather than just reflect current thinking."*
- **Not focus too much on social issues** (R27 TE – Israel):
  - R23: *The contexts mentioned above are wonderful, but the focus should be placed on technological- /engineering-related aspects rather than on social issues.*
- **Be big examples:** The development of the paper clip, as described by Petroski (R4 PHC – Netherlands)
- **Be local.** (R5 TE/ PHC - UK)
  - *A universal approach locks out local context. For example, the context of transportation worked out for a city will be very different from the same worked out for a rural area. The rural version might not be relevant to students living in an urban area and vice versa. This raises the question as to whether school education should insist that children from rural areas understand life in the context of urban areas and vice versa. My own view is that provided the conceptual issues are dealt with, the contexts should remain local*.[9]
- **Dependent on concept**
  - Some respondents wanted to first work out the list of concepts and then find suitable contexts for each concept. Sometimes a concept was mentioned with a context in the comment boxes.
- **Cover the technological domains**
- Use the **"Designed World Standards"** in **"Standards for Technological Literacy"** (R11 EE - USA) (PS: only mentioned in round two)
- **All of the contexts are potentially suitable.** But they should best fit **three considerations:** (R3 TE/ER[10] - USA)
  - fit to the concepts;
  - familiarity to the learner;
  - ability for the instructor or curriculum designer to provide more and less complex versions of the contexts that help make salient the critical feathers and relationships.[11]

One respondent (TE R6 - Australia) noted that before trying to find a set of contexts, we need an overarching "supercontext" to work within. "Purpose" could be such a supercontext.

Actually almost all the approaches listed above could be viewed as overarching supercontexts and used to frame the search for a set of suitable contexts. Only the approach that the contexts must remain local might be hard to use to this purpose.

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[9] Summarized and somewhat adapted by author for more clarity

[10] ER: Educational Researcher

[11] We copied this description to use in the round 2 questionnaire as it aptly described what we felt were important considerations for rating a context as suitable or not. While respondents may disagree with this, it gives them a starting point for considering a score for a context.

One respondent (R3 TE/ER – USA) noted that the grand challenge is really to find contexts, more so than concepts. Another respondent (R24 EE – USA) seems to agree and notes: “the issue with all contexts is to select topics/problems that are truly relevant to students’ own lives. This is much harder to do than it appears, in my opinion.” He adds that: “gender- and culture-specific attitudes and interests also need to be taken into account. Not all contexts will be equally appealing to all students.”

It is interesting to note that there is a huge variety in level of generality and broadness among the contexts. We have tried to include as many contexts as possible, though we did have some limits to specificity and broadness, as illustrated in the analysis. We wanted respondents to decide on the appropriate level of generality for contexts, so left it to them to give contexts that are too broad or too narrow a low rating.

There is then of course much crossover between the contexts, as one respondent noted: e.g. biotechnology and medical technologies. This is also due to the fact that contexts are suggested with different approaches in mind.

3.1.4 Critiques on the study:

(R25): Engineering Educator:

Engineering and technology (or technological literacy) are two completely different areas of study. I have difficulty combining them under the same area of study. I believe that for your study to have merit, you must frame your study to be either engineering or technology (not both together)…. And for each (or either), you will need to identify four or five core concepts to emphasize and many of the concepts/themes listed above can then be grouped together under these core concepts, and then rated for their relevance. If your true goal is to move technology to engineering, you will need to restructure your study, and rely predominantly on engineers working in industry (not in academia, since their perspectives are quite different, and rarely have engineering professors worked for a significant time in industry. This study must select either engineering or technology. They are not the same. The contexts chosen are from an engineering perspective related to technology, rather than engineering.

3.2 Analysis round 2

Table 2: Respondent Totals Round 2

Philosophy/History and Communication of Technology:	5
Engineering Educator	5
Technology (Teacher) Educator	21
Total respondents	31

3.2.1 Concepts:

For this round we calculated the average scores, modes and standard deviations[12] of each concept and the percentage of respondents giving a concept 4 or higher. We found the following:

Table 3: Statistics Old Potential Unifying Concept/Theme.

Bold and underscored are high scoring concepts. Bold also has over 2/3 majority 4 or 5 rating.

Old Potential Unifying Concept/Theme	Mean	Mode	SD	% rating with 4 or 5	Number of valid respon-dents
Resource	3,71	4,00	0,69	64,5	31
Materials	3,97	3,00	0,84	64,5	31
Energy	3,72	4,00	0,94	60,0	30
Information	3,58	4,00	0,92	58,1	31
Invention	3,55	4,00	0,99	58,1	31
Innovation	3,77	4,00	0,84	64,5	31
Social interaction	**4,27**	**5,00**	**0,73**	**80,7**	**31**
Technology assessment	3,66	4,00	0,60	58,1	31

[12] Standard deviation: If a data distribution is approximately normal then about 68% of the values are within 1 standard deviation of the mean. (Wikipedia)

Practical reasoning	2,87	3,00	0,99	19,4	31
Trade-offs	3,89	3,00	0,89	60,0	30
Specifications	**4,03**	**4,00**	**0,75**	**80,7**	**31**
Complexity	2,81	3,00	1,01	22,6	31
Quality assurance	3,08	3,00	0,79	23,3	30
Efficiency	3,21	3,00	0,91	25,8	31
Optimization	**4,05**	**4,00**	**0,92**	**74,2**	**31**
Structure	3,45	3,00	0,68	48,4	31
Working principle	2,70	3,00	0,88	20,0	30
Function	**3,58**	**4,00**	**0,96**	**67,7**	**31**
Heuristics	3,16	3,00	0,90	32,3	31
Algorithms	2,87	3,00	0,85	12,9	31
Design (as a verb)	**4,78**	**5,00**	**0,41**	**96,7**	**30**
Design (as a noun)	**3,90**	**4,00**	**0,91**	**74,2**	**31**
Modeling	**4,44**	**5,00**	**0,62**	**90,3**	**31**
System	**4,37**	**5,00**	**0,88**	**83,9**	**31**

Table 4: Statistics New Potential Unifying Concept/Theme.
Bold and underscored are high scoring concepts. Bold also has over 2/3 majority 4 or 5 rating.

New Potential Unifying Concept / Theme	**Mean**	**Mode**	**SD**	**% rating with 4 or 5**	**Number of valid respon-dents**

25 Standards	3,19	4,00	1,17	45,2	31
26 Intellectual property	2,71	3,00	0,97	19,4	31
27 Technological trajectory	2,53	3,00	0,82	6,7	30
28 Product lifecycle	3,37	3,00	0,84	41,9	31
28 Application of science	3,24	4,00	1,02	41,9	31
30 Sustainability	**3,92**	**4,00**	**0,86**	**74,2**	**31**
31 Risk and failure	3,67	4,00	0,92	60,0	30
32 Measuring	3,42	3,00	1,09	45,2	31
33 Tolerance	2,77	3,00	0,76	12,9	31
34 Modularity	3,00	3,00	1,10	32,3	31

As a measure for consensus, we used the standard deviation and a criterion copied from Osborne (2003). A standard deviation below 1 already signifies significant agreement among respondents.

As a measure for consensus on what the most important concepts are, we used the stricter criterion from Osborne that 66% of respondents should rate the context 4 or above. Eight of the old concepts and one of the new concepts made it through this filter. These top nine concepts were “social interaction,” “specifications,” “optimization,” “design (as a verb),” “design (as a noun),” “modeling,” “system,”

“function,” and “sustainability.” Second places are taken by “resource,” “materials,” “energy,” “information,” “invention,” “innovation,” “technology assessment,” “trade-offs,” and “risk and failure.”These have high average scores (> 3,5), modes of 4 (except for “materials” and “trade-offs”), but no 2/3 respondent majority rating them 4 and above.

Although most standard deviations are under 1, they could be better. Also, we needed to check if respondent ratings are stable, and what the reasons for divergence are. We therefore had to carry out another round of rating. In the third round we included the average ratings for the concepts from round 2. We asked them to rate the concepts again, this time carefully considering the average rating. We asked the respondents to give a rating close to the average and argue for their position if they diverged more than 1 point from the average rating.

General remarks on concept part:

There were not many remarks in this round. Mainly a plea for more structure and for grouping items together. More fundamental was one comment asking for normative overarching conditions for the concepts.

Engineering Educators:

"There is need for a hierarchical structure," (R11) points out. "There are only a few key concepts and the rest are subconcepts to the big ideas. The fact that all of the concepts come out of round 1 with similar average scores points out the lack of a hierarchical structure.

Technology Educators:

"More entries can be grouped together," notes (R3). I also found that my evaluation mattered depending on whether I was considering education aimed at vocational training or a program with a more academic or college preparatory focus.
"The technical aspects described above should have issues relating to ethics, sustainability, and criticality as overarching conditions," (R5) pleads.

We decided not to structure the concepts yet, as there were different ideas about what are key concepts and which sub-concepts belong under them. First getting a list of top concepts would give some us a better idea of the generally desired level of abstraction of key concepts. Respondents seemed to have different opinions on this so the structuring of the concepts makes for a separate exercise.
The remark about vocational versus academic preparatory programs we addressed in the text accompanying the third questionnaire. We emphasized that the end goal is to develop a conceptual framework for secondary school, general education; aimed at *all* students. So the distinction between vocational training versus academic or college preparation should not be made here[13].
The last comment is interesting as it seems there are even different approaches for choosing and evaluating the concepts, not only for evaluating the contexts. Whether we need overarching conditions for concepts as well as for contexts is a point for discussion.

