Educating Future Engineers and the Image of Technology
Applying the Philosophy of Technology to Engineering Education

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DOI
10.4233/uuid:9caf6c42-7976-45bd-a709-a53d3ab5ce70

Publication date
2017

Document Version
Final published version

Citation (APA)
Ghaemi Nia, M. M. (2017). *Educating Future Engineers and the Image of Technology: Applying the Philosophy of Technology to Engineering Education*. [Dissertation (TU Delft), Delft University of Technology]. https://doi.org/10.4233/uuid:9caf6c42-7976-45bd-a709-a53d3ab5ce70

Educating Future Engineers
and
the Image of Technology

Applying the Philosophy of Technology to Engineering Education

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Proefschrift

ter verkrijging van de graad van doctor
aan de Technische Universiteit Delft,
op gezag van de Rector Magnificus prof.ir. K.C.A.M. Luyben;
voorzitter van het College voor Promoties,
in het openbaar te verdedigen op
Dinsdag 26 September 2017 om 12:30 uur

door

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Master of Business Administration
Sharif University of Technology, Iran
Geboren te Urmia, Iran

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ISBN 978-94-6233-744-2

An electronic version of this dissertation is available at
http://repository.tudelft.nl

“We realize the extent of human’s continuation from his great talents;
since he has endless talents, he continues infinitely,
and, for such an infinity,
he must nurture his talents and grow powerful legs, …”

(Ali Safaei Haeri)

Dedicated to my beloved family

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01

Chapter. 1

INTRODUCTION

INTRODUCTION

> *"Nowadays we attempt to educate 21st-century engineers with a 20th-century curriculum taught in a 19th-century institution."* (Grasso & Burkins, 2010)

The statement of Grasso and Burkins (2010) above expresses an essential and much-studied concern to be addressed in this thesis: the failure of educational curricula and methods to keep pace with rapidly changing developments of the technological world, in both research and practice. This is a problem for education in general but is particularly critical in engineering and other STEM fields.

Education is a crucial human activity, because all subjects of study at their core, whether meteorology, music, or manufacturing technology, enable us to enhance our quality of life or even our survival. This premise is fundamental to philosophical reflections on education as well as to educational methods and curricula. How we approach education is directly linked to what we can achieve.

Recent discussion among scholars of the philosophy of education underlies the specific approach of this thesis to engineering education. It has been claimed that the holistic aims of education are better achieved by providing learners with comprehensive insights regarding the discipline to be learned about, as opposed to narrowly focused knowledge and skills. This view challenges the dominance of the latter approach in both educational literature and practice with claims that this approach has led to ineffective knowledge-gathering or truth-seeking and a failure to yield the comprehensive understanding necessary for real life and the intended practices (see, e.g., Ballard, 2007; Dewey, 1916; Howard & Maton, 2011; Kneller, 1971; Warnock, 1976; Papastephanou, 2014; Strawson, 1971).

The same critiques have recently been raised for the narrower field of engineering education as well, and the necessity of delivering a comprehensive image of engineering and technology has been considered seriously in various proposals for reforming engineering education. According to Goldberg (1994), engineers currently live in a technologized environment that necessitates continuous updating of their understanding and skills. Crawley et al. (2014), in their book *Rethinking Engineering Education*, call attention to changes over the last century regarding the interrelation of engineers, technology, and society. They propose *a new engineering identity*. Mitcham (2014) sees the matter of *self-knowledge* – in the sense of “critical thinking about what it means to be an engineer” in relation to society and humanity (p. 19) – as *the true grand challenge for engineering*, which Mitcham claims has been neglected. In differing approaches, Cunningham et al. (2005), Knight and Cunningham (2004), and Li et al. (2008) address the serious challenge of the diminishing rate of American students’ interests and enrollment in engineering schools during recent decades. In these discussions, the challenge is considered to be rooted mainly in students’ existing *negative* or *incorrect image* as to the nature of engineering. This problem can be generalized to other countries as well (Mitcham, 2014). Studies by Frankel (2008), Stevens et al. (2007), and Yurtseven (2002) claim that inaccurately negative perceptions have led to problems in recruitment and retention, resulting in a decline in the number of well-educated engineers, particularly in the US.

In line with such viewpoints are two studies worth noting, which treat the concerns in question in greater depth. The first is the 10th chapter of Crawley et al. (2014) in which, through presenting a brief historical sketch of the revolution of engineering education, the authors emphasize an essential point to be regarded in reforming plans proposed for engineering education. Such reforms, in their view, should deliver practical insights regarding modern engineering. They hold that the lack of such practicality in the most relevant proposals from the 1970s on has made these proposals ineffective.

The second is another noteworthy study by Downey (2009) which addresses the critical question of what engineering studies are for. Downey relates the aforementioned deficiencies to the irrelevancy of existing theory to engineering education reforms. According to Downey, the dominant approach of such scholarship has little to do with what it means to be an engineer in practice and therefore needs to be scaled up to address many ignored aspects, both technical and non-technical, of engineering practice. This will provide the reform plans with a broader perspective of what needs to be understood about engineering and about the related competencies to be rendered in engineering education. Downey's account is, in fact, correlated with an axiom belonging to the philosophy of education in general, in which educational inquiries are conceived of as dynamic entities to be dealt with accordingly; that is to say, they have a consistent nature in principal that should be independently addressed in each era, according to the variable conditions and contingencies of that particular age (see, e.g., Noddings, 2012).

The last two concerns have laid the particular foundation of this thesis before us, although those mentioned earlier will be also be addressed to some degree. The approach taken here seeks to provide curricular reforms with a concrete understanding of engineering and technology, while also delivering a method for scaling up the realm of theoretical reflections on various aspects of engineering practice. That is to say, while taking advantage of philosophical reflections upon technology and engineering, the thesis contributes to examining the following principal research question:

> *In what respects do the current approaches to engineering/technology education deliver a comprehensive image of engineering/technology and*

the socio-technical style of the future work and life of engineers (as prominent designers and users of such technological systems)?

The significance of such a principal question becomes even more pronounced when considering the new characteristics of this century's technological paradigms and fast-growing engineering environments (see, e.g., Barrow, 2010; Cunningham & Allen, 2010; Siegel, 2009).

The necessity of improving, reforming, or even revolutionizing the process of preparing the next generation of engineers has been stressed in various ways, through the lens of different perspectives: some proposals concentrate on delivering insights relating to the complex paradigm of the future socio-technical world and its extremely different characteristics (e.g., Kurzweil, 2005; Mbe, 2015; Shanahan, 2015), some endeavor to philosophize about the nature of engineering and different aspects of its related knowledge (e.g., Christensen et al., 2009; Meijers, 2009; Michelfelder et al., 2013; Pitt, 2011), and a significant quantity of books, research and policy documents have made their effort to provide a comprehensive educational view about the real characteristics of engineering practice in the course of its postmodern progress (see, e.g., NAE, 2004, 2005, & 2008; Goldberg & Somerville, 2014; Duderstadt, 2008; Grasso & Burkins, 2010). The latter, which has more directly to do with education, focuses on extending the area of knowledge, skills, and attitudes of engineers, from various socio-technical perspectives.

The contribution proposed in this thesis is a combined but innovative approach. While taking advantage of the philosophical reflections on technology and engineering, it attempts to provide a concrete background for educating about them – with the aim of paving the way to delivering a sound and comprehensive image as to the very nature of technology and the socio-technical environments that students, particularly future engineers, will expect in their near future; the approach recommended by thinkers such as de Vries (2005), de Vries and Tamir

(1997), and Jones et al. (2013). The thesis can also be seen as linkable to the future and its technology-oriented considerations, but not in the sense of predicting and speaking about the future characteristics of technology in detail. Rather, it principally concentrates on equipping engineering learners through extending their perspective and, consequently, enhancing their power of reflection upon various aspects and possibilities of the world of engineering over the course of time.

Students as *future engineers* have been considered, in this attempt, to comprise two major, interrelated levels. The first is the level of primary and secondary school students, as *potential* engineering students (their education in this direction is highlighted in works such as Crawley et al. [2014], Cunningham et al. [2005], Knight & Cunningham [2004], and Miaoulis [2010]). The other is that of tertiary education, that is to say, the *real (actual)* students in engineering schools and universities. We can also reflect upon engineering education at each level through the lens of two different perspectives: (1) analyzing the problems of a particular level from an overall content perspective, in order to attain a general 'what is/what ought to be' image of the state of education, or (2) focusing on some specific issues of the intended level – particularly, *models* and *normativity* (as argued later on) – to enrich what should be learned about specific aspects or concepts of the real practice of engineers. These categorizations, as demonstrated in Figure 1, lay the main foundation of the body of this thesis and its portfolio-type articulation of chapters, as follows.

The argumentation line of the thesis begins with Chapter 2, through raising the first sub-question 'do standards for Technological Literacy render an adequate image of technology?' Concentrating on the realm of the current standards of engineering/technology education at the primary and secondary school levels, this chapter aims at underpinning a solid framework based on the philosophy of technology to assess and improve the structure of such standards of education, in terms of their approach to delivering a concrete technological literacy. It starts with

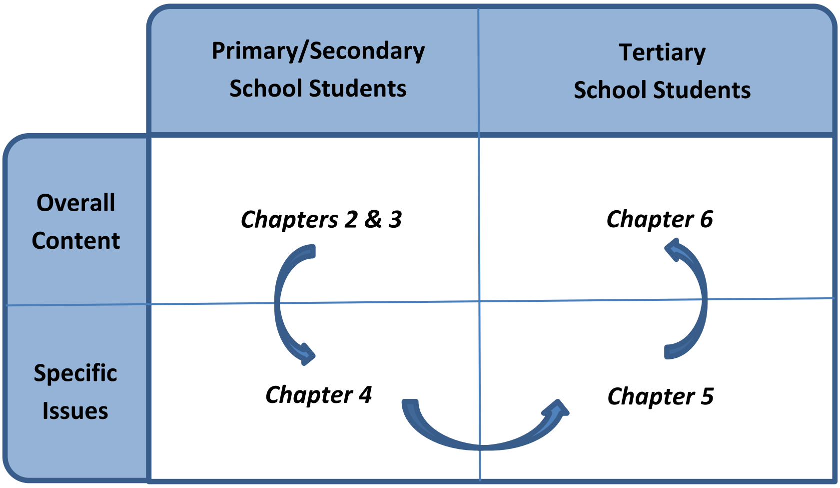

Fig. 1 Chapters articulation

presenting a historical look at the progression of teaching about technology and then discusses the reliability of the philosophical reflections on technology to be resorted to for achieving the intended aim. Mitcham's renowned four-sided perspective on technology will lay the foundation of the initiated framework – a model completed then with pertinent concepts and concerns put forward by known philosophers of technology. The model provided will be applied to the American case of *Standards for Technological Literacy: Content for the Study of Technology (ITEA, 2007)* as the most extensive policy document of technological literacy for primary and secondary school students. This application can yield remarkable outcomes for improving that standard.

Chapter 3 complements the previous chapter, applying the initiated framework to New Zealand's related policy document. This case is claimed by its authors to have taken advantage of philosophical reflections on technology and, particularly, to conform with Mitcham's four-sided framework. The sub-question of this section is 'to what extent could the specific approach of The New Zealand Curriculum foster a comprehensive understanding of the nature and various features of technology?' The core value proposed by this chapter is that, besides its contribution to improving the New Zealand case, it makes the innovative framework of the earlier chapter more concrete by applying it to another case with an entirely different approach than the first one. This, in fact, enhances the reliability of the proposed framework and concurrently demonstrates its broader potential to be used for other cases at a similar level. In addition, juxtaposing the results of this chapter and the first one leads to insights as to certain common shortcomings of the two (well-known) cases studied, to be addressed in further research.

The 4th chapter concentrates on one of those common shortcomings, that is, the concept of *model* (and the process of *modeling*) as an inevitable component of most engineering activities. The sub-question of this study is 'how can one deliver a comprehensive account as to the nature and various properties of *models* designed and used in engineering practice?' The chapter not only emphasizes that the significant concept of *model* (and *modelling*) should be taken into greater account in technological literacy attempts, but also calls attention once more to the advantage of the discipline of the philosophy of technology – this time, for providing more in-depth perceptions regarding a narrower concept; the approach that can be extended to contemplating other necessary concepts as well. Understanding *models* as *artefacts of a dual nature*, in this instance, yields a concrete and well-structured account of their nature and various characteristics.

The next significant concept, ignored in most educational approaches, is the notion of *normativity* (of technology) which will be taken up in the course of Chapter 5. To put another way, this chapter focuses on 'how does one deliver a concrete educational account about the normativity in technology?' However, unlike the preceding chapters, devoted more to discussion on the primary/secondary levels of education, this section attempts to take that of the tertiary level into account. This paves the way to extending the scope of the argumentation line of the thesis to reflections upon the education of future engineers, that is to say, entering the 2nd column of Figure 1. This chapter discusses the need for engineering students to acquire a sound grasp of ethics in order to be able to deal with the ever-increasing ethical issues of their future profession. *Normativity*, as concerned with the specific approach of this thesis (in resorting to the philosophy of technology), will correspondingly be discussed that has mostly been approached from *epistemological* perspectives and, hence, also needs to be considered from *socio-technical* vantage points related to the *volitional* aspect in Mitcham's account. The chapter will propose that engineers' activities in technology development be realized as *inherently normative practices* – comprising a genuine set of encapsulated, multi-layered, specific norms to be followed. This viewpoint is based on Dooyeweerd's (1955) non-reductionist, ontological approach to reality and MacIntyre's (1981) conception of social practices. Applying such an account to the case of *damming*, as one of the most ethically-controversial fields of technology development, will yield a well-ordered 'what is/what ought to be' insight as to the ethical aspects of engineers' powerful role in dealing with various aspects of their socio-technical environment.

The main discussion of the thesis ends up in the 6th chapter, by turning again to an overall content perspective on engineering education, this time at the tertiary level. The focal question of this part of the thesis is 'how can the current engineering education at the tertiary level be improved, considering the probable hindrances?' The chapter argues that in order to make appropriate and effective reforms in the plans of educating future engineers, there are two possible types of difficulties to overcome. The first is *scientific captivity* (Goldman, 1991), which has confined student learning to science-oriented content in most engineering schools, as was also illustrated to be the case for primary/secondary schools. This type of difficulty not only ignores a great deal of practical knowledge and skills to be acquired at this level of education, but also leads to delivering an incorrect image of the engineering profession, that is, viewing technology as applied science and, consequently, considering engineering proficiency as merely being knowledgeable in terms of mastering certain sciences. Nevertheless, the emphatic point of this chapter has to do with considering the second type of difficulty – *contextual captivity* – which pertains to the problems rooted in the specific context of the educational practice itself, in the sense of the social features and contextual infrastructures dominant in academia and its interrelation with industry. The latter difficulty, it is argued, is more significant in non-western contexts, and the selected Iranian case, *Mechanical Engineering Education* in *Sharif University of Technology (SUT),* provides considerable evidence in this regard. A good understanding of these problems will lead to a more effective image of the state of engineering in practice and, consequently, more realistic reform plans for education.

The thesis concludes in the 7th chapter with a recapitulation of the points previously discussed. It will also present an overall look at the proposed contribution of the thesis as well as the way it could be extended to further contemplation.

1

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02

Chapter. 2

'STANDARDS' ON THE BENCH

do standards for technological literacy render an adequate image of technology?

PUBLISHED PAPER :
Journal of Technology and Science Education / 2016
http://dx.doi.org/10.3926/jotse.207

	PRIMARY/SECONDARY SCHOOL STUDENTS	TERTIARY SCHOOL STUDENTS
OVERALL CONTENT	**CHAPTERS 2&3**	CHAPTER 6
SPECIFIC ISSUES	CHAPTERS 4	CHAPTER 5

‘STANDARDS’ ON THE BENCH:

DO STANDARDS FOR TECHNOLOGICAL LITERACY RENDER AN ADEQUATE IMAGE OF TECHNOLOGY?

2.1. Introduction

Fostering technologically more literate students was mentioned in the previous chapter that has received considerable attentions regarding the primary and secondary levels of education; the movement which can play an essential role in delivering more effective engineers in the next stages of education. However, the question here is whether such *Technological Literacy* attempts – their long-term policy documents as well as the standards they provide in particular – address sufficient learning about the nature of technology. This seems to be an important concern intended to be discussed throughout this study, through taking advantage of the philosophy of technology.

It is not so long ago that the issue of *technological literacy* was given a substantial place in education; various researchers all over the world have taken it into serious consideration and, consequently, numerous attempts have been initiated to design the educational contents of teaching about technology over the previous 30 years (see, e.g., International Technology Education Series, 2011-2015; De Vries, 1997 & 2005; Rossouw, Hacker & De Vries, 2010; Dakers, 2005; Head & Dakers, 2005, and also the ‘Standards’ or ‘long-term policy documents’ such as

Australian Education Council, 1994; Department of Education of South Africa, 2002; ITEA, 2007; and the Ministry of Education of New Zealand, 2007).

Even so, do these educational contents – specifically their resulting technological literacy Standards – render a comprehensive image of *the nature of technology* to students, who are expected to have more sophisticated interactions with it now and in the future? The answer can hardly be positive! For one thing, the concept of 'modelling' – as an essential part of most engineering activities – is claimed by the scholars such as De Vries (2013) that, as discussed later on, does not receive a desirable attention throughout the current Standards; this can be thought of only as one instance among others. Such a fact motivates us to seek a way to analyze these Standards, or other same types of long-term policy documents, to see the state of other relevant concepts within them as well and, even beyond that, to realize that to what extent these documents deliver an adequate understanding about the nature of technology. This endeavour will actually attempt to enhance the overall approach of such documents towards various and notable aspects of technology, as the current Standards are in general praiseworthy guidelines for organizing the relevant (and lower-level practical) curricula of technology education; they are not and should not be expected to be, themselves, detailed curricula bounded to strict rules or materials of teaching about technology.

Before moving any further, it is worthwhile also to make the approach of this inspection even clearer by giving emphasis to a fact, that is, the concept of 'technological literacy' is a broad view embracing more than just the 'image of' or 'understanding about' the nature of technology touched upon in this study; it indeed includes the other aspects of technology as well, such as 'ways of thinking and acting' and 'capabilities' in relation to technology (National Academy of Engineering, National Research Council, Pearson, & Young, 2002) which have not been addressed by this chapter; they can be considered separately.

That said, in order to get a wiser view on how to deal with this concern, we would firstly like to have a chronological flashback to approximately the 1980s when an international movement was initiated in the area of learning about technology: the mission of this movement was actually to underpin a new path shifting such learning, from its customary *craft-oriented* attitude, to a broader approach which would consider ‘technological literacy’ as the essential basis in this regard (De Vries, 2013).

This movement was in fact a significant next step in the field of technology-oriented reflections, which occurred less than a half century after the advent of its predecessor, i.e., philosophical attempts to deliberate on the nature and various aspects of technology (Dakers, 2005; De Vries, 2000 & 2006). Stated more clearly, the philosophy of technology in this point has initiated valuable resources for providing a conceptual basis for technological literacy reflections.

The primary approach of this movement by the late 1990s was mostly towards establishing an extensive discipline for technology education – that which eventually induced very beneficial contents, subjects, and even further philosophical reflections in this regard around topics such as the following:

- The necessity for technology education
- Conceptualization of technology education literature
- Transition from craft- and skills-oriented school approaches to the new one of a broader perspective on technology
- The significance of revising education curricula
- The importance of realizing science and technology as somewhat dissimilar disciplines
- Examining different actual and/or possible interactions between science and technology
- Normativity of technology education
- Necessary skills for technology teachers

- New approaches toward technological artefacts and systems studies
- Investigating technological designing processes and their various aspects

However, these attempts gradually gave rise to a more specific step, as well, concerned with the literacy of students in this respect and, from this point on, the mission of underpinning a sound discipline in technology education for students was taken into consideration (Jones, Buntting, & De Vries, 2011).

Performing such a mission in a suitable manner is no doubt a process which can be, and obviously should be, improved through continuous evaluation – to assess, as far as it relates to our study, the appropriateness of the image of and understanding about the nature of technology that is rendered by these educational curricula and Standards. Nevertheless, such an evaluation has not yet been implemented, and there exist some critical questions in this regard put forward by different scholars. Jones et al. (2011), for instance, enquire as to the main characteristics that constitute the nature of technology and the very concepts that should be, but are still not properly, taught and learnt in this respect; the researchers indeed put stress on the insufficiency of appropriate academic investigation into the manner that meets the needs of educational systems from this perspective.

It seems to us that these (types of) concerns could be tackled through taking advantage of the philosophy of technology; the discipline which, as will be discussed further on in this chapter, can once again provide a conceptual contribution as to the nature and various properties of ‘technology’ and what students are supposed to learn in this regard, from different points of view. This is the very mission undertaken by this study: comparing that articulated by the philosophers of technology with that proposed by an extensively-documented educational standard of the USA, i.e. *Standards for Technological literacy: content for the study of technology* (ITEA, 2007), as an exemplar long-term policy document of technological literacy. This yields a fruitful method to evaluate, in the same way, the adequacy of the Standards designed for teaching about technology and to propose the modifications needed to be considered in this regard.

This study proceeds as indicated below and begins with an essential explanation of 'why and how' this contribution has approached the philosophy of technology; this will end with a model categorizing most of the relevant concepts, proposed within the philosophical reflections on technology, to be used in technology education materials and standards (Section 2). Afterwards, in order to show how this developed model work, it will be thoroughly applied to the above-mentioned American case; this will yield an insight regarding the efficiency of that case, at least from our philosophy-flavoured perspective (Section 3). Finally, the last two sections draw the main points together and provide a conclusion to discuss, and open up some innovative approaches for further studies (Sections 4 and 5).

2.2. Philosophy of Technology; Why and How?

Philosophy of technology as an antecedent field of technological reflections, as mentioned earlier, can afford a fertile ground of perspectives, content, and analyses to enrich and strengthen the tree of technological literacy studies. This is not a new claim at all, and one can easily find some supportive ideas in this relation in these earlier studies, such as the following:

- Seeking an effective way of shaping concepts of technology for students, De Vries and Tamir (1997) state that, '[p]hilosophy of technology is a discipline that has much to offer for technology education. Insights into the real nature of technology and its relationship with science and society can help technology educators build a subject that helps pupils get a good concept of technology and to learn to understand and use concepts in technology' (p. 3).
- Delving into the different aspects of teaching about technology, De Vries (2005) speaks of two important issues to be taken seriously into account:

(1) what is a correct concept of technology, and (2) what educational settings need to be created in order to shift – and in point of fact, improve – pupils' actual concept of technology towards a correct concept in the experts' viewpoint. Nonetheless, '[c]ontrary to many other school subjects,' he continues, 'there is [yet] no clear academic equivalent of technology education, from which a good conceptual basis can be derived …' (p. 149); he believes that the philosophy of technology can afford such an appropriate basis.

- The philosophy of technology in the view of Jones et al. (2013) contains 'a rich source of inspiration that can be used to guide the development of technology education' (p. 194).

These are only some ideas among others that, although they speak of the significant potential of philosophical reflections to yield a more concrete conceptualization of what is needed to be learned about technology, have not yet led to a well-articulated scheme in this regard; this both inspires us and rationalizes our approach to strive to develop such a practical method.

However, prior to moving any further, it is worthwhile and essential to mention that our attempt has been initiated based on a satisfying account of *technological literacy*, in the first place; though one has difficulty finding a well-articulated definition for this concept, this mainly has to do with being more acquainted with the intrinsic nature of technology and its interrelationship with different individual and social aspects of human life (see, e.g., ITEA, 2007; and Jones et al., 2011). Consequently, this account will deal with a broad area of concepts and concerns that need to be taken into contemplation for teaching about technology.

The first step of this study was dedicated to compiling a list of such concepts and concerns. In order to do so, we conducted a survey into the former relevant research, and the article of Rossouw, Hacker, and De Vries (2010) seemed an insightful work in this step; benefiting from the ideas of various experts with philosophical, historical (together with educational) perspectives to technology, this study had composed an innovative list of concepts and contexts necessary for education regarding the nature of technology, as a contribution to the aims of technological literacy. Yet, though a valuable contribution, there were two problematic issues in that method: (1) the provided list had originated from an *experimental,* not a *philosophical,* analysis, and therefore it could not be guaranteed to be comprehensive, and (2) consequently, it was difficult to ascertain any categorization or classification related to the nature of technology, as addressed by the philosophers, within it. Thus, this list needed in our opinion to be completed and somehow changed so that it more effectively serves our goal.

Afterwards, the next step was devoted to conducting an extensive review of certain well-known books or references regarding the philosophy of technology, principal among which were:

- *Thinking through technology* (Mitcham, 1994)
- *Readings in the philosophy of technology* (Kaplan, 2004)
- *Philosophy of technology: An Introduction* (Dusek, 2006)
- *A companion to the philosophy of technology* (Olsen, Pedersen, & Hendricks, 2009)
- *New waves in philosophy of technology* (Olsen, Selinger, & Riis, 2009)
- *Philosophy of technology and engineering sciences* (Meijers, 2009)
- *A philosophy of technology* (Vermaas, Kroes, Van De Poel, Franssen, & Houkes, 2011)

This provided us with a more extensive list of relevant concepts that received the attention of philosophers of technology. However, we still needed an appropriate tool to be able to efficiently categorize this lengthy list. Then, as a complementary stage, we followed in accordance with Mitcham’s theory (1994), previously recommended by scholars such as De Vries (1997) and Frederik, Sonneveld, & De Vries (2010) to be considered in technology education. This theory was even resorted to, though only to a small extent, in the same way earlier by Compton (2007), as a philosophy-based criterion to assess and ensure the approach of The New Zealand Curriculum to teaching about technology. That is not to say that Mitcham's theory was the best; rather, it was *one* adequate method, among other possibilities, which fits our need here to classify the concepts.

Mitcham has distinguished four ways of defining technology: technology as *object*, *knowledge*, *activity*, and *volition.* In a later work, he explicates the background of his theory as:

> *[I]n the most general sense, technology is 'the making and using of artifacts,' but we should look at four deeper aspects of this phenomenon. First, this making and using can be parsed into the objects that we make and use, such as machines and tools. This is 'technology as object.' Second, if we focus on the knowledge and skills involved in this making and using activity, that's 'technology as knowledge.' Third, there is the activity in which technical knowledge produces artifacts and the related action of using them: this constitutes 'technology as action or activity.' Fourth, there is another often overlooked dimension of 'technology as volition' — the will that brings knowledge to bear on the physical world to design products, processes, and systems. This technological will, through its manifestations, influences the shape of culture and prolongs itself at the same time.*

(Mitcham, 2001)

Finally, the last step was dedicated to applying Mitcham's theory to the aggregated concepts, which yielded Table 1, i.e., a framework that could be employed as our desired tool to analyze the intended case(s) in a systematic way. It is worth mentioning that Mitcham's own extensive explanation of different sides of technology, in his well-known book of *Thinking through Technology* (1994), has been predominantly used here in developing Table 1 (see, for more detail, pp. 161-191 for 'technology as object'; pp. 192-208, for 'technology as knowledge'; pp. 209-246, for 'technology as activity', and pp. 247-266, for 'technology as volition').

Table 1 The Main Framework of the chapter: concepts of technology from different aspectual perspectives

Aspects of technology			
Technology as object	*Technology as knowledge*	*Technology as activity*	*Technology as volition*
- Artefacts (as objects) - Systems - A (specific) Design	- Representation of knowledge & skills - Normativity - Interrelation of science & technology - 'Know-that' & 'know-how' - Creativity	- Designing - Evaluation - Modelling - Innovation - Invention - Needs, wants, & demands - Use plan	- Artefacts (as volition) - Value-sensitive design - Ethics, values, & moralities - Aesthetics - Social construction of technology - Sociotechnical systems - Different contexts of technology - Technology & metaphysics - Technology & politics - Technology & society - Technology & culture - Technology & economy - Technology & environment - Technology, future, & humanity

That said, it is also worthwhile to emphasize here that this framework is not claimed at all to be a perfect one; rather, it can be seen as an initial version that can be improved, specifically in terms of its entailed concepts, in later works. Bearing this in mind, let us move to the next section to demonstrate the manner in which it works and how it enables us to realize the extent to which the intended 'Standards' – here, that of the USA – satisfy our approach to learning about technology's nature.

2.3. Case Study: The USA'S Standards for Technological Literacy

Among the existing Standards of technological literacy in the education systems of certain countries, the American case of *Standards for Technological Literacy: Content for the Study of Technology* (ITEA, 2007) can be regarded as the most extensive and elaborated document, serving as a vision as to 'what students should know and be able to do in order to be technologically literate' (p. vii).

This document (referred to henceforth as STL) has been sensibly organized to bridge the gap between students' life- and work-styles that are ever-increasingly dependent on technology and their understanding in this regard. By focusing on training K-12 students, STL has identified 20 principal standards necessary for them to learn about appropriately (Table 2); each standard in itself also entails certain benchmarks that present more practical and expounded instructions (ITEA, 2007, p.15).

Another structural characteristic of STL is its specific classification of students: they are trained according to their grade level regarding their diverse but related contingent needs, interests, and abilities whether physical or mental. In this respect, it suggests a form of grade-based categorization that begins with *K-2* and continues through *3-5*, *6-8*, and *9-12,* each accompanied by some further sub-categorizations (for more detail, see ITEA, 2007, p. 14).

Table 2 Listing of Standards for Technological Literacy in STL

Chapters	Standards
3- Students will develop an understanding of The Nature of Technology. This includes acquiring knowledge of:	1: The characteristics and scope of technology 2: The core concepts of technology. 3: The relationships among technologies and the connections between technology and other fields.
4- Students will develop an understanding of Technology and Society. This includes learning about:	4: The cultural, social, economic, and political effects of technology. 5: The effects of technology on the environment. 6: The role of society in the development and use of technology. 7: The influence of technology on history.
5- Students will develop an understanding of Design. This includes knowing about:	8: The attributes of design. 9: Engineering design. 10: The role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.
6- Students will develop Abilities for a Technological World. This includes becoming able to:	11: Apply the design process. 12:Use and maintain technological products and systems 13: Assess the impact of products and systems.
7-Students will develop an understanding of The Designed World. This includes selecting and using:	14: Medical technologies. 15: Agricultural and related biotechnologies 16: Energy and power technologies. 17: Information and communication technologies. 18: Transportation technologies. 19: Manufacturing technologies. 20: Construction technologies.