3.2.2 Contexts:

In the description of the context part of the round 2 questionnaire, we more explicitly mentioned the criteria we thought relevant for evaluating the contexts:

- suitable for explaining a variety of concepts in the same context;
- familiarity to the learner;
- usability for curriculum developers to provide more and less complex versions of the contexts that help make salient the critical features and relationships to be explained.

We copied this description from a round 1 remark (mentioned in the last section), as it aptly described what we felt were important considerations for rating a context as suitable or not. While respondents may disagree with this, it gives them a starting point for considering a score for a context.

[13] One can off course discuss whether this is a realistic or desirable aim.

For this round we also calculated the average scores, modes and standard deviations of each context and later also the percentage of respondents giving a context a 4 or higher. We found the following:

Table 5: Statistics Old Possible Contexts.
Bold and underscored are high scoring contexts. Bold also has over 2/3 majority 4 or 5 rating.

Possible Context	**Mean**	**Mode**	**SD**	**% rating with 4 or 5**	**Number of valid respon-dents**
Transportation (using vehicles, traveling)	**4,14**	**4,00**	0,80	**82,1**	28
2-way communicating: between individuals and/or groups	**3,82**	**4,00**	1,06	**75,0**	28
1-way communication: mass media	3,04	3,00	0,96	28,6	28
Medical technologies	**4,14**	**4,00**	0,80	**82,1**	28
<u>Sports and recreation</u>	<u>3,04</u>	<u>4,00</u>	1,04	42,9	28
<u>Domestic technologies</u>	<u>3,41</u>	<u>4,00</u>	1,15	55,6	27
Personal care	2,64	3,00	0,91	17,9	28
Do-it-yourself	2,93	3,00	1,09	32,1	28
Education	2,50	3,00	0,88	10,7	28
<u>Scientific research and exploration</u>	<u>3,21</u>	<u>4,00</u>	1,10	42,9	28
<u>Industrial production</u>	<u>3,61</u>	<u>4,00</u>	0,99	57,1	28

Table 6: Statistics New Possible Contexts.
Bold and underscored are high scoring concepts. Bold also has over 2/3 majority 4 or 5 rating.

New Possible Context	**Mean**	**Mode**	**SD**	**% rating with 4 or 5**	**Number of respon-dents**
Energy in society	**4,21**	5,00	0,77	**79,3**	29
Sustainable technology	**4,03**	**4,00**	0,87	**82,8**	29
<u>Global warming</u>	<u>3,48</u>	<u>3,00</u>	<u>1,09</u>	<u>48,3</u>	<u>29</u>
Biotechnology	**4,03**	**4,00**	0,91	**75,9**	29
<u>Nanotechnology</u>	<u>3,45</u>	<u>4,00</u>	<u>1,09</u>	<u>51,7</u>	<u>29</u>
Entertainment	2,93	3,00	1,13	24,1	29
<u>Toys</u>	<u>2,90</u>	<u>4,00</u>	<u>1,18</u>	<u>34,5</u>	<u>29</u>
Virtual reality	2,82	3,00	1,25	28,6	28
Digital photography	2,59	3,00	0,95	10,3	29
Music	2,93	3,00	1,07	24,1	29
Art and technology	2,41	3,00	0,95	6,9	29
Religions & technology	1,83	2,00	0,80	3,5	29
Politics and technology	2,79	3,00	1,11	24,1	29
Imagining the future	3,03	3,00	1,09	34,5	29
Robotization of society	2,82	3,00	1,22	32,1	28
<u>Safety/Security</u>	<u>3,45</u>	<u>3,00</u>	<u>0,95</u>	<u>44,8</u>	<u>29</u>
<u>Security / Big brother</u>	<u>3,07</u>	<u>4,00</u>	<u>1,13</u>	<u>44,8</u>	<u>29</u>
Technology for peace	2,90	3,00	1,21	27,6	29
Rescue	2,86	3,00	1,18	28,6	28
Crime scene investigation	2,72	3,00	1,19	24,1	29
Construction	**3,72**	**4,00**	0,65	**69,0**	29
Food	**3,79**	**4,00**	0,82	**72,4**	29

Water resource management	3,69	4,00	1,04	65,5	29
Packaging	2,75	3,00	1,00	25,0	28

Of the old contexts, there is consensus over the high suitability of: “transportation,” “2-way communicating,” and “medical technologies.”. Of the new suggestions, “energy in society,” “sustainable technology,” “biotechnology,” “construction,” “food,” and “water resource management” are deemed “very” or “most suitable” with consensus. “Water resource management” comes very close also. Second place with high modus or averages but low consensus are “sports and recreation,” “domestic technologies,” “scientific research and exploration,” and “industrial production,” from the old contexts, and “global warming,” “nanotechnology,” and “toys” from the new contexts.

It is interesting to note that standard deviations are significantly higher here than was the case with the concepts. About half of the contexts have standard deviations of more than one. Of the concepts only about a fifth had standard deviations over one.

General remarks on context part:

Once again we find clear indications for different approaches chosen in evaluating contexts.

Engineering Educators:

I think the contexts should be broad, so they can encompass the human-made world," defends (R2). Examples of areas are: manufacturing and construction, biotechnologies, information and communication technologies. These can further be refined into smaller domains.

"Again I think that the '**Designed World Standards'** in **Standards for Technological Literacy** provide meaningful and a limited number of categories," says (R11). He finds the new items more engineering-like and less kid-like. He found the old contexts, especially their examples, very elementary school oriented and suggested in round 1, "Give the context and then let it be made grade appropriate."

Technology Educators:

"I make no apology for giving many 5's for the new contexts, which are more ethical/moral/political contexts. I believe that normative aspects are seriously lacking in engineering and technology education. I believe the new contexts can be integrated into local technical scenarios. The old contexts, though, I have not rated as they are technical contexts and these should remain local (as explained in round 1). All the technical contexts are important, but the level of importance is determined by the relevance from the learners' perspective, which is dependent on local conditions," argues (R5).

Finally a warning from (R13): "Do not disregard the area of information, intelligence, data and so on in context with overlapping areas like transport, transformation, and storage."

3.3 Analysis round 3

Table 7: Respondent Totals Round 3

Philosophy/History and Communication of Technology:	5
Engineering Educator	5
Technology (Teacher) Educator	20
Total respondents	30

For this round we again calculated the average scores, modes, standard deviations of each concept and context and the percentage of respondents giving a concept or context a 4 or higher. This time we also compared the new averages with the Round 2 averages to see if they are stable. We borrowed a criterion for stability from Osborne (2003): less than 33% deviation from Round 2 average means stable. We used the formula (100*|new-old|/new). This criterion is met easily for all concepts. We also calculated the stability per respondent, and included the number of respondents that had more than 1.66 points between the Round 2 and Round 3 score. We found the following:

3.3.1 Concepts:

Table 8: Statistics for Round 3 Concepts. All items rated by 30 respondents.
Bold concepts have high averages combined with consensus.
Underscored concepts do not meet the standard for consensus, but do have a high average and a mode of 4.
**Stability: Less than 33% deviation from Round 2 average means stable. (100*|new-old|/new) This is met easily.*

Rank	Potential Unifying Concept/Theme	Mean	Mode	SD	% rating with 4 or 5	Stability*
1	**Design (as a verb)**	4,83	5	0,38	100,0	1,2
2	**System**	4,67	5	0,48	100,0	6,1
3	**Modeling**	4,50	5	0,57	96,7	1,9
4	**Social interaction**	4,26	4	0,64	90,0	0,5
5	**Optimization**	4,00	4	0,74	80,0	2,1
6	**Innovation**	3,85	4	0,68	70,0	1,5
7	**Specifications**	3,85	4	0,71	73,3	3,9

8	**Design (as a noun)**	3,83	4	0,59	70,0	2,0
9	**Sustainability**	3,83	4	0,59	73,3	1,4
10	**Energy**	3,79	4	0,62	76,7	2,2
11	**Materials**	3,78	4	0,74	73,3	4,0
12	**Resource**	3,72	4	0,67	73,3	0,6
13	**Trade-offs**	3,82	4	0,82	70,0	2,6
14	Technology assessment	3,76	4	0,69	63,3	2,0
15	Invention	3,70	4	0,73	63,3	4,6
16	Risk and failure	3,64	4	0,85	60,0	1,4
17	Information	3,59	4	0,74	60,0	0,4
18	Function	3,54	4	0,75	56,7	1,6
19	Structure	3,43	4	0,67	53,3	0,0

20	Product lifecycle	3,55	3	0,75	50,0	5,6
21	Measuring	3,32	3	0,77	36,7	2,5
22	Standards	3,31	3	0,69	36,7	2,3
23	Appl. of science	3,28	3	0,86	40,0	1,8
24	Efficiency	3,23	3	0,72	33,3	1,6
25	Heuristics	3,04	3	0,76	30,0	4,2
26	Quality assurance	2,97	3	0,61	16,7	3,8
27	Modularity	2,87	3	0,90	13,3	3,4
28	Working principle	2,82	3	0,89	16,7	4,5
29	Algorithms	2,80	3	0,85	13,3	2,5
30	Complexity	2,72	3	0,75	13,3	2,8
31	Intellectual property	2,66	3	0,67	10,0	1,6
32	Tolerance	2,49	3	0,64	3,3	11,0
33	Pract. reasoning	2,49	2	0,69	6,7	14,0
34	Techn. trajectory	2,38	2	0,59	0,0	6,0

Summary reasons for deviating ratings top concepts[14].