All this encouraged us to investigate such a structured long-term policy document to see to what extent it addresses our philosophical account regarding the concepts and concerns required to be learned about the nature of technology. Nevertheless, this was not as easy as it initially appeared because STL is actually not a curriculum directly related to the contents of educational materials nor is it detailed. Rather, being a very extensive *attainment target*, it entails a set of Standards for teachers in order to develop their relevant desired curricula, and this raised the challenging necessity of attempting to derive a distinct interpretation of the actual intention of some of its standards or benchmarks in terms of the concepts needed to be educated. For one thing, our results from the first inspection of STL were amazingly not entirely the same as those of the second, and this persuaded us to try again, this time bearing in mind these inconsistencies, to get to a more reliable result, as spelled out in Table 3.

2.3.1. An Overall Review of STL

As indicated in Tables 2 and 3, the standards have been categorized in a specific form, comprising five *chapters* – say five *angles of view to technology* – namely, *the nature of technology, technology and society, design, abilities for a technological world,* and *the designed world* (those which should be taught about, according to the aforementioned grade-based classification of students).

This type of categorization, though it might seem acceptable at first sight, is the subject of dispute and, as deliberated upon later on, while taking some of the concepts of Table 1 into proper consideration, it disregards some others or at least does not appropriately touch upon them. This may have roots in the fact that STL is the outcome of usual experience-based educational reflections: which typically, as stated by De Vries (2013), emerge from the customary craft-oriented approaches. The following subsections present a more detailed discussion in this regard.

Table 3 The concepts and concerns related to the nature of technology, in STL

Chapter 3: Nature of Technology	
1: The Characteristics and Scope of Technology	artefact (as objects) - artefact (as volition) - creativity - invention & innovation - needs & wants - social construction of technology - system
2: The Core Concepts of Technology	designing - evaluation - management - modelling - sociotechnical systems - system
3: Relationships Among Technologies and the Connections Between Technology and Other Fields	invention & innovation - system - technology & science
Chapter 4: Technology and Society	
4: The Cultural, Social, Economic, and Political Effects of Technology	technology & culture - technology & economics - technology & environment - technology & ethics – technology & politics - technology & society
5: The Effects of Technology on Environment	designing - invention & innovation - management - modelling - technology & economics - technology & environment
6: The Role of Society in the Development and Use of Technology	invention & innovation - needs & wants – social construction of technology
7: The Influence of Technology on History	artefacts (as volition) - designing - invention & innovation - social construction of technology - technology & culture - technology & economics - technology & politics - technology & science - technology & society
Chapter 5: Design	
8: The Attributes of Design	creativity - designing - evaluation - invention & innovation - modelling - value sensitive design
9: Engineering Design	creativity - designing - evaluation - modelling
10: The Role of Troubleshooting, Research and Development, Invention and Innovation, and Experimentation in Problem Solving	designing - invention & innovation
Chapter 6: Abilities for a Technological World	
11: [being able to] Apply Design Process	designing - evaluation - invention & innovation - modelling - value sensitive design
12: [being able to] Use and Maintain Technological Products and Systems	a design - system - use plan

Table 3 (continued) The concepts and concerns related to the nature of technology, in STL

13: [being able to] Assess the impact of Products and Systems	artefacts (as volition) - technology Assessment - technology & culture - technology & society - value sensitive design
Chapter 7: The Designed World	
This chapter mainly focuses on various 'technological contexts'.	

2.3.2. 'Technology as Object'

Beginning with this aspect, one can easily observe that the notion of *artefact,* as the most immediately apparent side of technology, has been suitably taken into consideration at the very opening of STL, where Standard 1 and its included benchmarks attempt to deliver an appropriate introduction about artefacts and artefactual features and also to enable students – who are typically accustomed to identify only the *high-tech* artefacts as technological (see De Vries, 2005, pp. 107-112) – to adjust their conceptual bias toward the actual essence of technical artefacts.

Speaking more philosophically, the concept of *the dual nature* of artefacts too has actually been to some extent considered among the Standards: they consider both the *physical* and *intentional* nature of artefacts, though not using the same terms, respectively through taking both the 'object' and 'volition' sides of them into account (see, e.g., benchmarks 1-3, and 13).

Nevertheless, STL scarcely provides a satisfying explanation as to the concept of '*a (specific) design'* of artefacts – particularly as to how such 'a design' relates the physical structure of an artefact to its function (or intention). In other words, even though this document attempts to provide some preliminary understanding about 'a design' through standards such as the 12th, such an inspection has not much to do with that of 'the dual nature' perspective – considering the specific design of artefacts as an essential element for the 'physical' and 'intentional' natures to interrelate and interact with each other.

The concept of *systems*, finally, has been properly looked at from different directions, mainly in (1) the 2^{nd} and 3^{rd} standards, where students are supposed to know more about the systemic nature of technology, and (2) the 12^{th}, where they learn to some extent how to use and maintain technological products and systems in more appropriate and accurate ways.

2.3.3. 'Technology as Knowledge'

Let us begin this section firstly by investigating STL's deliberation on different aspects of the *interrelation of Science & Technology*, in terms of characterizing various dimensions of technological knowledge in relation to the scientific dimension, expounding their distinctions, and delineating the interactions between them. These subjects have been fairly well discussed throughout this document; it yields a number of general descriptions of knowledge in science and technology (Standard 3), talks about some relevant historical evidences in this regard (Standard 7), and in the meanwhile even scrutinizes notions such as the knowledge of design (Chapter 5) and *creativity* (Standards 1 and 8) to elucidate the 'non-scientific' side of technological knowledge.

Nevertheless, there are still some missing points in this relation that deserve to be taken up more within STL. For instance, the *know-how* aspect of technological knowledge, as well as the manner in which it proceeds further hand-in-hand with the *know-that* aspect (see, e.g., Vermaas et al., 2011, pp. 63-64), is recommended to be considered far more than the minor reflection seen in its current speculation.

Technological knowledge has other substantial specific characteristics as well that have not been seriously taken into account in STL. This type of knowledge, for instance, may be manifested by different qualities across various artefacts directly *representing the level of their designers and/or engineers' knowledge and skills*, in terms of providing *effective* ways and tools to satisfy the intended functions (see, e.g., Vermaas et al., 2011, Chapter 4).

Normativity is the next considerable feature of technological knowledge that has not been seriously touched upon within STL; only a little implicit attention has been paid to the role of different needs, expectations, ethical views, and the like in this regard. This is while this concept has been reflected upon in many respects by philosophers of technology such as De Vries (2005), Franssen (2009), and Frederik et al. (2011). They argue about why and how our contextual beliefs, views, goals, and actions are strictly to do with our evaluations and judgments and lead to specific types of technological knowledge and design, the reflections of which can provide significant and practical insights for students about the real character of technological knowledge.

2.3.4. 'Technology as Activity/Process'

This perspective on technology has a very different situation in STL, compared to those of *technology as objects* or *as knowledge*. That is to say, the problem of the case has not to do with covering the related concepts; all of them, as seen later on, have been considered to varying degrees, through this document. Rather, the concern this time is that two prominent concepts among them – namely, *evaluation* and *modelling* – have not been examined in a manner that satisfies our philosophy-originated expectations. Let us present a profounder inspection of the state of all these concepts, in STL.

Beginning with *designing*, encompassing most other notions placed in the technological 'activities' cell (of Table 1), this broad process has expectedly drawn significant attention here: one chapter (Standards 8-10) has entirely focused on various aspects of 'designing' and its sub-notions (this could be also ascertained to some extent within Standard 2).

Turning to the concepts of (human) *needs*, *wants* and *demands* – as the main drivers of designing various artefacts – they too have been discussed in the course of standards such as the 1st and the 6th. Meanwhile, the critical role of the different types of *invention* and *innovation* in the designing process has been touched upon through the chapters 3 to 6.

However, regarding *evaluation* (or *assessment*), STL mostly determines it as what normally occurs in different steps by diverse ‘designers’; they, for instance, perform continuous assessments on their ideas, sketches, models, and prototypes, based on various feedback, in order to meet the desired function and quality: the aspect which has been referred to specifically in Standards 2, 8, 9, and 11. Nevertheless, ‘evaluation’ has another side as well that have not been extensively addressed in STL, that is, the side of the very aforementioned ‘feedbacks’ that in fact have root in customers’ assessment of artefacts. They do so in order to realize the extent of fitness for what they have paid for with what they actually need, in terms of the (quality of the) function of the intended artefact(s), or to recognize the impact of (a specific) technology on their individual and social life.

As to the notion of the *use plan*, it can be seen to be discussed too, at least as much as is expected of an attainment target, through Standard 12.

Finally, *modelling* can be thought of as the most problematic concept of this subsection and, viewed from the philosophical perspective of this study, it seems that students do not acquire a comprehensive understanding about different dimensions of the nature of modelling, in this way.

All the same, this notion may initially appear to have received suitable attention in STL, through considerations such as follows:

- General discussions regarding models as tools that can be employed in the design processes (Standard 8);

- Modelling for conducting communication, representation, and evaluation about the designed solution(s) (Standards 5, 9, and 11);
- Modelling for testing and receiving feedback in order to complete the final adjustments or improvements (Standards 9 and 11);
- Modelling for prototyping (Standards 8, 9, and 11);
- Modelling as a visual (two- or three-dimensional) tool to benefit the comparison and selection of the best solution(s) (Standard 11);
- Different types of modelling: graphical, mathematical, and physical (Standard 11).

Nevertheless, these do not seem to suffice the needs of students, who must become technologically literate; they need, as stressed by De Vries (2013), to learn more explicitly and more elaborately about the essence of models and the process of modelling – in the sense of what the nature of 'modelling' is, what various functions of 'models' are, how they come into use, etc. Indeed, these are the inquiries addressed in some way or another by the philosophers of technology who have realized more dimensions and categories of models in engineering practices. For instance, Boon & Knuuttila (2009) open up a compact, broad, but classified description for the goal of putting models to use in engineering sciences, that is '… to understand, predict or optimize the behavior of devices or the properties of diverse materials, whether actual or possible' (p. 693); they also emphasize the remarkable distinction between the *models* developed in 'engineering sciences' and those produced in 'engineering in practice'. Another valuable dimension elaborated on in this paper is the *epistemic aspect* of models: perceived by authors as not only 'representational' but also 'epistemic' tools – partially independent from theory and data – which assist engineers in enhancing their education by constructing and manipulating them and, sometimes, in realizing an unexpected innovative concept or area of research. Furthermore, philosophers such as De Vries (2013) also believe that students, in another aspect, must acquire a proper insight into the diverse typologies that classify models from different perspectives. He suggests a compact instance as to how models could be categorized, and recognized, based on their *types* and *functions*. All these are only some, among many other, philosophical considerations which have led us to realize the considerable gap between what *modelling* actually is – in its nature and practice – and how it has been considered in STL; the latter has only taken up modelling in a very limited manner confined to revealing certain representational functions of models (namely evaluation, test, prototyping, receiving feedback, and so on) accompanied by demonstrating a very simple classification in this regard.

2.3.5. ‘Technology as Volition’

This aspect of STL, as seen further on in this chapter, has only partly to do with the philosophical considerations about technology; that is to say, while embracing to some extent a number of concepts addressed in Table 1, there are certain others which have not yet been suitably taken into account. In addition, a substantial conflict within STL, too, can be also recognized when examining it in this respect.

To begin with, *artefacts as human volition*, which refers to the social nature of objects (see Vermaas et al., 2011, pp. 18-20), has been taken into consideration primarily in Standards 1 and 13. This makes sense because in order to be technologically more literate, in this sense, students should in tandem acquire (1) valuable knowledge about the social nature of artefacts (discussed under the subject of ‘The Characteristics and Scope of Technology’ in Standard 1) as well as (2) a proper level of abilities to live in a technological world (considered through the theme of becoming able to ‘Assess the Impact of Products and Systems’ in Standard 13). These two sides of reflection are, moreover, in collaboration with inspecting how the design of artefacts (or systems) ties in to various volitional values of human beings – touched upon under the term of v*alue sensitive design* – which has been considered in Standards 11 and 13.

There are some explicitly society-based aspects of technological volition as well, concerned with the relationship between technology and the various sides of a human being's social life and taken up, in the philosophy of technology, with notions such as *social construction of technology*, *technology and politics*, *technology and economics*, and *technology and culture*; such aspects have been specifically deliberated on within Chapter 4.

Turning to the other concepts, it can be perceived that STL has paid particular attention (Chapter 7, Standards 14 to 20) to developing students' understanding of and helping them to be able to select and use various contexts of technologies including *medical*, *agricultural and related bio-*, *energy and power*, *information and communication*, *transportation*, *manufacturing*, and *construction* technologies. As a matter of fact, this long-term policy document seems to provide a plentiful contribution in this sense as well.

Now let us take a look at STL's approach to *ethics, values,* and *moralities*, the concepts of which are undoubtedly the most prominent subjects of discussion in the contemporary philosophy of technology. These have been addressed in the 4th chapter; they make students become more literate, in this sense, on different levels of designing, making, and using technical artefacts (or systems), which is well-intentioned in its own right. However, a significant conflict exists, in STL, with the philosophical reflections in this regard that needs to be clarified, as the latter mostly argues against the *neutrality thesis* (which considers technology as a *neutral entity* completely dependent on a human decision to be weighed). Recent philosophers typically believe that (some) technical artefacts or systems do entail certain characteristics which create specific values and impose them on human life; there are some notable reasons resorted to in this regard, such as follows:

- The inherent side-effects, whether intentional or unintentional, of some technologies like harmful chemical plants or electromagnetic devices;

- The inherent value or disvalue put in the specific design and the main goal of using some technologies; speed bumps, for instance, entail the value of increasing people safety;
- The undeniable structure of sociotechnical systems, such as the civil aviation organisms, which cannot be excluded from the active role of its inside (human) actors as essential functioning parts – and not users – of that technological systems.

(See, for more detail, Vermaas et al., 2011, pp. 16-18)

This value-laden account of (some) technologies, absolutely, contrasts with the perception upon which STL was developed (as clearly asserted from its very beginning):

> *Students should come to see each technology neither good nor bad in itself, but one whose costs and benefits should be weighed to decide if it is worth developing.* (p. 5)

This perspective is also emphasized by Standard 4 where this benchmark appears:

> *Technology, by itself, is neither good nor bad, but decisions about the use of products and systems can result in desirable or undesirable consequences.* (p. 60)

This problem is not at all a slight or negligible one, and it indeed deals with students' foundational account of technology. Therefore, such a perspective is better to be amended according to the *non-neutrality* insight into technology; otherwise, students will most likely encounter genuine conflicts between what they learn, in this sense, and what they will later experience in practice.

There are also some concepts – such as *aesthetics* – supposed to be taken into more consideration in this document. It has indeed been argued by philosophers like De Vries (2005) that the 'aesthetical' aspect of technology needs to be seriously considered within the plans of teaching about technology; as the aesthetical values play prominent roles particularly in two important engineering fields: *architecture* and *industrial design*, that have coupled technology and art.

Last but not least, it appears as though STL has approached technology from the 'now' perspective through which students learn how to live better lives in their current customary sociotechnical world. However, it is difficult to find, for example, a significant benchmark discussing or tracing how different views on *metaphysics* have led (the 'past' outlook), do lead, or may lead (the 'future' outlook) to various types of interactions with technology and different lifestyles. The history of human life is full of substantial and attractive instances capable of guiding the minds of students to an improved understanding of technological evolutions and their relationship with various worldviews. It would then be interesting for them to know, for example:

- How specific beliefs of the ancient Egyptians led to the design and construction of the Pyramids;
- How Persians' perception of God influenced their particular architecture mainly rooted in the Safavid era;
- Why the modern account of science and technology has underpinned a new path of technological development such as inventing the steam-engine motor, and the like, particularly in the West, and how it has led to post-modern technologies which are extensively based on IT and virtual space.