<u>2: System</u>

R15 TE, lower: Systems is still a relatively abstract concept for secondary students, more favored by the adults than kids.

R22 EE, higher: Important to analyze and create products.

R29 TTE, higher: This is related to complexity, a very important concept in engineering termed "system dynamics and integration".

<u>3: Modeling</u>

R29 TTE, higher: I would argue that the concepts of mathematical modeling and prediction be included.

<u>4: Social Interaction</u>

R11 EE, lower: This is a sub concept. A better key concept would be "Outcome".

R12 TE, lower: Not core. While engineering activity is certainly embedded in and reflective of its social context, social interactions occur in a variety of other contexts.

R5 TE PHC, higher: Technology is merely a concatenation of inorganic stuff without human beings. Understanding the social dimension is therefore very important.

<u>5: Optimization</u>

R6 TE, lower: Optimization is one area where engineering education has been criticized. See note in general remarks. (Beware of using it as a "quick fix" to improve technology education.)

R9 PHC, lower: We optimize relative to a set of constraints, and any real engineering problem will have multiple and conflicting constraints. "Trade-offs" covers this better making optimization less central.

R17 TE, lower: Belongs to "design (as a verb)".

R19 PHC, lower: Rarely achieved. Optimization according to whom? Concept covered by "Trade-offs".

<u>6: Innovation</u>

R27 TE, higher: Knowledge and devices are the major outcomes of technology

R17 TE, lower: Belongs to "design (as a verb)".

R9 PHC, higher: A very large percentage of engineering effort is devoted to innovation: taking an existing technology and modifying and adapting it to a new situation. This process seems so central and ubiquitous that I stick with my "5" rating.

R23 TE, higher: I'm not sure ALL students really NEED to know all that much about the subcomponents of design, which comprise a significant % of the items at the left. But if we want students to know what engineering is about, I think invention and innovation are pretty fundamental to that understanding.

<u>7: Specifications</u>

R11 EE, lower: Part of Optimization

R17 TE, lower: Belongs to "design (as a verb)"

<u>8: Design (as a noun)</u>

[14] Some quotes have been summarized and adapted for clarity and compactness.

R3 TE, higher: As a noun, or a product, design refers to an intentionally created artifact or protocol. It can be evaluated along a number of dimensions, such as its elegant use of materials, ergonomic qualities, cost, aesthetics, and innovation. When making an evaluation, effective designers tend to think about their clients and consider the appropriateness of the final product, and how well it addresses the client's needs. Consider the success of the iPod – few consumers care about the process; rather it is the elegance of the product design and its fit to consumer uses and needs that made it such a remarkable success.

<u>9: Sustainability</u>

R17 TE, lower: Belongs to design process (as a verb)

R22 EE, higher: Thinking in longer terms is important.

R23 TE, higher: Here again, it seems like "without compromising future functioning ought to rate very highly in light of the great challenges facing our planet in the 21st century?

<u>10: Energy</u>

R12 TE, lower: While relevant, energy is certainly not unique to engineering. It is not a core engineering idea.

<u>11: Materials</u>

R17 TE, lower: Belongs to resource

R22 EE, higher: Very important

<u>12: Resource</u>

R12 TE, lower: While relevant, energy is certainly not unique to engineering.

R22 EE, higher: Resources are the basis for human survival.

<u>13: Trade-offs:</u>

R4 PHC, higher: Of central importance for developing (designing) technology. Without this notion it is not possible to get a good grasp what technology is about.

R10 PHC, higher: Informs decisions

R29 TE, higher: Should be constraints (engineering terminology).

R17 TE, lower: Belongs to "design (as a verb)"

<u>14: Technology Assesment. Border item; reasons for inclusion in top:</u>

R5 TE/PHC, higher: Students will become passive users of technology if they have no critical capacity

R10 PHC, higher: Informs public policy decisions

R23 TE, higher: Many (most?) of the great challenges on our planet in the 21st century (global warming, world hunger, pandemics, nuclear warfare, etc) have resulted from technological endeavor and/or will be addressed by technological "fixes." I think it's well past time we promoted the notion of technology assessment. I think it's far more important that kids understand that all technologies have unintended consequences and that we MUST assess them in that light (as well as for intended consequences).

Summary general remarks on concept part:

In the general remarks on the concepts we find some critical notes, warnings, and advice.

Engineering Educators:

One respondent (R22) believes that important list items should be concentrated on explaining what engineering is. From the average scores of the concepts he concludes that there are probably few engineers in our panel, and this seems to worry him.

Another respondent (R11) complains that there is no real dispersion in the results, and he contributes this to the lack of hierarchy in the list. He concludes that "there should only be a handful of concepts that can unify the field. The rest should be placed under the few really unifying concepts."

One remarks on the terminology (R29) that if we include engineering in the concepts we should use terminology from the engineering language system. "Trade-offs" should for example be called "constraints" and complexity should be "systems integration".

Technology Educators:

A respondent (R6) warns for superficial quick fixes to technology education. In the past, universities have responded to criticism on lacking creativity by adding a few design optimization courses and the *end* of programs, with little effect on the programs (Weber, Moder, Solie 1990). He suggests we consider whether we want to deal with engineering education as it is, or as it might be.

Another technology educator (R13) warns that technical (didactic) literacy cannot be established on its own. It needs well-established science- and knowledge-based literacy to have legs to stand on.

There is also a more fundamental critique on the concept part of the study (R5). "I do not accept the premise that each of the above descriptions can be standardized unifying concepts. I believe that they are all interdependent to varying degrees depending upon the context and the context is the important factor. However, if the context is given (as in a school-based problem), then it cannot be authentic and situated." This is a consideration to take into the discussion.

3.3.2 Contexts:

Table 9: Statistics for Round 3 Contexts.

Items marked with a cross (†) are rated by 29 respondents, the rest by 30 respondents.
Bold contexts have high averages combined with consensus.
Underscored contexts do not meet the standard for consensus, but do have a high average and a mode of 4.
**Stability: Less than 33% deviation from Round 2 average means stable. (100*|new-old|/new) This is met easily.*

Rank	Possible Context	Mean	Mode	SD	% rating with 4 or 5	Sta-bility*
1	**Energy in society**	4,37	4,00	0,72	93,3	3,7
2	**Biotechnology**	4,27	4,00	0,69	93,3	5,
3	**Sustainable technology**	4,23	4,00	0,63	90,0	4,7
4	**Transportation (using vehicles, traveling)**	4,14	4,00	0,62	86,7	0,1
5	**Medical technologies**	4,10	4,00	0,92	86,7	1,1
6	**Food**	3,94	4,00	0,58	80,0	3,8
7	**Industrial production**	3,85	4,00	0,74	66,7	6,4
8	**Water resource management**	3,84	4,00	0,79	73,3	3,9
9	**Construction**	3,74	4,00	0,72	66,7	0,4
10	**2-way communicating: between individuals and/or groups**	3,68	4,00	0,80	70,0	4,0
<u>11</u>	<u>Global warming †</u>	3,62	4,00	0,97	55,2	3,8
<u>12</u>	<u>Domestic technologies †</u>	3,60	4,00	0,79	58,6	5,4
13	Safety/Security	3,52	3,00	0,65	46,7	1,9
<u>14</u>	<u>Nanotechnology</u>	3,48	4,00	0,91	50,0	1,0
15	Scientific	3,31	3,00	0,90	36,7	2,8

	research and exploration					
16	Security / Big brother	3,04	3,00	1,00	33,3	1,1
17	Sports and recreation	3,01	3,00	0,86	30,0	0,9
18	1-way communication: mass media	2,97	3,00	0,82	20,0	2,3
19	Virtual reality	2,96	3,00	0,88	20,0	4,7
20	Imagining the future	2,90	3,00	0,88	26,7	4,5
21	Do-it-yourself	2,70	3,00	0,92	16,7	8,
22	Politics and technology	2,66	3,00	0,93	16,7	5,0
23	Rescue	2,62	3,00	0,69	0,0	9,0
24	Packaging †	2,58	3,00	0,87	10,3	6,7
25	Toys	2,56	3,00	0,86	13,3	13,0
26	Robotization of society †	2,55	2,00	0,82	10,3	10,8
27	Technology for peace	2,50	3,00	0,90	6,7	15,9
28	Music	2,50	2,00	0,90	10,0	17,4
29	Entertainment	2,46	3,00	0,90	6,7	18,9
30	Education	2,44	2,00	0,66	3,3	2,
31	Personal care	2,42	2,00	0,74	6,7	9,1
32	Digital photography	2,38	3,00	0,74	3,3	8,8
33	Art and technology	2,36	3,00	0,88	6,7	2,1
34	Crime scene investigation	2,29	3,00	0,76	0,0	18,9
35	Religions & technology	1,59	1,00	0,72	3,3	14,6

Middle scoring contexts such as “art and technology”, “politics and technology”, “entertainment” and “security” it might be better to combine these contexts into one. A context proposed in round one: “technology and other disciplines” (R33) may serve as an umbrella context for all these. There is much support expressed in the comments for these kind of contexts. One respondent commented: “border crossing allows for rich context”. Most of these get a mode of 3, meaning they are found important, but not most important. “Technology and other disciplines” may be a context where the relationship of technology and disciplines of a very different nature are discussed. This can be a rich environment for exploring how (the individual in) society and technology is influenced by one another.