In this sense, students are really supposed to think more about the 'future' – in terms of tracking the current pathway of technology advancements and thinking of the future possible characteristics of technology and, consequently, the human life-and work-style, as well as contemplating which contexts of technology tend to gain a more impactful role and which will gradually diminish or be replaced by other fields of technological breakthroughs. They will learn much better in this manner how to enhance their abilities and knowledge in order to undertake more effective roles in shaping their own desirable future.

2.4. Conclusion

Summarizing the above-mentioned points can afford an overall picture as to how this study has taken advantage of the philosophy to contribute to improving the current Standards of technology education.

Through articulating the relevant concepts in an innovative way based upon Mitcham's characterization of various aspects of technology, this study could come up with a reasonable method to be used to address the proposed research question, which is concerned with delivering sufficient knowledge about the nature of technology to students. Then, applying the developed framework to STL, as an exemplar case, revealed that this long-term policy document, though a very useful contribution of certain strong points, could still undergo a number of modifications in order to yield a more comprehensive insight into the nature and various properties of technology, the claim which can be briefly recapitulated as Table 4 and briefly outlined as follows:

i. The particular attention of this Standard to 'the nature of technology' and 'design', respectively through the two distinct chapters of 3 and 5, affords a suitable account of technology as both 'object' and 'activity'; nevertheless, it still needs to pay more profound attention to 'the specific design' of artefacts, as what interrelates their physical and intentional natures, which has been scarcely discussed in an explicit way, as well as to the essence of 'modelling' and 'evaluation' which, though touched upon more or less, have not been talked over, at least, as compared to that described by philosophers of technology.

ii. As to the 'knowledge' aspect of technology, there are certain essential concepts that it is hard to find any clear discussion of throughout STL, and it is therefore suggested that they are incorporated into upcoming revisions; students are proposed to become more acquainted with 'the normative nature' of technological knowledge and also distinguish its 'know-how' aspect from the 'know-that'; they also need to be capable of realizing how technological phenomena indicate diverse types and levels of knowledge and skills that support them.

iii. Chapter 4 associates the societal dimension of technology, which is later accompanied by an extensive discussion of its various contexts in Chapter 7; together these provide a satisfying deliberation of technology's 'volitional' aspect for students. Yet certain subjects seem missing, namely, those which relate the notions of 'aesthetics', 'metaphysics', and 'the future of human beings' to the essence of technology. Moreover, as far as the subjects of ethics, values and moralities are concerned, STL's 'neutral' view toward technology is highly recommended to be revised and replaced by the 'non-neutral' perspective.

We would like to end the chapter with some suggestions for further studies; since its initiated approach has been based upon a concrete ground of philosophical reflections on technology, it can be therefore applied to evaluate other Standards and even other types of curricula or materials of technological literacy as well. The following section, in view of that, will take up extending this study to the New Zealand Curriculum (Ministry of Education of New Zealand, 2007), along with its Technology Curriculum Support (Ministry of Education of New Zealand, 2010).

Table 4 A brief sketch of the significant technological concepts' state of consideration in STL

Aspect of Technology	Concept	State of consideration*		
		Adequately considered	***Moderately considered***	***Scarcely considered***
Technology as object	Artefacts (as objects)	✓		
	Systems	✓		
	Specific design			✓
Technology as knowledge	Representation of knowledge and skills			✓
	Normativity (of technological knowledge)			✓
	Interrelation of science & technology	✓		
	'Know-that' and 'know-how'			✓
	Creativity	✓		
Technology as activity/process	Designing	✓		
	Evaluation		✓	
	Modelling		✓	
	Innovation	✓		
	Invention	✓		
	Needs, wants and demands	✓		
	Use plan	✓		
Technology as volition	Artefacts (as volition)	✓		
	Value sensitive design	✓		
	Ethics, values and moralities		✓	
	Aesthetics			✓
	Social construction of technology	✓		
	Sociotechnical systems	✓		
	Different contexts of technology	✓		
	Technology and metaphysics			✓
	Technology and the future			✓
	Technology and politics, society, culture, economy, and/or environment	✓		

*** According to the deliberated state of each concept, in Section 5, three levels of considering them have been defined in this table: those which have been adequately considered and seem sufficient; those which have been moderately considered, in that they have been touched upon but not as much as needed, or even in a misleading way, comparing to the literature of the philosophy of technology; and those which have been barely considered, that is, the concepts missing or, at least, not clearly discussed in explicit terms .

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03

Chapter. 3

THE NEW ZEALAND CURRICULUM'S APPROACH TO TECHNOLOGICAL LITERACY

through the lens of the philosophy of technology

PUBLISHED PAPER :
Australasian Journal of Technology Education / 2016
http://dx.doi.org/10.15663/ajte.v3i1.38

	PRIMARY/SECONDARY SCHOOL STUDENTS	TERTIARY SCHOOL STUDENTS
OVERALL CONTENT	**CHAPTERS 2&3**	CHAPTER 6
SPECIFIC ISSUES	CHAPTERS 4	CHAPTER 5

THE NEW ZEALAND CURRICULUM'S APPROACH TO TECHNOLOGICAL LITERACY, THROUGH THE LENS OF THE PHILOSOPHY OF TECHNOLOGY

3.1. Introduction

As a long-term policy document of technology education, *The New Zealand Curriculum* (NZC) (Ministry of Education of New Zealand, 2007) – in tandem with the complementary document: *Technology Curriculum Support* (TCS) (Ministry of Education of New Zealand, 2010) – aims to provide students with a deep, broad, and critical literacy in technology (Compton, 2007; Compton & France, 2006). These documents, accordingly, attempt to benefit from a focus on the philosophical basis of technology – an approach, it is claimed, that appropriately conforms to Mitcham's (1994) categorization and elaboration of the four main aspects of the nature of technology (Compton, 2007). That said, as an approach that takes advantage of the philosophy of technology to teach students about technology, New Zealand's curriculum can accordingly be subject to two evaluative questions from a philosophy-of-technology perspective: firstly, to what extent could such an approach foster a comprehensive understanding of the nature and various features of technology? and secondly, how well could that approach conform to a well-structured perspective – particularly, as claimed, to Mitcham's philosophical outlook on different aspects of technology?

Such questions are not particularly novel, nor is it even very new to suggest the philosophy of technology be employed to evaluate the approaches of technological literacy documents. Both concerns have been addressed in one way or another by scholars such as de Vries (2005), Jones, Buntting and de Vries (2013), and Nia and de Vries (2016a). They argue that the discipline of the philosophy of technology has to do essentially with explaining and elaborating different aspects of the nature of technology and, therefore, can provide a foundation of various viewpoints to enrich and fortify technological literacy studies. Nia and de Vries have developed a framework – based on Mitcham's perspective (discussed later) – for performing a robust analysis on the American case of *Standards for Technological Literacy* (ITEA, 2007), and have suggested that the method can also be applied to other cases such as that of New Zealand.

New Zealand's case, nevertheless, adopts a different style as a reference for teaching about technology than that of the USA: in contrast to the weighty body of the latter (entailing eight extensive chapters describing twenty standards) (see ITEA, 2007, p. 15), the former has attempted to offer a much less extensive document, in terms of both structure and content. The NZC comprises, as discussed later, only three main *strands* and eight *sub-strands* (known as 'components' in New Zealand's curriculum) supplemented with some prefatory explanation regarding how to engage with each of them in different levels of education (see Ministry of Education of New Zealand, 2010, pp. 9-10, 70-95).

Having said that, this chapter begins with presenting a brief sketch of the approach of NZC (in tandem with TCS) to various aspects of technological literacy, and will then by analysing it according to Nia and de Vries's (2016a) proposed framework. The study will conclude with an overall discussion and related recommendations.

Prior to the main discussion of the study, it is worth mentioning that this analysis must be seen as a tribute to New Zealand's innovative approach. In contrast to most of the customary standards of other countries, NZC has made a serious attempt to incorporate the philosophy of technology in technology education plans – an attempt that, although not perfect, seems to have a promising potential to deliver more technologically literate students. This is why this case was selected for this study, in the hope of helping the curriculum to be improved even more in its subsequent versions.

3.2. The *New Zealand Curriculum*: Structure, Approach, and Content

NZC, as expounded through TCS, has strived to provide sound content for teaching about technology in the primary and junior secondary schools (Compton & Harwood, 2006; Ministry of Education of New Zealand, 2010). A structure described by Ministry of Education in New Zealand (2010) as "a dynamic and future focused framework for teaching and learning in technology [to give] the students challenging and exciting opportunities to build their skills and knowledge as they develop a range of outcomes through technological practice" (p. 4). It proposes a framework restructured around three strands: *Technological Practice*, *Nature of Technology*, and *Technological Knowledge.*

Each strand entails some sub-strands or components embracing the relevant topics and concepts required to be taught about technology (Ministry of Education of New Zealand, 2010). Table 1 is an overall summary of these.

Such an approach, including its specific structure and content, was asserted by its authors to benefit from a robust philosophical and theoretical base for technology education. Compton (2007), as the primary author, wrote:

> [*The Nature of Technology] is focused on developing a philosophical understanding of technology as a discipline, including an understanding of how it is differentiated from other forms of human activity, and how technological outcomes differ from other artefacts. It rests upon a sociotechnological stance …, [and] learning within this strand focuses on*

developing philosophical understandings of two components - Characteristics of Technology and Characteristics of Technological Outcomes ... [Technological Knowledge] is focused on developing key concepts in technology that are generic to all technological endeavours, and … learning within this strand focuses on developing conceptual understandings of three components - Technological Modelling, Products and Systems… . [Finally, Technological Practice] provides students with opportunity to examine the technological practice of others to inform their own practice in an increasing sophisticated fashion. Student technological practice can result in the development of a range of outcomes, including concepts, plans, briefs, and technological models, as well as fully realised products or systems. Student learning within this strand focuses on developing capability within the three iterative components of Brief Development, Planning for Practice and Outcome Development and Evaluation. (pp. 10-12)

Table 1 The concepts and concerns related to the nature of technology in NZC (& TCS)

Strand	**Sub-Strands (Components)**
Technological Practice	Planning for practice Brief development Outcome development and evaluation
Technological Knowledge	Technological modeling Technological products Technological systems
Nature of Technology	Characteristics of technology Characteristics of technological outcomes

It was claimed that this approach would conform to Mitcham's perspective on various aspects of technology, in order to "support the development of a technological literacy that is broader, deeper and more critical than that achieved from the [previous version]" (Compton, 2007, p.13). This conformity was delineated as follows:

- Technology as Volition – addressed via Nature of Technology – specifically in terms of the Characteristics of Technology.
- Technology as Artefact – addressed via Nature of Technology – specifically in terms of the Characteristics of Technological Outcomes.
- Technology as Knowledge – addressed via Technological Knowledge – specifically in terms of Technological Modelling, Technological Products and Technological Systems.
- Technology as Activity – addressed via Technological Practice – specifically in terms of the Brief Development, Planning for Practice and Outcome Development and Evaluation. (Compton, 2007, p. 12)

Although this is an admirable approach that has barely been realized in other countries (even in the more extensive one of the USA), this case, too, can be subject to continuous improvement, as all curricula are reviewed and improved over time, with the recognition that ideas and contexts change. The thesis of this chapter is that consideration of a number of philosophical issues could provide some additional rationale for changes to the NZ Curriculum, as suggested by Nia and de Vries (2016a).

3.3. Research Method and Analysis

The study's main purpose was to understand to what extent the *New Zealand Curriculum* can deliver a comprehensive understanding about technology, and how well such an approach conforms to Mitcham's philosophical outlook on different aspects of technology. The research was conducted by drawing on Nia and De Vries's (2016a) framework, which, as seen in Table 2, provides an analytical tool by taking advantage of philosophical reflections on technology, a discipline which "can afford a fertile ground of perspectives, content, and analyses to enrich and strengthen the tree of technological literacy studies." (Nia & De Vries, 2016a, p. 7).

Table 2 Concepts of technology from different aspects

Aspects of Technology			
Object	*Knowledge*	*Activity*	*Volition*
• Artefacts (as objects) • Systems • A (specific) Design	• Representation of knowledge & skills • Normativity • Interrelation of science & technology • 'Know-that' & 'know-how' • Creativity	• Designing • Evaluation • Modelling • Innovation • Invention • Needs, wants, & demands • Use plan	• Artefacts (as volition) • Value-sensitive design • Ethics, values, & moralities • Aesthetics • Social construction of technology • Sociotechnical systems • Different contexts of technology • Technology & metaphysics • Technology & politics • Technology & society • Technology & culture • Technology & economy • Technology & environment • Technology, future, & humanity

(Source: Nia & de Vries, 2016a, p. 9.)

That framework can be briefly explained in two parts:

i) The framework's main structure is principally rooted in Mitcham's perspective on the four aspects of the nature of technology, that is, technology as *object*, *knowledge*, *activity*, and *volition*. The background of such a categorization is well expounded by Mitcham (2001):

> *In the most general sense, technology is 'the making and using of artifacts,' but we should look at four deeper aspects of this phenomenon. First, this making and using can be parsed into the objects that we make and use, such as machines and tools. This is 'technology as object.' Second, if we focus on the knowledge and skills involved in this making and using activity, that's 'technology as*

knowledge.' Third, there is the activity in which technical knowledge produces artefacts and the related action of using them: this constitutes 'technology as action or activity.' Fourth, there is another often overlooked dimension of 'technology as volition' — the will that brings knowledge to bear on the physical world to design products, processes, and systems. This technological will, through its manifestations, influences the shape of culture and prolongs itself at the same time. (n.p.)

ii) Regarding its content, nonetheless, Nia and de Vries (2006a) believe that there are many significant points in terms of the relevant concepts and concerns addressed by several other philosophers that could be embraced by the framework mentioned above. The points and concepts under the four main aspects shown in Table 2 are their findings in this regard, resulting from an extensive review of the existing literature of philosophy of technology, such as Dusek (2006), Kaplan (2004), Meijers (2009), Olsen, Pedersen, and Hendricks (2009), and Vermaas, Kroes, Van de Poel, Franssen, and Houkes (2011).

Such a framework, therefore, appeared to be a useful and practical tool for assessing the effectiveness of New Zealand's policy documents on technological literacy, just as it has been applied to the case of the USA. In order to accomplish an acceptable assessment, this study needed to make a concrete investigation into the documents of NZC and TCS. The investigation was conducted based upon a *qualitative data analysis* (Bryman, 2012) and has benefited from an acceptable level of research quality by performing an iterative examination of texts and using an acceptable procedure of analysis.

Performing an iterative (three times or even more for some parts) examination of the texts – accompanied with necessary discussions of the results and comparing the findings of different stages of inspection – has led to an adequate level of *reliability* of the findings.

The study was underpinned by a procedure for observing, identifying, and analysing the intended cases, proposed by Mason (1996), and Bryman (2012) (Figure 1). The process of investigating the texts was initiated with the general question as to which aspects or properties of the nature of technology, as outlined by the philosophers of technology, can be recognized in the New Zealand policy documents. The study passed through the subsequent steps of selecting the relevant parts of NZC and TCS, i.e., examining the important sections and critical sentences or keywords that have to do in one way or another with the nature of technology (steps 1 to 3); gathering all the necessary data regarding the general question mentioned above; and, consequently, analysing and interpreting them with the aid of the proposed framework, portrayed as the circular loop of steps 4, 5, 5a, and 5b. The final stage (step 6) delineates the findings of the study. For instance, in order to see how different features and functions of 'modelling' are considered through NZC and TCS (step 1), all relevant sections and sentences, particularly the 'Technological Modelling' component, were examined to collect the necessary data (steps 2 & 3). Then data gathered were analysed and interpreted with the aid of the existing explanations of TCS (step 4), and an attempt was made to delineate them in a conceptual framework, through the lens of the philosophy of technology (step 5). This raised further, but more detailed, questions about various aspects of 'modelling' (5a) which led again to more focused data collection and interpretation steps modifying the conceptual framework (steps 5b, 4, & 5), a loop which finally led to some appropriate results and conclusions about the state of 'modelling' in NZC and TCS (step 6).

3.3.1. On 'Technology as Object'

By means of the research procedure mentioned above, the study concluded that NZC, together with TCS, presents an adequate package about the 'object' side of technology's nature; a package regarding, as noted by Mitcham (1994), "… the most immediate, not to say simplest, mode in which technology is found manifest, ... [including] all humanly fabricated material artefacts whose function depends on a specific materiality as such" (p. 161).

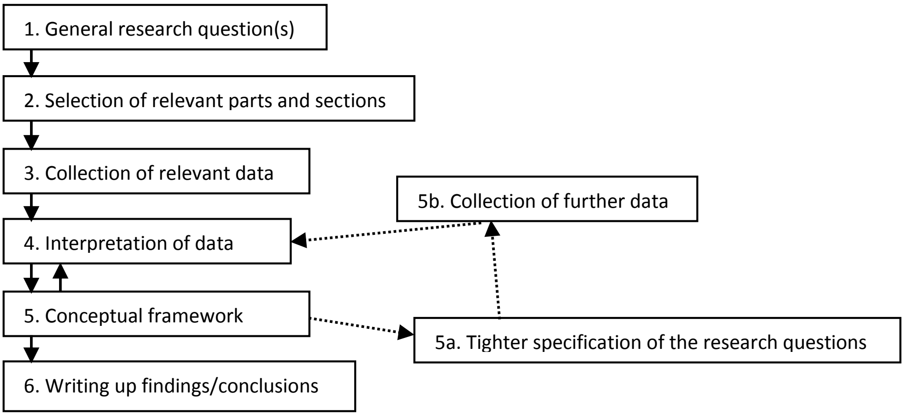

Fig. 1 An outline of the key steps of qualitative research
(Source: Amended from Bryman, 2012, p. 384.)

The concept of *dual nature*, in terms of both the *physical* and *functional* natures of artefacts, has been explicitly considered within the *Characteristics of Technological Outcomes* sub-strand (see, Ministry of Education of New Zealand, 2010, pp. 37-42). Even the matter of *interrelation* of those two natures has received particular attention within this curriculum:

> *Understanding this relationship is crucial when undertaking technological practice to develop a technological product or system for a specific purpose. This understanding allows technologists to recognise that several potential options exist for an outcome's physical and specific functional nature. … the functional nature requirements will set boundaries around the suitability of proposed physical nature options, and the physical nature options will set boundaries around what*

> *functional nature is feasible for a technological outcome at any time.* (Ministry of Education of New Zealand, 2010, p. 38)

It might initially seem that it is the *Technological Products* sub-strand that points to products' *objectness*. However, that sub-strand has concentrated on the *materialness* of products and the *objectness* of them is regarded, instead, through the *Characteristics of Technological Outcomes* view.

The next point is the latter sub-strand's specific attention to different aspects of *function*, that is, the prerequisites of artefacts to be able to carry out some *function*(s), or even to contain the potential for malfunction(s). (Ministry of Education of New Zealand, 2010, pp. 37-42)

NZC also yields an appropriate, though somewhat implicit, understanding of artefacts' *specific design* in the light of discussing their dual nature: the design element of artefacts is related to both their physical and functional natures as well as their interrelation. This approach emphasizes the significance of the 'physical-functional' interrelation in acquiring a suitable understanding regarding "how physical and functional factors were prioritised in the design and development of an outcome in order for that outcome to be considered fit for purpose" (Ministry of Education of New Zealand, 2010, p. 38)

The notion of *systems* has been extensively taken up in the strand of *Technological Knowledge,* which has not only devoted a specific component to technological systems, but also strives to acquaint students with relevant concepts like *subsystems*, *black box*, *control*, and *operational parameters* (see Ministry of Education of New Zealand, 2010, pp. 62-64).

3.3.2. On 'Technology as Knowledge'

The strand of *Technological knowledge* seems to be the place expected to deliver a sound understanding as to the nature of such knowledge – the expectation overtly claimed by the authors of the last version of NZC would be appropriately met through this curriculum and would fit well with Mitcham's perspective in this respect (Compton, 2007).

Such 'fitness', however, is subject to challenge: reflecting on Mitcham's own conceptualization of this side of technology, one can realize that his considerations revolve around subjects such as the following, as related to the nature of technological knowledge:

- Various structures and types of technological knowledge;
- Phenomenology of technical skills;
- Technological maxims, laws, rules, and theories;
- Different bodies of knowledge of technology compared to science;
- Against technology as applied-science;
- The know-how feature of technological knowledge;
- The path of growing technological knowledge process, and the nature of this transformation; and
- Ancient and modern technology, in terms of their different landscapes of knowledge. (pp. 192-208)

Mitcham's approach has roots in an epistemological direction to technology, which has more to do with excavating different features of technological knowledge in a way that strongly conforms to other philosophers' points and opinions in this respect (see, for instance, Kaplan, 2009, pp. 511-551; Meijers, 2009, pp. 23-404; Olsen, Pedersen, & Hendricks, 2009, pp. 49-128; Vermaas et al., 2011, pp. 55-66). This is summarized by Nia and de Vries (2016a) in Table 2.

The approach of NZC's *Technological Knowledge* strand is quite different from that of Mitcham; rather than delving into the nature of such knowledge and describing the various features thereof (as compared to those of scientific knowledge), this curriculum concentrates on explicating some generic concepts of technological developments:

> *[It] provides students with a basis for the development of key generic concepts underpinning technological development and resulting technological outcomes. These concepts allow students to understand evidence that is required to defend not only the feasibility of a technological outcome, but also its desirability in a wider societal sense. Within this strand students will be able to develop technological understandings in terms of levelled achievement objectives derived from three key components of technological knowledge – Technological Modelling, Technological Products and Technological Systems.* (Ministry of Education of New Zealand, 2010, pp. 15-16)

In addition, while the most philosophical reflections in this regard consider the 'know-how' aspect of technological knowledge in much detail, the strand focuses on the 'know that' side (Ministry of Education of New Zealand, 2010, pp. 15-16). It leaves the 'know-how' side to be only slightly covered in the *Technological Practice* strand (Ministry of Education of New Zealand, 2010, p. 15). The latter strand, moreover, touches in only a minor way on the 'interdisciplinary' nature of technology: rather than unfolding the 'interrelation' of science and technology as two different disciplines of knowledge, it mostly elaborates on the interrelation of various technicians and engineers of dissimilar disciplines in collaborative technological practice (see, e.g., Ministry of Education of New Zealand, 2010, p. 44).

In the same vein, one can see that the other features of the nature of technological knowledge, as well, have barely been taken into account in New Zealand's policy document; only the notion of *creativity* has been slightly considered in the *Nature of Technology* strand (see Ministry of Education of New Zealand, 2010, p. 44).

3.3.3. On 'Technology as Activity/Process'

This aspect of technology is mostly explored throughout the *Technological Practice* strand, which aims to provide suitable knowledge as to what occurs or should be done during various steps of technological processes.

Technological processes are expounded that have generally defined plans, especially in today's technologically complex activities. These plans, in the broadest view, begin with recognizing the *needs* or realising the *opportunities* and proceed through various, not necessarily linear, increments and processes, such as *modelling*, *designing*, *evaluating*, and *developing*. Most of such concepts are given due attention within the *Technological Practice* strand (see Ministry of Education of New Zealand, 2010, pp. 18-36); however, this study, as outlined in Figure 1, showed that there remain some significant issues to be (re)considered in this regard.

First of all, a substantial critique can be raised against the curriculum's approach to *models* and *modelling* (in terms of the nature of models and various ways of designing or making use of them in technological activities), which is discussed mainly in the *Technological Knowledge* strand. Regardless of such an articulation, the subject of *models* and *modelling* is not considered in a comprehensive manner in this strand and is confined to some brief discussion about various types of models and only two types of modelling: "functional modelling [which] allows for the ongoing testing of design concepts for yet-to-be-realised technological outcomes … [and] … [p]rototyping [which] allows for the evaluation of the fitness for purpose of technological outcome itself … [both types are used] to justify decision making within technological practice." (Ministry of Education of New Zealand, 2010, p. 49).

The philosophical reflections, however, deliver extensive descriptions that, as highlighted by Nia and de Vries (2016b), are worth considering in technological literacy programmes. Morrison and Morgan (1999) and subsequently Boon and Knuuttila (2009) have made prudent attempts to release 'models' from the customary perspective of considering them to be merely *representational* tools – the perspective which, by the same token for NZC and TCS, sees *modelling* merely as *representing a reality* (Ministry of Education of New Zealand, 2010, pp. 16, 49). In Boon and Knuuttila's view, models have a broader *epistemic* nature, and modelling is used "to understand, predict or optimize the behaviour of devices or the properties of diverse materials, whether actual or possible" (p. 693). Hence, after a wide investigation into different accounts regarding the nature and various properties of models, Nia and de Vries (2016b) argue that these tools should be considered as *techno-scientific artefacts* with their own dual nature – *intrinsic* and *intentional*. Their well-categorized framework sketches the nature and different features of models and emphasizes their multifunctional roles in *modelling* activities, far from confining them to only a few functions (Figure 2). That study ironically also opens a way to apply its framework to New Zealand's long-term policy document, through delivering a preliminary conclusion that:

> *The case … does not give a notable clue delineating the essence of models, … and seems to be [merely] confined to speaking of 'functional models' and 'prototypes'; both can be assigned to [only] the 'decisional' space of the 'communicational' function of models.* (p. 24)

Turning to the other notions, one can see that the notions of *innovation* and *invention* have not been given any notable consideration within New Zealand's curriculum, although a deeper level of analysis may reveal some implicit support of such concepts throughout the curriculum. Furthermore, the concept of 'use plan' also has no place in this case. NZC's focus on 'plans' has mostly to do with 'planning for practice', in order to support successful development of technological outcomes (Ministry of Education of New Zealand, 2010, pp. 24-25) – not with various aspects of 'the process of using' artefacts, as in the meaning of 'use plan' that is extensively explained by Mitcham (1994, pp. 230-240) and other philosophers such as Vermaas et al. (2011, pp. 5-20).

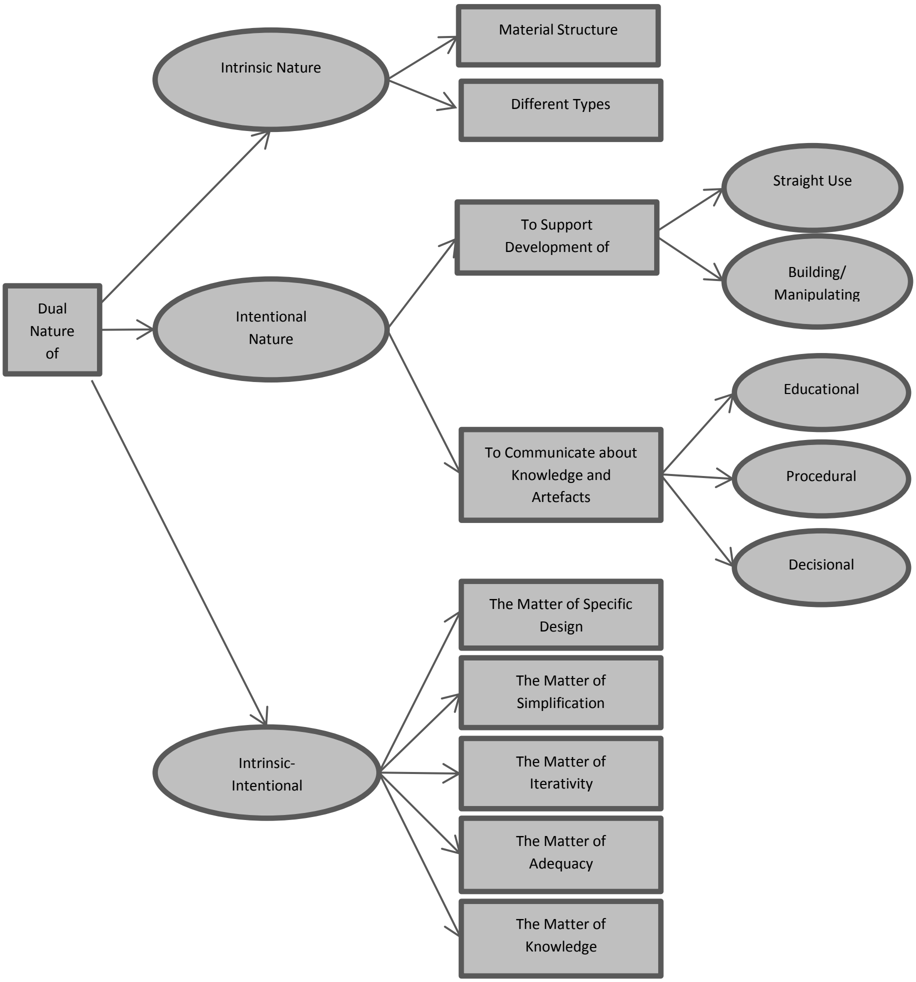

Fig. 2 Dual nature of models in a brief sketch
(Source: Nia & de Vries, 2016b, p. 24.)

3.3.4. On 'Technology as Volition'

Through explorations of the *Nature of Technology,* students come to perceive the volitional aspect of technological artefacts. They become familiar with *the social* *construction* account of technology, and learn to examine various societal facets of technological volition appearing in interrelationship with notions such as *culture*, *environment*, *politics*, *economics*, etc. (Ministry of Education of New Zealand, 2010, p. 37-48). Such an approach, though not very explicit:

> *rests upon a sociotechnological stance which … views as inseparable the complex interweaving of the technological and sociocultural aspects of any technological development … and indeed the specific political and historical context of its development and placement.* (Compton, 2007, p. 10)

The same holds true for the *ethical* and *value-related issues* which lie not only in the strand of *Nature of Technology* but throughout the whole document (Ministry of Education of New Zealand, 2010, pp. 96-99). This manner of education leads subsequently to the notion that 'value' should be given appropriate consideration in teaching about *design*, even if not mentioned exactly in terms such as v*alue-sensitive design*.

Another notable point is that this curriculum does not insist on paying particular attention to various *contexts* of technologies such as *medicine*, *agriculture*, *energy*, *information*, *transportation*, and so forth – an approach in contrast to that of cases such as the American Standards for Technological Literacy (ITEA, 2007), which has dedicated an independent chapter to discussing many such contexts (see ITEA, 2007, pp. 140-197). The approach of NZC is attributed to its preceding experiences of both classroom practice and research, clearly showing "that learning in technology often goes across a number of technological areas and contexts and beyond those named" (Compton, 2005, p. 2)

Eventually, concerning the concepts ignored in NZC and TCS, it is difficult to ascertain any useful consideration on notions such as *aesthetics*, *metaphysics*, and *the future of humanity*. These notions deal mostly with the social aspect of human life and, hence, have been taken into serious account in recent literature of the philosophy of technology (Nia & de Vries, 2016a).

3.3.5. Overall Results

The discussion above can be represented through Table 3. This table can also provide a holistic view as to the state of various aspects and features of technology within New Zealand's curriculum, compared to the claim by its main authors.