Summary reasons for deviating ratings top contexts.

1: Energy in society:

R17 TE, lower: Important but not suitable context as it’s not general enough.

R9 PHC, higher: I lumped this and the following two categories together. I see that they can be separated, but typically they are treated together, and I think they should be. Beyond this, they are all extremely important.

2: Biotechnology:

R20, higher: Biotechnology implies the application of technology to change the naturally-occurring.

R23, higher: The fastest growing “industry” on the planet… We now have new departments at my university titled BioSystems Engineering, BioMedical Engineering, and BioInformatics… which is the biggest $ getter of all right now.

3: Sustainable technology

R23, higher: What’s more important to the future of our globe?

4: Transportation:

R17, lower: Not general enough. Compared with agricultural technology (-> food) it’s only a poor generalization.

R22, higher: But “mobility” would be better.

5: Medical technologies:

R1, lower: In fact, interest in medicine has drawn students away from the STEM pipelines and into med school or other medical-related fields.

R13, lower: Curricula for technology education have no medical items integrated.

R22, lower: Medical Technology get's only a 1, whereas medicine technology would get a 4.

6: Food:

R22 EE, higher: Technology has a great influence and has therefore a context in technology education

R23 TE, higher: Combine with the earlier home food prep item and global hunger, and agriculture. How can this not be one of the biggie contexts for engineering?

R26 TE: Pretty key survival – and very political… great to explore ethics as well…

<u>7: Industrial Production:</u>

R3 TE/ER[15]*, higher:* I am not sure the description included does justice to this context. More than "finance," this rich context can be quite captivating, especially with the advent of computer numerically controlled machines, FabLabs for actually "printing" objects. It also has some familiarity in that what is produced are often common goods.

R13 TE, higher: Important complex interaction.

R22 EE, higher: If you have no practical experience you are not able to understand the social dimension of technology

R23 TE, higher: I don't want to go back to IACP Mfg… but there can be no question that industrial production is a very important context for engineering.

<u>8: Water resource Management:</u>

R17 TE, lower: Important but not suitable context. It's not general enough. Better add this to food.

R9 PHC, higher: There are compelling arguments that the 21st century will be all about water scarcity. Wars may be fought over water. Beyond this, it is a basic resource that we all use and understand in a superficial way. Yet it is very complicated, in both political and technical terms. It seems to me that it deserves the highest context rating.

R13 TE, higher: Really important subject.

R22, EE, higher: Of central importance for human survival.

R23 TE, higher: Again, how can this not be one of the big ones??? I like broadness of this nomenclature… from potable water and desalinization to river and flooding control to reservoir building to bottled water to…

<u>9: Construction:</u>

R22 EE, higher: Very important for living and to design an agreeable environment.

R23 TE, higher: MUCH broader than "city planning." As in food, clothing, and shelter. I think all three of these SHOULD be contexts. If clothing isn't on the list… add it…. Since everyone wears it and it is increasingly "engineered" Also more X chromosome friendly engineering than the more popular robot kill competitions, etc.

<u>10: 2-way Communication: between individuals and/or groups:</u>

R11 EE, lower: I see this is useful to engineers but not central to understand

R22 EE, lower: No relevance for technology education

R9 PHC, higher: Look at the amount of time students spend with one form or another of two-way communication. Clearly this is a context that students will have opinions about, and interests in. Furthermore, it is a very important set of systems. I stick with my "5" rating.

R 23 TE, higher: Combine with one way communication!

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[15] ER = Educational Researcher

On the border:

11: Global warming:

R3, higher: This is easily connected to huge wave of interest students have in “green technologies.”

R5, higher: If this is not an important issue let’s give up now!

R9, higher: I lumped Energy in society, sustainable technology and global together. I see that they can be separated, but typically they are treated together, and I think they should be. Beyond this, they are all extremely important.

R22, higher: Technical chance influences the problems in our world

R23, higher: Consider combining this item to the “Energy in Society” item above. Don’t they belong together??? If not, why not??? I think we SHOULD be connecting the curriculum to important world problem… Engineering has an important role to play in the

R17, lower: Important but not suitable as a context; it’s not general enough.

12: Domestic technologies**:

R13, higher: Especially automation

R26, higher: Suggest most relevant as they are so much a part of student’s everyday life

R11, lower: Part of students' lives but not central.

13: Safety/security:

R3 TE, higher: Engineering is especially well-poised to address these pressing social issues such as protecting the planet from human and environmental impact, and balancing security and privacy. These are solid emergent themes in the 21st Century.

R5 TE/PHC, higher: This links to politics. Every aspect of technology is political in my view (and many more notable others). Technology changes our lives in profound ways – some people, including politicians, believe that we can fix global warming with technology for example. This offers the subject a great potential for the implementation of critical pedagogy. I believe that this is the most important issue that is missing from technology education.

R20, higher: But separate safety (avoidance of injury) and security (freedom from intrusion)

14: Nanotechnology:

R8, lower: I think this will be very difficult to teach to kids in k-12. Mostly you can lay the foundation. (A: perspective: is it understandable/translatable to kids in k-12. NB, the “more or less complex versions” and “relevant to” consideration).

R19, lower: Nano is overrated, requires sophisticated lab resources. It’s more science at this stage than technology.

R5, higher: This has massive implications for the future.

R13, higher: Innovative technology

R22, higher: Very important to understand also the goals of innovations.

Big switches from round 2 to round 3

From Round 2 to Round 3 a few contexts drop their modes from 4 (very suitable) to 3 (suitable) and perhaps need to be reconsidered before excluding them altogether. They are: “Sports and recreation”, “Scientific research and exploration”, “Toys” and “Security (Big Brother is watching you)”.

Observations: more approaches for evaluating contexts

Analyzing the arguments for rating contexts higher or lower we find a few extra approaches to add to the overview from Round 1.

Contexts are important when they:

- **Encourage students into STEM pipelines** (R1 EE).
- **Are very broad** (R17 TE).
- **Are central to understand** (*technology*[16]) (R11 EE).
- **Are part of student’s everyday life** (R26 TE, R9 PHC).
    - Or for (designing enjoyable) living in general (R22 EE)
- **Are up to date; involve today’s big developments**.
    - Emergent technologies that will change the way we live (biotechnology, nanotechnology) (R23 TE).
    - What’s important to the future of our globe (R23 TE).
    - Big implications for the future (R5, TE/PHC)
- **Involve important complex interaction** (R13 TE).
- **Help to understand the social dimension of technology** (R22 EE).
- **Are broad and basic to human life**:
    - Food, Shelter, Clothing are musts. (R23 TE)
        - Food is key to human survival (R26 TE, R22 EE)
- **Are more X-chromosome friendly** (R23 TE)
- **Technology has a great influence on it** (R22 TE)
- **Offer an environment for exploring ethics** (R26 TE, on Food)

<u>Summary general remarks on context part:</u>

Engineering Educators:

– “Contexts should be chosen such that they give a holistic view on technology and its consequences for our lives,”[17] (R22) pleads. He argues that only then can technology education survive in public schools. Technology must be taught from the perspective of contributing to improve living conditions and solve social problems in the world.

– “I have emphasized contexts that have industrial importance and not necessarily those that might be exciting for adolescents. All the contexts can in principle be used to teach unifying concepts,” notes (R11). He asks again for criteria to obtain dispersion.

[16] Added by author.
[17] Quotes are summarized and slightly adapted for clarity by author.

Technology Educators:

– "Several of the new items seem substantially out of place," remarks (R20). From the comments on the contexts it seems he is referring to the contexts on 'religion,' 'politics,' and 'imagining the future.' He also objects to the "value-laden" terminology used in "robotization of society" and "big brother is watching you."

Of a different nature is the comment of (R13) suggesting we view technology development and education in a more holistic way, in terms of a process.

Again, the different approaches as to what constitutes appropriate contexts are clearly visible.

4 Conclusions and recommendations

4.1 Concepts

The results of the Delphi study have shown that a number of concepts stand out as possible foundations for an engineering and technology education curriculum.

The concepts "design (as a verb)," "system," "modeling," "social interaction," and "optimization" were given the highest average score by the Delphi experts. Of these, "optimization" gave rise to somewhat more disagreement among the experts than did the other concepts in this top-five list.

"Second-best" concepts were "innovation," "specifications," "design (as a noun)," "sustainability," "energy," "materials," "resource," "trade-offs," "technology assessment," and "invention." Of these ten, "trade-offs,", "technology assessment," and "invention" had somewhat less consensus than the other seven.