As seen in Table 3, 'technology as object' is covered well by the curriculum, but not only via the strand of *Nature of Technology*; the notion of 'systems' is discussed in *Technological Knowledge*. On the other hand, the strand of *Technological Knowledge* itself does not deliver much in the way of philosophical reflections on this aspect of technology. The state of 'technology as activity' can be seen as in between: some concepts are touched upon appropriately, and some require more serious contemplation. Lastly, most volition-related features of technology have been considered through the strand of *Nature of Technology*; there are only a few notions that are not captured.

3.4. Concluding Remarks and Recommendations

This chapter commenced with questions about the New Zealand Curriculum approach to technological literacy, namely, does this document provide a suitable path for learning about the nature of technology, and more specifically, does such an approach satisfy Mitcham's perspective in this regard as claimed by its main developers?

An attempt to address those questions was made in this study through a philosophy-of-technology based analysis. Nia and de Vries's (2016a) method was used as an appropriate tool for that purpose, a tool based upon a compilation of Mitcham and other philosophers' opinions as to the nature and features of technology. The findings then unveiled some issues in the New Zealand curriculum. These issues were:

- NZC's approach to categorizing different aspects of technology does not entirely conform to Mitcham's perspective as explained by him and many other philosophers; rather, in some places it presents its own interpretation of such a perspective and can therefore be subject to substantial reconsideration in this regard; and
- In addition to many important concepts that are well covered by NZC and soundly elaborated by TCS, there still exist some features that are entirely missing or, at least, not appropriately discussed through those documents; these need consideration, as captured by Table 3, to provide a more comprehensive package of technological literacy.

3.4.1. Improvement Proposals

The final contribution of the present research is its recommendation for a preliminary schema for amending the issues raised. Developing subsequent, more detailed, and applicable suggestions will certainly demand further study.

The proposed amendments – developed on the basis of the aforementioned discussions and analyses – can be sorted into two categories: those pertaining to the *structure* of NZC, and those pertaining to the *content* of such a structure.

Regarding the *structure* of NZC, it would align more with Mitcham's perspective with the following modifications (as shown in Figure 3):

- It is proposed to make T*echnological Modelling* a sub-strand of *Technological Practice.* As discussed earlier, 'modelling' (as intended in NZC) has more to do with the field of various activities carried out in the course of engineering practices, and has much less to do with reflections from the epistemological view of *Technological Knowledge*.

Table 3 The state of different aspects of technology in NZC and TCS.

Aspect of technology	View		
	Published authors'	This research	
Object	Addressed via *Nature of Technology* – specifically in terms of the *Characteristics of Technological Outcomes*.	Artefacts (as objects)	Adequately considered within *Nature of Technology*
		Systems	Adequately considered within *Technological Knowledge*
		A (specific) Design	Adequately considered within *Nature of Technology*
Knowledge	Addressed via *Technological Knowledge*	Representation of knowledge and skills	Barely considered
		Normativity of technological knowledge	Barely considered
		Interrelation of science and technology	Barely considered
		'Know-that' and 'know-how'	Slightly considered within *Technological Practice*
		Creativity	Slightly considered within *Nature of Technology*
Activity	Addressed via *Technological Practice*	Designing	Adequately considered within *Technological Practice*
		Evaluation	Adequately considered within *Technological Practice*
		Modelling	Slightly considered within *Technological Knowledge*
		Innovation & invention	Barely considered
		Needs, wants, & demands	Adequately considered within *Technological Practice*
		Use plan	Barely considered

Table 3 (continued) The state of different aspects of technology in NZC and TCS.

Volition	Addressed via *Nature of Technology* – specifically in terms of the *Characteristics of Technology*	Artefacts (as volition)	Adequately considered within *Nature of Technology*
		Value-sensitive design	Adequately considered within *Nature of Technology*
		Ethics, values, & moralities	Adequately considered within *Nature of Technology*
		Aesthetics	Barely considered
		Social construction of technology	Adequately considered within *Nature of Technology*
		Sociotechnical systems	Adequately considered within *Nature of Technology*
		Different contexts of technology	Barely considered
		Technology & metaphysics	Barely considered
		Technology & politics	Adequately considered within *Nature of Technology*
		Technology & society	Adequately considered within *Nature of Technology*
		Technology & culture	Adequately considered within *Nature of Technology*
		Technology & economy	Adequately considered within *Nature of Technology*
		Technology & environment	Adequately considered within *Nature of Technology*
		Technology, future, & humanity	Barely considered

- The *Technological Products* sub-strand, as it deals with the 'dual-nature' subject, appears consequently more suitable for merging into that of Characteristics of Technological Outcomes. The same is suggested for *Technological Systems*.
- It is strongly recommended that some sub-strands with an epistemological approach to the nature and different features of technological knowledge be embedded into NZC (the required content for such a sub-strand can be seen in the discussion immediately below).

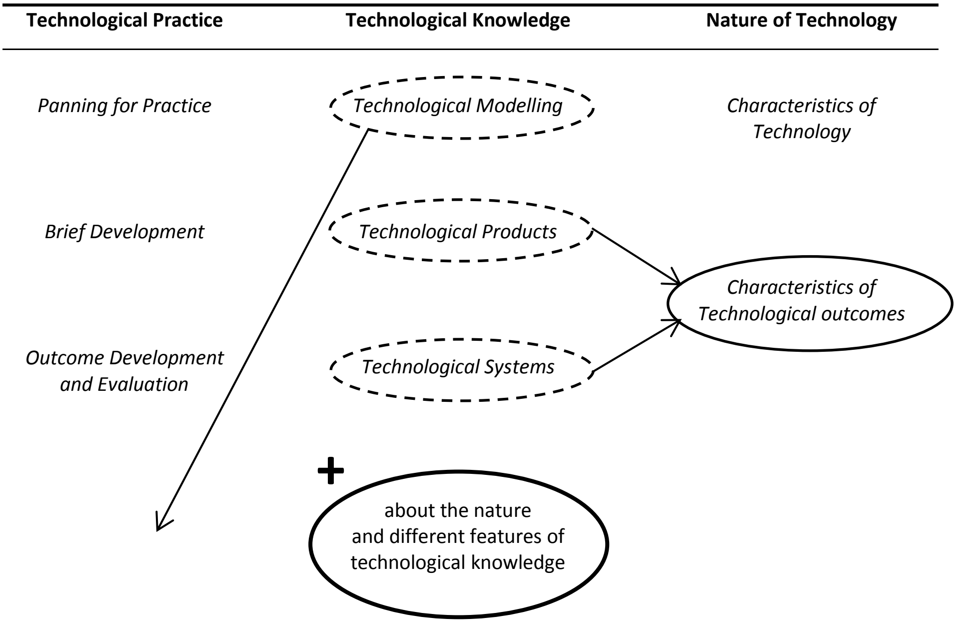

Fig. 3 Restructuring proposal for NZC

In terms of *content*, there are certain concepts, summarized in Table 3, which are barely or inadequately considered in NZC. Such concepts should be embraced more fully and explained in the appropriate places in both NZC and TCS.

- *Technological Knowledge* needs to be touched upon from a more epistemological perspective (compared to the current approach of relating it to different attributes or functions of 'models', 'products', and 'systems'). It should be discussed in terms of the various features of such knowledge, its 'know-how' aspect (as opposed to 'know-that'), 'normativity', and key 'distinctions' and 'interrelations' with scientific knowledge.
- *Technological Activity* should cover concepts such as 'innovation', 'invention', and 'use plan', as they are notions that play a pivotal role in most engineering processes. In addition, the concept of 'modelling' (including 'models') could be discussed much more than it currently is in both NZC and TCS.

- It is strongly suggested that *Nature of Technology* – more specifically, its *Characteristics of Technology* component – devote some space to acquainting students with the 'aesthetic' and 'metaphysical' sides of technology's nature, as well as 'future trends' in terms of how to deal with it or have an effective role in making it.

Finally, the significant point is that this package of proposals does not claim to be a perfect one for improving the quality of NZC, nor is the suggested method believed to be the best in utilizing the philosophy of technology. Rather, the intention of this chapter is to address certain challenges and opportunities embodied in the approach of the case studied, so that it could deliver a more comprehensive understanding about the nature and various features of technology. With this said, the presented analysis can itself be subject to necessary enrichment in terms of providing more from the discipline of the philosophy of technology to be used in technological literacy attempts. Moreover, the aforementioned analysis can be considered further in more detailed studies. The aim is for such proposals to lead to more effective material and the conclusions to be embedded in the existing approach in a consistent and effective way.

We would like to end this section with making a noteworthy point, that is, this study highlights again the lacking of the two significant concepts of *model* (and *modelling*) and *normativity* in a *technological literacy* standard; the problems once mentioned that hold for the American case of STL, too, and will be taken up, respectively, in the course of the two following chapters.

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04

Chapter. 4

MODELS AS ARTEFACTS OF A DUAL NATURE

a philosophical contribution to teaching about models designed and used in engineering practice

PUBLISHED PAPER :
Int'l Journal of Technology and Design Education / 2016
http://dx.doi.org/10.15663/ajte.v3i1.38

	PRIMARY/SECONDARY SCHOOL STUDENTS	TERTIARY SCHOOL STUDENTS
OVERALL CONTENT	CHAPTERS 2&3	CHAPTER 6
SPECIFIC ISSUES	**CHAPTERS 4**	CHAPTER 5

MODELS AS ARTEFACTS OF A DUAL NATURE:

A PHILOSOPHICAL CONTRIBUTION TO TEACHING ABOUT MODELS DESIGNED AND USED IN ENGINEERING PRACTICE

4.1. Introduction

Models play an increasing role in the course of most engineering activities, and it is easy to observe how extensively various kinds of models are being used in different layers of today's engineering processes and in technological designs and developments (see, e.g., various discussions in this regard in Vincenti 1993; Veveris 1994; Hazelrigg 1999; Boon and Knuuttila 2009; Nersessain and Patton 2009; Pirtle 2010; Rossouw et al. 2011; Schätz 2014; and particularly in Brockman 2008, where 'modelling' has been included in the title of the book, thereby giving a general introduction to this engineering activity). Therefore, the way to properly learn about these types of models has, accordingly, also received the attention of many educational approaches (e.g., Compton 2007; De Vries 2013; or long-term policy documents such as International Technology Education Association 2007; Ministry of Education of New Zealand 2007, 2010; South Africa's Department of Education 2002).

However, as acknowledged by scholars such as De Vries (2013), it seems that not much has yet been developed to educate about the content of models that are used in engineering practice, and "[students] are not challenged to reflect on the nature and function of [models]" (De Vries 2013, p. 123). Such a point of view believes that the essence of such engineering-related models—referred to hereafter as 'models'—should be expounded in more explicit terms in educational perspectives, and that students are expected to acquire an appropriate level of understanding about various aspects of these engineering tools, in addition to engaging with, constructing and using them. These types of reflection on teaching (or learning) about models, even those which view technology through the lens of (applied) science, attempt to provide a contribution to the training of more skilful and more knowledgeable students with regard to models: learners should be able to explore models, comprehend their internal properties, and to some degree explain models' certain underlying logic, design, and structure; they are also expected to acquire some knowledge as to the processes of the design and production of models, as well as the limitations thereof (Petrosino 2003; Harvard Graduate School of Education 2008; Ornek 2008; Ministry of Education of New Zealand 2010; Seeds of Science/Roots of Reading 2012; De Vries 2013). These are some subjects, among many, which have not previously been sufficiently considered in the texts of technological literacy.

Having said this, there are two concerns relevant to this study: the first is the lack of any comprehensive rationale in the current literature used in technology education that explains the diverse nature of models (De Vries 2013); second, it can be observed that the existing literature considers models from various, but not unified, perspectives, which in total hardly deliver a well-structured packet of the various aspects and characteristics of these significant engineering tools. This all has led to the aim of this contribution being set on developing a concrete, all-encompassing framework (an umbrella, so to speak) to be used in teaching about the various and interconnected aspects of models: a framework capable of understandably (a) conveying a fairly comprehensive account of the nature of models, and (b) providing a well-organized, teachable packet which can categorize and delineate various properties of them together.

Accordingly, the argumentation line of this chapter is as follows:

It begins with a study of two well-known cases in the technological literacy arena—the USA's *Standards for technological literacy* (International Technology Education Association 2007), and *The New Zealand Curriculum* (Ministry of Education of New Zealand 2007, 2010)—as only two instances among others, to investigate some currently suggested concepts and contents that have been proposed to be taken into account for learning about models. This provides a basic understanding of the necessity of seeking a robust rationale that explains the nature of models as well as a well-ordered framework which spells out the various features of this nature. Here is the point where philosophical reflections will provide a very fruitful ground in which to accomplish such a mission, because philosophy (of technology) is, as is known, the discipline that engages with exploring the nature of (technological) entities and attempts to provide a sound delineation of different features of those natures (Durbin 1983; Ferre 1995; Feenberg 2003). This stage explores the ways in which various aspects and properties of models have been reflected by certain philosophers of science or technology. This then paves the way to the following section, which argues that models should be considered as techno-scientific artefacts with their own dual nature; a philosophy-based account which can lead to enriching the field of technology education. Next, the subsequent three sections respectively discuss each of the two natures as well as their interrelationship. Finally, the chapter concludes by drawing the major points together, accompanied by showing some initial advantages of applying the suggested approach to the intended cases, which hopefully will lead to further, more detailed inspections and new, extended contributions.

4.2. Case Studies: Making the Problems Clearer

A number of cases[1] would have been suitable for scrutiny for the described purpose of this chapter; however, due to limited space, there were certain reasons that led to the selection of those of the USA and New Zealand.

The cases were selected based upon the *typical case (purposive)* sampling approach, aiming to exemplify the essential dimension of the research interest (Bryman 2012), that is, to acquire a primary outlook of the state of affairs of models in the two notable long-term policy documents of technology education. The former seems to be the most extensive document serving as a guide for teaching about many aspects of technology, and the latter is claimed (by its authors) that it is based on a philosophical perspective, in its technology-related sections (Compton 2007). Both are cases that have drawn much attention across the literature and in various conferences about technology teaching (e.g., De Vries 2009; Jones 2009; and numerous papers in diverse issues of *International Technology Education Series, International Journal of Technology and Design Education*, and proceedings of PATT conferences). Moreover, as the complementary reason to exclude the other cases, these two documents were sufficient as an observation of the existing inefficiencies and considerable variances of some current approaches of teaching about models, and, consequently, to trigger the authors to develop a concrete rationale and a well-articulated structure delineating the nature and different aspects of models (let alone that none of the other cases, such as those of England, Australia, or South Africa, yield a more, if not saying a less, comprehensive sketch in this regard).

[1] E.g., the long-term policy documents such as *A statement on technology for Australian schools, a joint project of the states, territories and the commonwealth of Australia* (Australian Education Council 1994); *Revised national curriculum statement grades R-9 (schools); Technology* (Department of Education of South Africa 2002), and *National curriculum in England: Design and technology programmes of study* (Department of Education of the UK 2013).

The cases were studied based on a *qualitative data analysis* (Bryman 2012). However, prior to taking up the findings of the study, it is worth assuring readers here of its level of quality.

Due to the iterative (more than three times[2]) examination of the texts by the authors, and repetitive discussions and comparisons of the results, the findings benefit from an acceptable level of reliability. Additionally, in order to reach a satisfactory level of validity, the research attempted to move forward step by step based on an appropriate method of observing, identifying, and analysing procedures (Mason 1996; Bryman 2012), as portrayed in Fig. 1. It began by putting forward a general sub-question (of this phase of study, and not the main question of the chapter) that, *how have 'models' been described within the intended cases?* The texts were chosen based on the above-explained reason, and the relevant data have been collected and interpreted accordingly. The phase of analysing and interpreting data and placing the results in a categorized conceptual framework was performed through an iterative manner of moving back and forth between the texts and the framework, as shown again in Fig. 1 (the reciprocal interrelations of steps 4, 5, 5a, and 5b[3]), and this all has led to the findings explained in the following subsections.

4.2.1. *Case 1: Standards for Technological Literacy (the USA)*

Standards for Technological Literacy (STL) (2007) is a prominent contribution to the USA's educational system. It describes the essential technological knowledge and skills that all K-12 students need to acquire. Therefore, this study examined this document thoroughly to determine how the concept of 'model' has been taken into account within it. The findings are shown in detail (by referring to the exact phrases and page numbers) in Table 1; however, to render a summarized

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[2] Some parts of texts that were not clear or explicit enough were examined and compared up to five times, in order to arrive at more accurate findings.

[3] This can be realized as the sub-questions seeking the more specific sides of 'models' in the analysed cases.

description, it can be declared that students are meant through STL to become acquainted with a number of *functions* of models. These include:

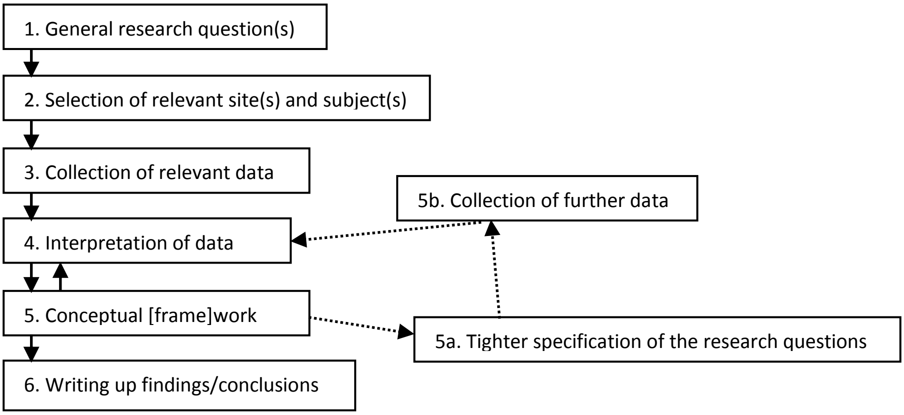

Fig. 1 An outline of the main steps of qualitative research (taken with some changes from Bryman 2012, p. 384)

- *Demonstrating* That is to say, one of the primary goals of making models is to demonstrate (or represent) the provided design concepts, to try out the visions and ideas, or to show how different technological devices work or are used (see Table 1; rows 5, 11, 13, and 37).
- *Designing* Students learn to model their design proposals by being asked to sketch and determine the proper features and scales of their needed models. This function of models relates every so often to some other functions, such as testing and (re)evaluating, and frequently amounts to the action of redesigning (see Table 1; rows 2–3, 16–17, and 27).
- *Testing and (re)evaluating* Learners are taught that models are used for testing and (re)evaluating ideas, solutions, designs, and processes in order to determine how well they meet the identified requirements and targets. Designers, according to STL, should ensure the quality, efficiency, strength, or productivity of their designed models. They will also carry out at this stage any needed redesign and improvement to achieve their optimal model.

Sometimes even the original design might be dropped and another tried (see Table 1; rows 1, 5, 8–10, 15–19, 22–23, 26, 28, 31, 34–35, 38–40).

Table 1 The concept and functions of models in STL

Row	Phrase(s)	Page	Function(s)
1	The selected design is modeled and tested, and then reevaluated. If necessary, the original design is dropped and another is tried.	6	Testing, (Re)evaluating
2	Students generally work in teams when building models of their design proposals, and, depending on the device, they may build working prototypes as well.	6	Designing, Prototyping
3	Each student sketched and determined the proper scale needed to make a model of the art[e]fact he or she had chosen.	7	Designing
4	Computers are used to develop models before a product is actually made.	27	Simulating
5	The process of making models, as well as modeling in virtual environment, is used to demonstrate concepts and to try out visions and ideas.	33	Demonstrating, Testing
6	Students should have opportunities to use simulation or mathematical modeling, both of which are critical to the success of developing an optimum design.	41	Simulating, Different types
7	Systems thinking … uses simulation and mathematical modeling to identify conflicting considerations before the entire system is developed.	42	Simulating, Different Types
8	An optimum design is most possible when a mathematical model can be developed so that variations may be tested.	42	Testing
9	To build models of each house and then test them for strength and durability.	46	Testing
10	The students could then design a rocket and build a model to test their design.	48	Testing
11	After building a model of an elevator, they could see how pulleys and counterweights work to create a machine that can move people and goods up and down.	59	Demonstrating, Simulating
12	Students could research, design, and build a model showing a cutaway view of their local terrain, complete with caverns, sand, soil, water flow patterns, ponds, and lakes. Such a model could be used to show how spilled fuels or other liquids affect watersheds and bodies of water.	71	Simulating
13	Once they have gathered their information, the students could present it to the class in various formats, such as building a model, making a slide presentation, …	83	Demonstrating

Table 1 (continued) The concept and functions of models in STL

14	By practicing these problem-solving methods, students acquire a number of other valuable skills … using a variety of tools, working with two- and three-dimensional models, …	90	Problem solving
15	They should have the freedom to model, test, and evaluate their designs before redesigning them.	94	Testing
16	The process is intuitive and includes such things as creating ideas, putting the ideas on paper, using words and sketches, building models of the design, testing out the design, and evaluating the solution.	94	Designing, Testing, (Re)evaluating
17	In searching for the best solution, the designer redesigns, tests, refines, and models again and again.	97	Designing, Testing, (Re)evaluating
18	The design process includes … a model or prototype, testing and evaluating the design using specifications, refining the design, creating or making it, and communicating processes and results.	97	Prototyping, Testing, Evaluating, Communicating
19	To help evaluate the solutions, models and prototypes can be built and tested, and the result can then be used to determine how well the solutions meet the previously identified requirements.	99	Prototyping, Testing, Evaluating
20	As they use the engineering design process, students should communicate their ideas and solutions … using sketches, models and verbal descriptions.	100	Communicating
21	Expressing ideas to others verbally and through sketches and models is an important part of the design process … sketches are more efficient than words for conveying the size, shape, and function of an object, while models are effective in imparting a three-dimensional realism to a design idea.	100	Communicating
22	Models are used to communicate and test design ideas and processes. Models are replicas of an object in three-dimensional form. Models can be used to test ideas, make changes to designs, and to learn more about what would happen to a similar, real object.	102	Communicating, Testing, Simulating
23	A design proposal … can be communicated through various forms, such as sketches, drawings, models, and written instructions. Models allow a designer to make a smaller version without having to invest the time and expense of making the larger item. Physical, mathematical, and graphic models can be used to communicate an idea.	103	Communicating, Different Types
24	Modeling, testing, evaluating, and modifying are used to transform ideas into practical solutions ... Models are especially important for the design of large items, such as cars, spacecraft, and airplane because it is cheaper to analyze a model before the final products and systems are actually made.	103	Testing, Simulating

Table 1 (continued) The concept and functions of models in STL

25	A prototype is a working model that is conceived early in the design process.	104	Prototyping
26	A prototype is a working model used to test a design concept by making actual observations and necessary adjustments.	105	Prototyping, Testing
27	Build or construct an object using the design process …, students can build or construct it in three-dimensional form … include[ing] building a scaled-down model of the objects.	116	Designing
28	After the design proposal has been finalized and the model has been created, it is important to perform tests and evaluate the results as they relate to the pre-established criteria and constraints.	120	Testing, Evaluating
29	A model can take many forms, including graphic, mathematical, and physical.	121	Different types
30	The major new skill students develop will be working with prototypes, which can be full-size or scale models, depending on the size of the final product or system.	123	Prototyping
31	Prototype and other models should be used to test and evaluate the solutions.	123	Prototyping, Testing, Evaluating
32	Students should be exposed to more sophisticated conceptual, physical, and mathematical models …	123	Different types
33	Refine a design by using prototypes and modeling to ensure quality, efficiency, and productivity of the final product.	124	Prototyping
34	Evaluate the design solution using conceptual, physical, and mathematical models at various intervals of the design process in order to check for proper design and to note areas where improvements are needed.	124	Testing, Evaluating, Different types
35	Evaluate final solutions and communicate observation, processes, and results of the entire design process, using verbal, graphic, quantitative, virtual, and written means, in addition to three dimensional models.	124	Testing, Evaluating, Different types
36	Students could research various climate forecast models and project what could occur if the earth's polar region warmed by 2° C or 4° C. they then could analyze a plan to address global warming and assess its potential solution.	138	Simulating
37	In learning how different medical technology devices work, students could design and build models that would demonstrate how they are used.	145	Demonstrating, Learning
38	For example, students could study and learn how a laser works by making, testing, and evaluating a model and then relating its adaption to use in many surgical procedures.	147	Testing, Evaluating, Learning
39	Students may test soil run-off for various pollutants and design and develop a system that might serve as a model for improving environmental conditions.	155	Testing

Table 1 (continued) The concept and functions of models in STL

40	They can then build models of their ideas and test them.	162	Testing
41	For example, in a unit of study about the solar system, students could use a computer to create a graphic representation of the planets, or they could apply their building skills to make a model of the stars.	168	Simulating
42	[They could use a model of a hot air balloon] to explore how air transportation vehicles has changed throughout history … [and to] learn about the development of various air transportation vehicles and find out how a hot air balloon moves through the air.	177	Learning
43	To increase their understanding of these subsystems, students may design and develop models of them. For example, the structural subsystem includes the framework and body of a vehicle. Students should design and develop a model of a new vehicle to be used on land, in the sea, in the air, or in the space in order to see firsthand how the structural subsystem is related to the environment in which the subsystem is used.	178	Learning
44	Students design structures and make models of them. They should understand that certain structures can be thought of as part of a much larger system that underlies the functioning of the entire society.	195	Learning
45	[S]tudents could design and construct a model of a wastewater treatment system that moves and filters contaminated water [to enhance their skill and comprehension level to tackle design and problem-solving activities that require attention to greater details for long periods of time.]	217	Learning

- *Prototyping* Students learn about prototypes; that they are working models used to test a design concept by making actual observations and necessary adjustments, or to test and evaluate the solutions. All these too might be accompanied by redesigning and making any needed refinements (see Table 1; rows 2, 18–19, 25–26, 30–31, and 33).
- *Simulating* Learners should have opportunities to learn and use simulation as a method or tool that is critical to both the success of developing an optimum design and forecasting or foreseeing possible outcomes, consequences, benefits and risks. Simulations are used as well for learning about the complex systems in simpler ways (see Table 1; rows 4, 6–7, 11–12, 22, 24, 36, and 41).
- *Problem solving* Students learn to make and use models in specific problem-solving methods (see Table 1; rows 14 and 45).

- *Communicating* Since expressing ideas and solutions to others constitutes an important part of the design process, students learn how to communicate their ideas and design proposals through various forms of modelling without having to invest time or expense in making real or large items (see Table 1; rows 18, 20–23).
- *Learning* Students should be taught to design and build models to demonstrate how some technological devices are developed and/or used. They also increase their understanding of technological systems by the aid of designing and developing related models. Finally, engaging with modelling plans can help students to "enhance their skill and comprehension level to tackle design and problem-solving activities" (see Table 1; rows 37–38, 42–45).

Lastly, and beside the above-mentioned 'functions', students learn in the context of STL that models can be of various types such as *physical*, *mathematical*, *graphical*, *conceptual*, etc., and can also take certain two- or three-dimensional forms (see Table 1; rows 6–7, 23, 32, 34–35).

4.2.2. *Case 2: The New Zealand Curriculum*

The New Zealand Curriculum (NZC) (2007) is another contribution which aims to provide students with "a fundamental level of technological literacy" as well as "an educational foundation for technology related careers" (Ministry of Education of New Zealand 2010, p. 4); and in this line, it has dedicated a substantial part of the curriculum to enhancing students' practical skills as they develop models, products, and systems (see Ministry of Education of New Zealand 2007, 2010). The interesting point is that the NZC and its explanatory version, *Technology Curriculum Support*[4] (TCS) (2010), are claimed to take proper advantage of philosophical reflections on technology and the nature of its various elements (Compton 2007).

[4] A package of documents and papers developed by The Ministry of Education of New Zealand (2010) to support schools and teachers to implement the technology curriculum of *The New Zealand Curriculum*.

In addition, both these documents also pay significant attention to the concept of 'model', which makes them noteworthy to be analysed in this respect.

The place in NZC that seriously touches on models is the Technological *Knowledge* strand[5]; this categorizes modelling into two related types: *functional modelling* and *prototyping*. These differ from each other in "what is being modelled", "the purpose of the modelling", and "the stage in the development" (Ministry of Education of New Zealand 2010, p. 50). It is now worthwhile to have a detailed look at each of these types, to see how they take on the role of 'models' in technological practices.

1. *Functional modelling* As indicated by its name, this type of modelling mainly focuses on functional models which allow for the ongoing testing of (well-functioning of) concepts, during and after being designed; whether the "design [of] ideas for parts of an outcome" or the "complete conceptual design for the outcome as a whole" (Ministry of Education of New Zealand 2010, pp. 49–55). This type of modelling has been considered through TCS from different perspectives:

    - First of all, it may take dissimilar names across different domains of technology (e.g., "as test or predictive modelling in biotechnology, animatics in film making, a toile in garment making, and mock-ups or mocks in architecture and structural engineering"). However the pivotal point of all these cases, as pointed out by TCS, is that "what is being modelled, or represented, is the yet-to-be realized technological outcome for the purpose of testing design concepts with regards to the physical and functional nature of the outcome required by the brief" (pp. 49–55);

[5] NZC has assumed three strands for technology: *Technological Practice*, *The Nature of Technology*, and *Technological Knowledge*. The third strand has, for its part, three interconnected components, that is, *Technological Modelling*, *Technological Products*, and *Technological Systems* (for more detail, see Ministry of Education of New Zealand 2007, 2010).

- It can act as a tool to provide a conversant forecast of the yet-to-come future effects. In other words, through exploring and evaluating designed concepts, functional models enable decision takers to evaluate the technical feasibility of their proposal's outcome, and take 'go/no go' decisions;
- Functional modelling enables technologists to reduce waste or resources, instead of taking a fast route toward the realization phase and "relying on a more 'build and fix' approach to technological development" (p. 50);
- It also enhances the confidence level about being fit for purpose, and amounts to fewer unknown or undesirable side-effects;
- Risk identification and more informed management could be considered as the other benefits of using this type of model;
- Functional models, however, have their own limits as they are only a simulation or some part of a real product or system, and thereby the provided test results are confined by specific boundaries.

2. *Prototyping* Unlike 'functional modelling', which allows for the evaluation, in the sense of fitness of the design for the specified function considered for a technological outcome, prototyping provides an assessment of fitness of the technological outcome itself for the *intended purpose*. That is to say, the latter focuses on pursuing a social demand by introducing a certain product (or service) and "seeks to gather further evidence to inform subsequent decisions focusing on establishing its acceptability for implementation or the need for further development" (p. 50); it also enables a greater degree of studying the impact(s) of an outcome, be it intended or unintended, on people and the physical and social environment, before releasing. As for prototyping, there are also some attributes in TCS:

- This type of modelling as well "can result in a 'no-go' decision or in a significant change, meaning a need to revise the design concept" (p. 50);
- Any decision to develop further, after prototyping, can lead to a risk reduction as well as "less dramatic modification, or refinement of the outcome to enhance its performance and/or suitability" (p. 51);
- Prototyping can have another usage, that is, "for the purpose of testing 'scale-up' opportunities, and … [to] provide key information regarding decisions around ongoing or multi-unit production and marketing for commercial purposes" (p. 51).