The concept "function" made an important change from round 2 to round 3. In round 3 it receives a significantly lower percentage of 4 and 5 ratings. It dropped from 67% in round 2 to 58% in round 3, thus not making the criterion for top concept in the final round. This is combined with a lower standard deviation in round 3. As our criterion is a flexible one, we may consider including this concept in the final list of "most important concepts".

Then comes a whole list of concepts that get only lower average scores and higher standard deviations. These concepts are apparently at least problematic. At the bottom of the list we find the concepts "technological trajectory," "practical reasoning," "tolerance," "intellectual property," "complexity," "algorithms," "working principle," "modularity," and "quality assurance." For two of these, namely "working principle" and "modularity," there was substantial lack of consensus. Several experts took the trouble to deviate from the round 2 average score and account for the deviation. In their opinion these concepts were more important than suggested by the average score. Less disagreement existed about rejecting "practical reasoning," "complexity," and "algorithms." But here too we find experts defending a higher score. One of the experts suggested that the concept "practical reasoning" is very important but could be a subconcept of "design (as a verb)." Similarly, another expert suggested that "complexity" could belong with "systems." A third expert suggested that "modularity" could also be put under "systems." These suggestions seem worth considering. The remaining concepts with low scores (below 3) were rejected by agreement.

4.2 Contexts

Compared to the fairly good agreement on the concepts, it is striking that the contexts gave more rise to disagreement. Standard deviations were generally higher here (0.80 on average) compared to the concepts (0.70 on average). But let us start with what was clearly agreed upon. The contexts “energy in society,” “biotechnology,” “sustainable technology,” “transportation” and “medical technologies” stand out as useful. Of these, “medical technologies” gave rise to the most disagreement. One expert explained that he scored it lower because these technologies seem to draw students to medical schools rather than engineering programs. The context “nanotechnology” scores a mode of four but gives rise to much disagreement. Proponents state that as an emergent technology that has big consequences for our future it is a very important context. Others view it as rather inaccessible and doubt its suitability for teaching technology to young learners. One expert also remarks that this context is much more about science than about technology. Next are “food,” “industrial production,” “water resource management,” “construction,” “two-way communication,” “global warming,” and “domestic technologies.” Of these, “global warming” gives rise to more disagreement; some experts suggest it is close to, and should be integrated with, “sustainable technologies.” Rejected with agreement were the contexts “religions and technology,” “crime scene investigation,” “art and technology,” “digital photography,” “personal care,” and “education.” The experts found most of these too narrow and suggested that they could be subsumed under one of the other contexts. The exception was “religions and technology,” which seems difficult to turn into practical material. Also, it may put the teacher in a difficult position as it can be a loaded subject. For the contexts “entertainment,” “digital photography,” “art and technology” and “religion and technology,” there are nevertheless one or two enthusiastic supporters with arguments for their position. One interesting defense for the last two is that boundary crossing provides rich contexts. Several experts argued to include “digital photography” under “communication” or as a form of “art and technology” under “entertainment.” Entertainment is defended as most relevant as it is so much part of the social, emotional, and physical well-being of students (influencing them both positively and negatively). The remaining contexts got only average scores (2.5-3.5) and often a lack of agreement. Highest standard deviations amonst these were found for “scientific research and exploration,” “politics and technology,” “security / big brother,” “music,” and “technology for peace.” Several experts commented that they ranked “do-it-yourself” higher than the round 2 average because this context was the route to engineering for many students.

It is striking that the traditional domains of application in the U.S. remain popular, as we see “transportation,” “communication,” “production,” and “construction” all in the list of highly scoring contexts. One of the experts expressed concern about this and wondered if there is a need to take a step forward. Biotechnology was already fairly popular in U.S. technology education curricula and it features strongly here. Perhaps the most interesting outcome is that some new contexts stand out: “energy in society,” “sustainable technology” (with overwhelming support) and “global warming” (with less agreement) seem to be related to an awareness of the global importance of these contexts. This is reflected by what one of the experts wrote, who could see “making the world a better place” as the umbrella context. Several experts suggested combining the three contexts, and they see global warming as a subcontext or discussion item within these or other contexts. Apart form this, most remarks highly favor the subject.

“Food” is highly supported by 80% of respondents, for different reasons: it touches upon current societal problems on world scale, is heavily influenced by technology and is a basic human need (so familiar to all of us). Though it gets a lower average rating and higher standard deviation, "water resource management" is highly praised in the comments. Different experts appreciate this context and used similar arguments as those used for food: it is increasingly becoming an issue of high societal relevance, is heavily influenced by technology, and is a basic human need. A single expert commented that it is too narrow. This is probably the reason for the lower ratings. At the same time another expert is taken by the broadness of it: "from potable water and desalinization to river and flooding control to reservoir building to bottled water to…"

"Medical technology" is another definite winner. "Domestic technologies" gets 4+ from little over half of the respondents (with remarks as "especially automation" and "part of student's life") but with much less strong agreement.

Another expert observed that the more practical contexts of lower abstraction level did not survive, in spite of the fact that these are strongly promoted by current educational research. Traditions seem to be strong among the experts.

4.3 Remaining issues for debate

Some remarks made by the experts give rise to more general discussions and therefore need more attention. In the first place, there is the issue of the level of abstraction, both in the concepts and in the contexts. Several experts remarked that the Delphi study would result in a list of separate concepts, while actually the list should be structured. Some concepts are at a higher level of abstraction and generality than others. Also there are numerous connections between the concepts that remain hidden in the list. This is clearly one of the limitations of this Delphi study, and it probably could not be avoided, given the limitations of the Delphi method. One could argue that bringing structure to the list is a necessary next step in the process of developing a curriculum. One way of doing this can be to draw a concept map that contains all of the concepts identified by the experts as important. The map should also feature the subconcepts. (The experts saw the subconcepts as important but ranked them low because of their low level in the hierarchy of abstraction.) The same problem arises in the list of contexts. Several contexts were seen as very important by the experts but were ranked low because of their specificity. Another issue for the debate is what to do with the recent insight in educational research that contexts should be practices in which students can be involved (see chapter 1). That idea clearly was not a priority in the experts' considerations. Is this a matter of traditionalism or a lack of awareness of the latest educational research studies? Or did the experts consciously reject this new idea, preferring instead the more traditional, broader contexts? Several experts mentioned that the broad and general contexts should be read as umbrella terms that need further concretization and operationalization. In defense of the broader contexts, several experts remarked that in their view engineering and technology education should involve students in the wider global challenges, and this opinion seems to be a valid consideration.

A second issue that several experts noted was whether or not the concepts should be specific for engineering and technology. Sometimes experts remarked that they rejected a concept because it was not specific for engineering and technology. How should we value that consideration? Would it lead to the immediate rejection of one of the highest scoring concepts, "systems," because it emerged not in engineering but in biology, and is used in many disciplines other than engineering and technology? Why then was this criterion of uniqueness (for engineering and technology) not applied more consistently? Were relevant concepts lost not because they were less important but because they were less specific for engineering and technology? How do we value that?

A third issue concerns the term "engineering and technology." Some experts suggested that engineering and technology are different and cannot be taken together in one expression that suggests they are almost the same. This raises the question, would separating the two have resulted in two different lists of concepts? If so, how would that be valued? To what extent is this remark related to the perceived difference between general and vocational education, which may suggest that engineering is for the latter and technology for the former? A related remark is that according to some experts the list of concepts was too focused on the design process and did not do justice to the social aspects of technology. Did that suggest a vocational bias? In the list of preferred concepts, this fortunately does not seem to be a problem, because several concepts in this list are directly related to the social aspects of technology. The argument though is: *all technologies exist only with human praxis. Therefore, this relationship needs to be embedded in each concept and not treated as something distinct to be considered separately*. Looking at the list, we see that the concepts "design (as a verb)," "social interaction," and "technology assessment" seem to have the human–technology relationship embedded most clearly. Should all concepts clearly reflect the human–technology relationship?

A fourth issue is the relationship between concepts and contexts. Some experts remarked that they had difficulty separating the two. The choice of contexts, according to them, cannot be independent from the preferences for certain concepts. Contexts are not infinitely flexible. Some are more suitable for learning certain concepts than others. The setup of the Delphi rounds did not take that into account. Here too we see a necessary next step in the process leading toward curriculum development.

The fifth point concerns the different approaches taken by experts in evaluating suitable contexts and the question for an overarching context. Is there a best approach, or can the approaches be combined? It seems that two types of contexts received high averages in the final round: the traditional contexts and the contexts on the border crossings of the different approaches. An example of such a context is the high scoring "food." This context is suitable from several approach viewpoints as it arguably is:

- truly relevant to students' lives
- exemplifying an enduring human concern (fundamental to human nature and relevant in variety of cultures and societies)
- situated around societal issues/problems
- heavily impacted by technology

(It is perhaps less relevant from the perspective that the contexts should encompass the human-made world, and is also given a 3 by the respondent who suggested this approach.)

If we make the effort to identify a suitable set of contexts, should we first find a best approach (or overarching context), or rather look for rich contexts that are valuable from different perspectives?

Also, considering the approach mentioned by one respondent that contexts should remain local, should we even try to identify universal contexts? Or do "suitable contexts" change too dramatically, depending on the culture, geography, and age of students?

Finally, several respondents, from both the Philosophy, History and Communication and the Technology Education groups posed fervent appeals for a more central place for normative issues in technology education. Issues relating to ethics, sustainability, criticality, and the relationship between humans and technology should be factored into (all) the concepts. Contexts should be used as a discussion arena for these normative issues. In round 1 a concept was suggested that we did not include in the new list but that is related to this: “unintended or unanticipated consequences”: *The idea that all technologies have consequences that are not anticipated by the designers. These consequences may be positive or negative.* It seems this is a notion that is still lacking.

Another respondent (R23: TE, on technology assessment) adds: “*Many (most?) of the great challenges on our planet in the 21st century (global warming, world hunger, pandemics, nuclear warfare, etc.) have resulted from technological endeavor and/or will be addressed by technological ‘fixes.’ … I think it’s far more important that kids understand that all technologies have unintended consequences and that we MUST assess them in that light (as well as for intended consequences).”*

On the other hand, a respondent (R32: TE) warns: *“Teachers shouldn’t put themselves in the position of seeming to push a political agenda, so sensitive topics must be handled carefully. Some of the contexts could be very tricky to handle (like religion, politics, and technology for peace).”*

Also one respondent remarked that some of the concepts are too value laden (“robotization of society” and “security / big brother is watching you”) and should be more neutral.

The question here seems to be how neutral and “technical” technology education should or can be. Can or should we want to teach on the nature of engineering and technology without involving normative aspects?

4.4 Recommendations

Having considered the outcomes of the Delphi study and some of the issues that need further reflection, we recommend the following:

(1) Some issues need to be debated before a final list of preferred concepts and contexts can be drawn up (these issues have been identified in section 4.3; a comparison with choices that have been made in the Standards for Technological Literacy would no doubt be useful here).

(2) The list of concepts and to a lesser extent the list of contexts need the structuring and hierarchy indicated. This can be accomplished by drawing a concept map as far as the list of concepts is concerned; the list of contexts needs further elaboration and operationalization in the sense of more practical contexts of a lower level of abstraction.

(3) A matrix needs to be developed in which the relationship between concepts and contexts is made explicit. This matrix can serve as the basis for curriculum development.

This process can lead to a curriculum in engineering and technology education that is based on a set of concepts and contexts agreed on by an international and interdisciplinary panel of experts.

5 Panel Meeting

The international Delphi Study described in this paper involved 30 experts in engineering and technology education (ETE) who interacted online in three rounds of discourse to identified key concepts and contexts to guide a new knowledge based to guide the design of new programs.

The outcomes of the Delphi study were used as input for an August 4-6, 2009 face-to-face meeting of a subset of the panel (n=10) who reviewed the results and created a template of concepts and contexts that could serve as a framework for ETE curriculum development. The panel consisted of five participants of the Delphi study plus three other experts that had not been involved in the Delphi study. Also two of the researchers (Hacker and De Vries) were present. The process was as follows: first, the group reflected on the contexts that came out of the Delphi study; and second, reflected on the overarching concepts. Both of the lists were found to lack structure and hierarchy, which is understandable from the methodology of the Delphi study. An analysis was made of the nature of the consecutively ranked concepts and contexts to provide the necessary structure for use as a curriculum framework.

The contexts that ranked high on the list that resulted from the Delphi study appeared consisted of two sub-groups of contexts. First, the panel recognized contexts that traditionally had been used in the U.S. as curriculum organizers: construction, production, transportation, communication, and biotechnology. The remaining contexts reflected major global concerns and included energy, food, water, and medical technologies. The motivation for including these contexts was expressed by one of the experts in the Delphi, who suggested that the study of ETE should be all about “making the world a better place.” During the discussion, the panel realized that both the traditional and the global concern contexts were related to basic human needs that can be addressed by engineering and technology.

Thus, the panel developed a single list of contexts that reflected engineering and technological endeavors in the context of addressing personal, societal, and global concerns. This list includes the following: food, shelter (our translation of the context that was originally called ‘Construction’), water, energy, mobility (originally called ‘Transportation’), production, health (the former ‘medical technologies’ context), security, and communication. This list both does justice to the outcomes of the Delphi study (it covers the top nine of the contexts list) and has a logic to support it (they are all basic human concerns). Another consideration was that the list would need to do justice to the fact that some of these contexts were put forward by the Delphi experts from a ‘global concern’ point of view, but other contexts originally were put forward because they allowed for deriving more concrete practices that would appeal to the learners because of their daily life character. So the panel decided to add the recommendation that when developing a curriculum, the contexts should be elaborated in two directions: in a ‘personal concern’ (or ‘daily life practice’) direction and in a ‘global concern’ direction.

The next step was to reflect on the concept list. It was evident that this list contained concepts of different levels of abstraction. Therefore it was decided to identify those concepts with the highest level of abstraction and to put the remaining concepts under these ‘main’ concepts. Starting from the top of the list, the panel identified the following concepts as the most abstract: design (as a verb), systems, modeling, resources, and human values. The last-mentioned concept did not feature as such on the list but was introduced by the panel as a heading for several concepts in the list that were value-related. It also reflected the concern of a number of Delphi experts to make the normative dimension of technology and engineering visible in the list of concepts. The remaining concepts could then be put under these five main headings, but here the panel realized that there is no sound basis for drawing the line between those concepts that were included and those that were not. In fact, all concepts on the list (except for two) were given at least a score of ‘3’, which indicates that even though not all were considered equally important, nearly all concepts were seen as fairly relevant. It would therefore be a missed opportunity for innovation of the curriculum to leave out concepts based on an arbitrary decision about where to draw the line. The panel decided to mention the concepts that ranked high on the Delphi list as those examples that had a certain status of priority because they were ranked highly by the Delphi experts. Thus the panel ended with the following list of concepts and sub-concepts:

Design (as a verb): optimization, trade-offs, specifications, technology assessment, invention

Systems: artifact (the panel’s translation of ‘design as a noun’), function, structure

Resources: materials, energy, information

Values: sustainability, innovation, risk, failure, social interaction

Finally the panel decided to put forward a number of remarks concerning a possible next step, namely developing these lists into an ontology-based curriculum. In the first place, the panel noted that there are two possibilities of structuring the curriculum: according to the contexts, or according to the concepts. The first option results in modules like ‘Water’, ‘Energy’, or ‘Mobility’ and can be used to show the versatile nature of the concepts because these will all feature in the module. The second option will result in modules like ‘Systems’, ‘Resources’ or ‘Values’ and can be used to teach and learn the concepts in the way that is suggested by the current ideas on concept-contexts learning (learning a concept in a series of different contexts, which gradually leads to an insight on more abstract level, and thereby also transferability to new contexts). Both options are justifiable and a curriculum could even contain a combination of modules based on both options. A second remark is that before developing the curriculum it is necessary to investigate the specific meaning concepts get when they are applied to the different contexts. This is necessary, because current theory claims that the concepts are indeed ‘colored’ by contexts are therefore are context-dependent to a certain degree. A third remark was that it would be useful for curriculum developers to have vignettes that illustrate how the framework of concept and contexts lists can be developed into a curriculum. A fourth remark was that the framework does not yet reflect the need to develop both qualitative and quantitative activities when developing the curriculum. Current technology education curricula are often biased towards the qualitative, but the engineering dimension requires serious attention for the quantitative also.

After the session, the panel felt that justice was done to the outcomes of the Delphi study, while at the same time the result now was more systematic and structured. The group decided to start developing project proposals in which the framewotk is elaborated and transformed into a curriculum proposal.

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Attachments

A. Descriptions of concepts and contexts

B. Respondents and their affiliations

C. Suggestions for concepts treated as sub concepts

A. Descriptions of concepts and contexts

Descriptions of Concepts

Rank	Unifying Concept / Theme	Description
1	Design (as a verb)	The process of originating and developing a plan for a product, structure, system, process or component with intention. (Includes problem recognition, analysis, experimentation, testing, teamwork, c communication, customization and design cycle) .
2	System	A group of interrelated components and functions designed to collectively achieve a desired goal. (This includes such concepts as control, input, process, output, feedback.)
3	Modeling	Representing a system, device or process to promote understanding and prediction of (certain aspects of) the real system, device or process. (Includes the concept of prototyping.)
4	Social Interaction	The effect of technology and engineering on individuals and society and vice versa. (Includes human-machine interaction.)
5	Optimization	The process of balancing design alternatives in order to meet all design criteria as effectively as possible.
6	Innovation	The successful development of a new device, process, or concept or the improvement of an existing one. (Concept includes the notion of entrepreneurship.)
7	Specifications	The performance requirements that a design must fulfill in order to be judged to be acceptable by the makers and/or the users. (Includes the notions of needs, requirements and constraints.)
8	Design (as a noun)	The final embodiment of the design process
9	Sustainability	Functioning well in the present without compromising future functioning.
10	Energy	The capacity to do work. Energy takes many forms.
11	Materials	Substances of which something is composed or from which something can be made.
12	Resource	An asset – human (including knowledge and skills), material, time-related, or capital – which can be used to accomplish a goal.
13	Trade-offs	A decision based on an exchange of benefits and disadvantages associated with one or more solutions, techniques, products or paths.
14	Technology Assessment	A process to determine the possible risks and benefits that technological endeavors present to people, society, or the environment.
15	Invention	The creation of an idea for a novel device, process, or concept using thought, experience or experimentation.

16	Risk and Failure	Determining the probability of an action or event, adversely affecting an entity's ability to achieve its objectives.
17	Information	Data that have meaning and/ or relevance to someone.
18	Function	The action or purpose for which something has been designed, or that users ascribe to it.
19	Structure	The manner of construction of a human made entity and the arrangement of its parts.
20	Product lifecycle	The various phases in the life of a product such as design, production, use, disposal/recycling.
21	Measuring (includes instrumentation and units)	Determining the units (measure) and quantity (measurement) in which different resources (human, energy, material, distance, area, time, etc.) are used or needed for an activity.
22	Standards	Established norms or requirements, resulting in uniform engineering or technical criteria, methods, processes and practices.
23	Application of science	The use of scientific knowledge in the development of new products and processes.
24	Efficiency	The ratio of system output to system input.
25	Heuristics	Experience-based, open ended search rules in a problem solving process.
26	Quality assurance	System for ensuring the maintenance of proper standards regarding the whole life cycle of a product.
27	Modularity	The approach to design and construction that recognizes the boundaries of partially independent subsystems in terms of their input/output characteristics.
28	Working principle	The set of rules/conditions that describes how a device works/behaves.
29	Algorithms	Recipes or fixed rules in a problem solving process.
30	Complexity	A condition in which numerous elements are combined and have multiple interactions within an interrelated system.
31	Intellectual property	A formal, legal recognition of rights associated with a particular invention or innovation that are retained by its creators and protected against infringement.
32	Tolerance	Maximum deviation from a nominal value.
33	Practical (e.g. means-ends) reasoning	A line of thought aimed at arriving at decisions or intentions to act.
34	Technological trajectory	The phenomenon of a (suboptimal) system becoming a standard because of the difficulties involved in changing it.

Descriptions of Contexts

Rank	Context	Description
1	Energy in society	Includes generation, use, and storage of energy.
2	Biotechnology	Technology based on biology, especially when used in agriculture, food science, and medicine.
3	Sustainable technology	Sustainable use of resources, environmental stewardship, and recycling.
4	Transportation (using vehicles, traveling)	Includes all forms of traveling by people, and the transportation of goods. Concerns both the vehicles and the infrastructure.
5	Medical technologies	Includes going to the doctor or hospital, medical diagnostics, receiving medicine, undergoing an operation, technologies for disabled etc.
6	Food	Includes production, processing and preservation of food and includes global food issues.
7	Industrial Production Commerce	Includes working in an industrial company, commerce, marketing, and manufacturing.
8	Water resource Management	Includes water harvesting, storage, distribution, quality, use and conservation.
9	Construction	(City planning)
10	2-way Communication: Communicating between individuals and/or groups	Includes making phone calls, sending e-mails, web 2.0, etc.
11	Global warming †	Includes climate change issues
12	Domestic technologies †	Includes food preparation, home management, furniture and interior, heating/cooling.
13	Safety/Security	Including that of people, animals, society, and the environment.
14	Nanotechnology	Technology based on the control of matter on the nanoscale (atomic and molecular scale). Includes material development and innovation.
15	Scientific research and exploration	Includes working in a lab, conducting surveys, experimentation, space travel, ocean exploration, etc.
16	Security in the sense of "big brother" (whoever it is) is watching you.	Includes mass surveillance, biometric surveillance, RFID tagging, hacking, identification issues, telephone tapping, data mining and profiling.
17	Sports and recreation	Includes playing football or tennis, hiking, mountain climbing, and camping.
18	1-way Communication: Mass Media	Includes watching television, reading books or newsprint, listening to CDs/mp3s or radio etc.
19	Virtual reality	Includes gaming and simulation

20	Imagining the future	Futuristic technologies
21	Do-it-yourself	Includes tinkering, maintaining, and repairing.
22	Politics and technology	Includes elections, parties, social discourse, policy making within societies, international disputes and agreements, economic cooperation and competition. All heavily influenced by technologies.
23	Rescue	\Includes disaster recovery, accident recovery, rescue robots.
24	Packaging †	*No description added*
25	Toys	*No description added*
26	Robotization of society †	Includes social robots
27	Technology for peace building	(Includes issues concerning world peace v.s. countries at war)
28	Music	Includes entire industry sector including artists, producers, lawyers, marketers, distribution channels, concerts, repurposing, licensing, branding, ancillary product lines. Also including making, playing, recording music (instruments, systems, recording technologies.
29	Entertainment	Includes concerts, discotheques, and movies. Also includes event organization and management.
30	Education	Includes learning, learning tools, attending classes, being at school, preparing for and taking exams.
31	Personal care	Includes eating, sleeping, showering.
32	Digital photography	Includes how a picture is transformed into digital data; photo enhancement, face recognition.
33	Art and technology	Includes painting, sculpting, restoration of masterpieces.
34	Crime scene investigation	Includes material analysis.
35	Religions & technology	Includes formal organized religions as well as spirituality that manifests itself in myriads of ways in modern societies, the quest for transcendence.

B. Respondents and their affiliations:

Group 1: Engineering Education

	Name	Affiliation	(Sub)category
1	Larry Genalo	Iowa State University Materials Science and Engineering	Engineering Educator
2	Dr. M. David Burghardt	Co-Director Center for Technological Literacy, Hofstra University	Engineering Educator
3	Gerhard Salinger	National Science Foundation	Association / Foundation Leader
4	Walther Theuerkauf	University of Braunschweig, Germany	Technology Education /Engineering Educator
5	Laura Bottomley	College of Engineering North Carolina State University	Engineering Educator
6	Greg Pearson	National Academy of Engineering	Association / Foundation Leader
7	Taryn Bales	Univ. of Maryland Baltimore Chem& Biochm Eng. Dept.	Engineering Educator
8	Thomas Liao	State University of NY at Stony Brook	Engineering Educator

Group 2: Technology (Teacher) Education

	Name	Affiliation	(Sub)category
1	Mitchell Nathan	University of Wisconsin-Madison/Wisconsin Center for Educational Research	Educational Research / Cognitive Science
2	John Dakers	Glasgow University, UK	Technology Educator /Philospher of Technology
3	Howard Middleton	Griffith University, Brisbane, Australia	Technology Educator
4	Dennis Cheek	Kaufmann Foundation, USA	STS Education
5	Rodney Custer	National Center for Enginee-	Technology Teacher

		ring and Technology Education / Illinois State University	Educator
6	Jurgen Wehling	University of Essen, Germany	Technology Educator
7	John Williams	Edith Cowan University, Australia	Technology Educator
8	David Crismond	City College of New York	Educational Research / Cognitive Science
9	Martin Fislake	University of Koblenz, Germany	Technology Educator
10	Chitra Natarajan	Homi Bhaba Centre for SE, India	Science/technology Education
11	Dan Householder	Center for Engineering and Technology Education Utah State University	Technology Teacher Educator
12	Eric Parkinson	University of Canterbury, UK	Technology Educator
13	Mark Sanders	Virginia Tech, School of Education Dept of Teaching & Learning	Technology Teacher Educator
14	Vicky Compton	University of Auckland, New Zealand	Technology Educator
15	Moshe Barak	Ben Gurion University of the Negev, Israel	Technology Teacher Educator
16	Kendall N. Starkweather	ITEA, USA	Technology Educator
17	Michael De Miranda	Colorado State University	Technology Teacher Educator
18	Kenneth Welty	University of Wisconsin-Stout Natl Ctr for Eng & Tech Ed	Technology Teacher Educator
19	Marie Hoepfl	Appalachian State University/Dept of Technology	Technology Teacher Educator
20	William Dugger	ITEA, USA	Technology Teacher Educator
21	Alister Jones	University of Waikato, New-Zealand	Technology educator

Group 3: Philosophers, Historians and Communicators of Technology

	Name	Affiliation	(Sub)category
1	Peter Kroes	Delft University of Technology, the Netherlands	Philosopher of Technology
2	Christine Cunningham	Museum of Science Science Park, Boston	Science/Technology Communication
3	Davis Baird	University of North Carolina, USA	Philosopher of technology
4	Roald Verhoeff	Science and Technology Communication Teacher and Researcher, The Netherlands	Science and Technology Communicator
5	Louis (Larry) Bucciarelli	School of. Engineering, Massachusetts Institute of Technology, Cambridge	Philosopher of Technology

C. Suggestions for concepts treated as subconcepts

Full list of suggested concepts viewed as subconcept.

R13: Technological process

This should be a holistic description of interdependencies concerning material, energy and information relevant systems (take a look at different system approaches).

R17: Process/method

makes the innovator an inventor or the diffence between an artist and an engineer

(Part of design.)

R18: Motion

Change of location of a component or system.

R27: Noise

Noise is an important technological concept, for example, in communications systems or digital image processing.

R7: Unanticipated consequences

Things that happen for good or bad in relation to a product, device, or process that cannot be foreseen in advance but only emerge upon immediate or longer term use

(Part of technology assessment)

R24 Unintended Consequences

The idea that all technologies have consequences that are not anticipated by the designers. These consequences may be positive or negative.

(See also R7)

R26: Unintended or unanticipated consequences

Common results of technology and engineering reflecting the uncertainty within which these disciplines function.

R23: in a remark on the concepts Technological Assesment in Round 3:

Many (most?) of the great challenges on our planet in the 21st century (global warming, world hunger, pandemics, nuclear warfare, etc) have resulted from technological endeavor and/or will be addressed by technological "fixes." I think it's well past time we promoted the notion of technological assessment. I think it's far more important that kids understand that all technologies have unintended consequences and that we MUST assess them in that light (as well as for intended consequences).

R8: Multiple solutions

An engineering problem may have multiple solutions. The relative ranking of these has to do with the criteria and constraints

R13: Analog/digital computing

Real life is not digital oriented but analogue. This is important for setting up process simulation, which are sometimes implemented much easier in an analogues way instead of using numerical methods.

R15: Ill-defined Problem Solving

See Herb Simon – problems that allow for multiple framings, and there multiple solutions, i.e., no correct solution

(Part of design as a verb)

R24: Open-ended nature of engineering problem solving

The idea that engineering problems may have multiple solutions that satisfy the design criteria. There is no single "right" answer in engineering.

(See also R15.)

R17: Communication

To use and produce technical information

(See also R26 and R29)

R29: Communication

The technological method used to communicate the final design solution and specifications.

(See Brief, R26 and R17.)

R26: Brief

A succinct communication of the type of outcome to be developed and the specifications it should fulfill.

R23 Technological literacy

I'm not sure this one belongs here... but I do think it's critical that we address the concept of literacy when we address engineering & technology in grades PK-12. We MUST differentiate between "literacy" and "expertise" in ways we never have.... And I think students should be made aware of those differences as well... But again, it may not belong here....

R26: Technological literacy

The goal of technology and engineering education.

R28: Experimentation

The act of trying a new procedure, process or activity

R12: Research

Investigation or experimentation aimed at the discovery and interpretation of facts, revision of accepted theories or laws in the light of new facts, or practical application of such new or revised theories or laws

R6: Opportunities

Identifying possibilities for achieving suitable solutions within particular contexts.

(Part of design as a verb.)

R7: Creativity

The capacity to generate ideas that are simultaneously original and that satisfy the criteria appropriate to the design and technology arena

(Part of design. But actually also a separate concept….)

R9: Reasoning from fast principles or agreed-upon starting points

Not all reasoning is means-ends. Some is from first principles, and this is part of the process.

(Part of design and practical reasoning.)

R9: Reasoning by analogy

Using prior art (material or conceptual) as an analogy for a new design or solution.

(Part of design and practical reasoning.)

R11: Behavior

Changes in the system in time

(Part of system and modeling.)

R12: Visualization

The ability to conceive of an object or process in the abstract.

(Part of modeling.)

R12: Research

Investigation or experimentation aimed at the discovery and interpretation of facts, revision of accepted theories or laws in the light of new facts, or practical application of such new or revised theories or laws.

(Part of application of science.)

R14: Life cycle analysis

The effect a product has on the environment from the initial concept to disposal.

(Part of product life cycle combined and technology assessment.)

R17: Economy

Belongs to conditions.

(Conditions is part of specifications.)

R17: Conditions

To accept the conditions makes the innovator an inventor.

(Part of specifications. Description not very clear.)

R17: Decisions

As a common part of the design process often compromises instead of going ahead—sometimes social competence.

(Part of trade-offs. The description seems to make it part of design, teamwork, though.)

R19: Prosthetics

Aids and extensions to human sensory and locomotion capability.

R19: Infrastructure

The resources—both local and global— that engineers can draw upon in their work at any point in time.

R19: Instrumentation

Sensors and data processing equipment used to obtain measures of performance of big world as well as prototypical devices, etc.

(Concept of measurement included in measurement.)

R19: Consistent units

Requirement that combinations of variables maintain consistent units.

(Part of standards.)

R19: Estimation, order of magnitude.

Parameter quantification via crude deductive reasoning.

(Part of design a a verb.)

R21: Materials/Structures

What both built forms and natural forms are composed of. An understanding of materials and structures assists in bridging ideas between the natural world—with natural materials and naturally occurring forms and structures—and the made world.

R21: Environments

These may be subsets of systems, but are a more recognizable expression of these.
(Part of specification, as in constraints. See also R26.)

R21: Artifacts / Made forms

Artifacts as human-made forms help in both defining humans and technology. The fact that humans can make, manipulate, model, and mend helps differentiate them from other living things.

(Part of design as a noun.)

R26: Fitness for purpose

The ability of an outcome to serve its purpose in "doing the job" within the intended location, where the job to be done is clearly defined by the brief.

R26: Technological or engineering practice

An iterative process of design and development for the purpose of developing a product or system to resolve an identified need or realize an opportunity.

(Part of design as a verb.)

R26: Ingenuity

The human dimension of invention and innovation including knowledge creation.

(Part of invention.)

R26: Environment

The totality surrounding conditions and circumstances affecting the ability to do work.
(Part of specifications.)

R29: Ideation/solution generation

The process of researching and bringing to consideration plausible design and problem solutions.

(See also R6, R8. Part of design as a verb.)

R32: Impacts

The effects or outcomes of a system. Can be examined from environmental, economic, social, political, and technological perspectives.

(Part of technology assessment. Economic and political included in societal.)

<u>Full list of concepts included in “Social interaction”:</u>

R5: Historicity

What and how can we learn from history, about the development of a technological system. (Not explicitly mentioned as learning from history)

R5: Cultural embeddedness or localization:

Universal solutions do not always solve local problems. They are often culturally embedded. (Not explicitly mentioned in this terminology.)

R14: Human factors/ergonomics

Analysis of Interactions between humans and other elements of a system to maximize human well being and system performance. (Included as “man-machine interaction”)

R15: Understanding Users

Intended audience for which the design is intended. (Included as “man-machine interaction”)

R16: Users

Intended or not intended (end-) users, e.g. consumers, patients, industries of a product

R16: User-Producer interaction

Participation of (end) users in the innovation process to optimize the quality and economic success of innovations

R17: Psychomotor domain

Being able to do things (Somewhat part of man-machine interaction.)

R17: Empathy

This is what helps to make new ideas economic, efficient.

“Don’t make me think” (Part of social interaction. Not mentioned explicitly.)

R18: Socio-cultural Influence

The influence of social and cultural contexts on the activity.

R19: Social context of practice

The setting and organization of engineering work including modes of social exchange among participants in a task. (Part of teamwork in design, part of social interaction in general.)

R19: Technology & Culture

The ways culture influences forms of innovation and how innovation influences development of culture.

R26: Sociotechnological perspective

A view of technology and society as inextricably linked where technology is seen as a defining characteristic of human nature

R26: Stakeholders

People or groups who have an interest or potentiallly will be impacted by a technological or engineering outcome or its development practices (including resources and additional outputs such as waste. (Also somewhat part of technology assessment)

<u>Full list of concepts not used because their nature is too different or they are related to subconcepts:</u>

R2: Reverse engineering

Working backward from preexisting products or processes that are desirable to a set of principles and that are often then used to mass-produce or widely disseminate the product.

(Part of design as a verb.)

R2: Feasibility

Cost and labor considerations.

(Not included specifically. See also R32.)

R2: Benchmarking

Use of common questions or criteria so function can be considered across multiple contexts, or allow for comparisons of important parameters (e.g., speed, power load).

R4: Value

Measure of desirability of something, either as a means to some end or for its own sake.

R4: Know-how

Skills necessary to make or use something.

R5: Normative aspects

Serious consideration, by way of consultation, needs to be given to the "should we" aspect as opposed to the "we have the technology" aspect.

R9: Human systems

Arrangements, policies, and procedures that involve humans as individuals and as formal or semiformal groups. (Part of social interaction, but also concept on its own.)

R9: Return on investment

The amount an investor can expect to gain/lose on an investment in some project.

R13: Mechatronics

This concept brings up some interchanges for material, energy, and information by focusing on mechanical elements. (Too narrow.)

R16: Technology

(Too general.)

R19: Exemplar

A problem whose solution embodies the essential concepts and principles of a particular, paradigmatic engineering science.

R21: Responsibility / ethical dimensions

The idea of the responsibility of the designer/originator of a new idea or artifact. New ideas and artifacts impact on others and not always favorably. Ethical considerations of consequences of actions.

(Included in social interaction and technological assessment.)

R22: Technological Processes

Structure material, energy, and information processes

R22: Mechatronics

Mechatronics is, besides the coöperation of different technical disciplines, a philosophy. It makes it possible to impart a holistic view on technology.

R22: Communication

For technology it is on the one hand between persons and on the other hand with networks is very important.

R23: The nature of technology

R23: The nature of engineering

R23: The relationships among, and interdependence of, the STEM disciplines

R23: History of technology

R23: Systems model

R26: Codes of practice

Codified technological knowledge that serves as a reference for related technological and engineering developments.

R32: Cost-benefit analysis

A tool used for analyzing the feasibility or desirability of a system.

(See also R2, Feasibility. Part of design and part of trade-offs and technology assessment.)