Beside functional modelling and prototyping, the subject of different media and types of models has been slightly alluded to in TCS, where it talks about "drawings on paper or within computer programmes", "dimensional mock-ups", and using "easily manipulated materials such as clay, cardboard, Styrodur foam, and CAD software" (pp. 49–55).

4.3. The Problems; A Preliminary Sense

The above discussion leads to a preliminary sense about the lack of a suitable account of models within these documents. For instance, one can observe that the two cases possess different approaches to models: STL renders a sort of scattered description (and not a well-ordered framework) of models' different aspects such as functioning as 'demonstrating', 'testing', 'communicating', or 'learning' tools; on the other hand, NZC places a narrower but somewhat deeper focus on only 'functional models' and 'prototypes'. In addition, neither appears to deliver a proper account of the nature of models in terms of, at least, how models are constructed and used, and which intentions and elements play a significant role in such constructions and usages, etc.

One should note that these types of challenges are not merely confined to STL or NZC; these cases are, as mentioned earlier on, only two (more extensive) exemplars among several others for which the same problem also goes. That said, such reasons are sufficient motivation in themselves, in this step, to seek a richer account of the nature of models and to attempt to describe their various properties through a more appropriate structure — though the necessity and significance of such effort will be revealed more in the final section.

4.4. The Philosophical Literature

Following this line of exploration, a wise subsequent stage was to resort to the disciplines of philosophy of science and technology, where many helpful points, ideas, and theories as to the nature and the various properties of models, as well as the processes of modelling, have been put forward. The aim of this section is therefore to show how these philosophical reflections can pave the way in providing the required comprehensive account of models, to be used in educating about them.[6]

In order to have an efficient procedure for selecting the most useful and relevant texts, the literature selection (to review) was conducted based on *constrained snowball sampling* via *citation network analysis* (Lecy and Beatty 2012). The process began with the examination of the relevant texts of the book *Philosophy of Technology and Engineering Sciences* (Meijers 2009) which, in its fourth section, attempts to elucidate the different sides of models in engineering sciences. Reviewing these texts while simultaneously tracking their included citations in each step, and consequently continuing the same process with the new texts in the next stages, led in total to a considerable collection of pertinent points and discussions shown later on. A notable advantage of taking this overview approach to the literature was gaining a compelling understanding of specific debates and reflections on 'models' within a community of related scholars, in an

[6] This approach to taking advantage of philosophical reflections for developing a conceptual basis for technology education is not that novel, and has been aptly proposed earlier by scholars such as De Vries (2005), and Compton (2007, 2011).

efficient manner[7] (Lecy and Beatty 2012). The result of examining the gathered articles was a set of many interesting ideas and points about models, raised from various angles and points of view. The upcoming argumentations and discussions of the chapter thus have much to do with, and actually have roots in, these ideas and points, and it is worth having a compact overview of them in this step:

1. *Fundamentals of models* This subsection begins by referring to Müller's (2009) chronological study in which he attempts to present a lexicographical reflection of the notion of 'model' and its various origins and evolutions in the course of history. Although his reflection has not been confined to 'technological' models, and sometimes embraces other disciplines such as 'psychology', 'science' (in general), and 'philosophy', it provides a well-ordered resource for those interested in having an image of the background of today's so-called models made use of in engineering enterprises.

   However, moving one step further in this line, and exploring the basic conceptual reflections on the nature of models, one may point to 'representation' as their first and the most common and fundamental role, specifically in the philosophy of science or technology. Models have been considered in this type of account, in one way or another, "as such they give us knowledge because they represent their supposed external target objects more or less accurately, in relevant aspects" (Boon and Knuuttila 2009, p. 696). These "external target objects" can be described in various terms by scholars as "parts of the world, or … the world as we describe it" (Hughes 1997, p. S325), "objects or systems in the world" (Morrison 1999, p. 38), "some aspect of the world, or some aspect of our theories about the world, or both at once" (Morrison and Morgan 1999, p. 11), "physical systems, processes, phenomena, or situations" (Nersessian 2002), "some aspects of

[7] Lecy and Beatty (2012) put forward that this way of snowball sampling—combined with the citation network analysis—is an effective way to avoid facing the onerousness of exponential rate of sampling growth (p. 1).

some real systems or their functioning" (Knuuttila and Voutilainen 2003, p. 1494), "observable phenomena or … the underlying structure of the real target system" (Knuuttila 2005, p. 42), "a real world system" (Godfrey-Smith 2006, p. 733), "real world phenomena" (Weisberg 2007, p. 207), "objects … [or] events of processes" (De Vries 2013, p. 124), "the design of a device or its mechanical workings … [or] the behavior of different devices or the properties of diverse materials" (Boon and Knuuttila 2009, p. 693), and so forth (e.g., French and Ladyman 1999; Suárez 1999; Da Costa and French 2000; Frigg 2002; Bailer-Jones 2003; Giere 2004).

Further, having agreed upon the representational task of models, one can also observe there has been different formulation suggested as to how such a role is played: ranging from the *semantic* conception which concentrates more on real target systems and models as the *mirrored* pictures of those systems (Giere 1988, 2004), to the pragmatic conceptions which conceive modelers, too, as active interveners—who build, interpret, and learn in modelling processes—and consider representation as a kind of rendering instead of merely *mirroring*. Furthermore, while the semantic view is restricted to focusing on, specifying and analysing the representational relationship between models and their target systems through views such as *isomorphism* (Suppes 1962, 1989; Van Fraassen 1980; French and Ladyman 1999; French 2003), the pragmatic conception has more to do with taking more profound properties of models and also modelling processes into account (Morrison 1999; Morrison and Morgan 1999; Boumans 1999; Godfrey-Smith 2006; Weisberg 2007; Knuuttila and Voutilainen 2003; Knuuttila 2004, 2005, 2011; Boon and Knuuttila 2009). For one thing, models have been considered as *autonomous agents*—partly released from only representing theories and world—mediating somewhat as independent investigation instruments in the hands of modelers (Morrison 1999; Morrison and Morgan 1999).

2. *Thingness of models* The next step in reflecting on models has begun in works such as Morrison (1999), and Morrison and Morgan (1999) in which the authors have strived to loosen the customary focus from the grip of lengthy discussions on models' representational role hovering between theories and the world. Delving more into the nature of models, these philosophers have made an effort to take the thingness of models more into account. For them, models are *autonomous agents*, that is, (partial) independent constructions which ultimately give rise to their independence in function as well; the role of humans is absolutely clear and unavoidable here. In the same vein, Nersessian (2002) too drew attention to the construction of models and spoke of the underlying iterative efforts of making these objects. Nevertheless, in our opinion, the works of Knuuttila and Voutilainen (2003), Knuuttila (2004, 2005, 2011), and Boon and Knuuttila (2009) can be regarded as a turning point in this way.

   In some senses, they initiated the noticing and emphasizing of models' *materiality*. Models, in this regard, have turned out to be considered as (certain types of) artefactual tools; purposefully and complexly constructed man-made things that incorporate various ingredients, and as a whole, are endowed with intended uses. This account, acknowledged and used throughout this study correspondingly reveals some other points as to the essence of models as well.

3. *Multi-functionality of models* Improving the typical *representationalistic*[8] approach of scholars such as Giere (1988) and Suárez (1999), Morrison and Morgan (1999) mentioned a newer account that proposes a model to be conceived of as an *instrument* which can function "as a 'representative' rather than a 'representation' of" a reality (p. 33), in a variety of ways such as:

[8] This term has been formerly used by Knuuttila (2005) to describe the views predominantly focused on the representational aspects of models and to observe every other property of them through this lens.

- to build or correct a theory, or to explore processes for which our theories do not give good accounts;
- to explore or experiment on a theory that is already in place; or
- to even investigate other models.

One can also address other fairly similar perspectives in this line such as those seen in Boumans (1999), and Justi and Gilbert (2003). However, even these approaches face serious criticisms by Knuuttila and Voutilainen (2003). They believe that Morrison and Morgan's (1999) attitude to models, though insightful, is still somehow confined to the representational function belonging to the arena of the 'theory-world' relationship. Instead they suggest a more practical approach; by putting emphasis on models' complex and *multifunctional* nature, and by drawing on *parsers*[9] as certain types of models, these philosophers pay particular attention to the models' diverse *built-in epistemic functions*, in that various types of knowledge can be derived through building, manipulating, and using them. Later, Knuuttila (2005) has expounded that models are inherently 'for' rather than 'of' something, because they are 'multifunctional things'. This account opened up, or chimed with, new ways of reflecting on various functions of models and seeing them, in some instances, as:

- "not only as tools and inference generator, but also as research objects in their own right" (Knuuttila, 2005, p. 69);
- mediators to bridge between theory and data (Knuuttila, 2005), and to learn about real-world phenomena (Weisberg, 2007); and
- a 'buffer' to enable communication and cooperative work across diverse scientists (Godfrey-Smith, 2006);

or treating them as tools:

[9] Language-technological artefacts that assign morphological and syntactic mark-up to written input texts and in this way provides a partial interpretation of the text (Knuuttila and Voutilainen 2003).

- “to understand, predict or optimize the behavior of devices or the properties of diverse materials, whether actual or possible” (Boon & Knuuttila, 2009, p. 693);
- “to represent the design of a device or its mechanical working” (Boon & Knuuttila, 2009, p. 693);
- to give a theoretical description or interpretation of the (specific) function of a device (Boon & Knuuttila, 2009);
- to serve as hubs for interlocking various concepts, methods, materials, contexts and so forth to create new knowledge and new know-how (Nersessain & Patton, 2009);
- “to explain the workings of something that already exists” as well as “[to show] how something can be built to perform a certain function” (Hodges, 2009, p. 672);
- to test the designed concepts and outcomes prior to or after release (France et al., 2010); and
- to support the development of new products or systems as well as to support communicating about them (De Vries, 2013).

4. *Quality of models* Among many discussions on diverse features of models, the question of what makes them ‘good’ has also received the attention of some scholars. There is a sort of general agreement in this regard, in that models are not really intended to be assessed in terms of concepts such as ‘accuracy’, ‘truth’, or even ‘the degree of similarity’; this holds because of reasons such as the following:

- More often than not, models bear a certain degree of deliberate *idealization*, *abstraction*, or other types of *false characterizations* (Morrison, 1999). The only perfect model in this sense is the world itself. As a matter of fact, the process of modelling welcomes many types of inaccurate, unrealistic, and even false (or wrong) models, if useful, to be accepted as (certain types of) satisfactory ones (for more detail, see also Teller, 2001; Knuuttila, 2004; Toon, 2010; Parker, 2011; Knuuttila, 2011; Rescher, 2012); models in this sense can be also seen as kinds of "caricatures" (Cartwright, 1983, p. 150).

- Models are sometimes a basically partial, and not perfect, rendering of a target system; this is very common, for instance, in Quantum physics (see Morrison & Morgan, 1999; Teller, 2001).
- Some models are not intended to describe any actual system at all; they only provide us with an understanding, for instance, of very general facts about what makes some phenomena possible or impossible, or still not possible to exist. These are particularly very customary in technological practices (Weisberg, 2007).

It is worth noting however that the subject of assessing models – in terms of their suitableness – has not been entirely ignored, and some scholars suggest their own criteria in this regard. For instance, Parker (2011) puts forward the 'adequacy-for-purpose' as the target of model evaluation; Knuuttila (2011) prefers to speak about 'success', which may be for its part defined in terms of success in reliability, empirical adequacy, explanatory power, truth, or so on; and finally De Vries (2013) talks of 'effectiveness' to describe useful models.

5. *Other characteristics of models* Exploring the literature, one may find some other related points about models. These points reflect, for instance:

- several types of models, in terms of their physical or structural properties as well as their appearance (e.g., Vincenti, 1993; Morrison & Morgan, 1999; Justi & Gilbert, 2003, Knuuttila, 2004; Hodges, 2009), or regarding various types of knowledge behind their development processes (Vincenti, 1993; Knuuttila, 2004);
- different possible states of models in the relation between theory and data or the world (Morrison & Morgan, 1999; Suárez, 1999);

- justification and/or discovery in constructing models (Boumans, 1999); and
- possible constraints of modelling practice, such as 'time' and 'money' (De Vries, 2013), 'spatial', 'temporal', 'topological', or 'material' limits (Nersessian & Patton, 2009), as well as those constraints drawn from both the 'target' and 'source' domains (Nersessian, 2002).

That said, it is now time to demonstrate how the abovementioned complex and extensive reflections and opinions can be turned into a simplified, comprehensive account for our educational purpose. Such an initiation will be underpinned in the first place by concluding that models can be considered as (techno-scientific) artefacts; afterwards, taking the advantage of philosophical discussions on different features of artefacts, the various aspects of models will be examined.

4.5. Models as (Techno-Scientific) Artefacts

The argumentation can be developed based upon a simple and fairly intuitive fact, that is, models are artefacts; because they are by definition *manmade things*. Actually, this fact is so evident that it has been pointed out without any reasoning in the literature of philosophy of science and technology (e.g., Knuuttila & Voutilainen, 2003; Nersessian & Patton, 2009).

Nevertheless, this study intends to go one step further too and speak of models specifically as 'techno-scientific artefacts'. To this end, it once again benefits from the philosophy of technology in which Vermaas et al. (2011) differentiate *artificial* facts – technical artefacts – from the other two existing types (i.e., *natural* and *social* objects), as follows:

- What distinguishes technical artefacts from natural objects is that the former results from purposive human actions while the latter does not; and
- technical artefacts are of another property as well that discriminates them from social objects; they fulfil their function through their physical

characteristics while the same cannot be said of social objects, such as bank notes, passports, driving licenses, and the like. The latter serve their function not on the basis of their physical properties; rather, "on the grounds of collective acceptance [of certain people]", in such a way that "[a]s soon as such collective acceptance disappears, [they are] no longer able to fulfil [such] function".

(See Vermaas et al., 2011, pp. 7-13).

Models, therefore, can be considered as technical artefacts: intentionally constructed objects that realize their function through their physical features and capabilities (Weisberg, 2007; Knuuttila, 2004; 2005). However, there is still a reason that raises some doubts: models have many scientific functions in addition to technical ones, particularly in some engineering sciences that do not necessarily find a way to application (Boon & Knuuttila, 2009). Therefore, models can be realized as 'techno-scientific artefacts', and consequently their further properties can be realized through this perspective.

Moving this argument forward, the artefactual approach yields an immediate result as to models: these engineering tools have a 'dual-nature reality', just as any other type of artefact. This approach will help us later on to come up with a well-ordered framework describing models' various properties. However, it is useful to first take a look at the primary aspects of the so-called dual nature theory.

Regarding the nature of technical artefacts, the dual-nature theory was first introduced by Kroes and Meijers (2006) to deliver a more comprehensive account of these types of objects. This perspective ascertains two interrelated aspects for technical artefacts:

1. The *physical* aspect, which deals with the material dimensions of artefacts, including its constitutive elements, and construction features.
2. The *intentional* aspect, which takes the goals behind artefacts' existence into contemplation. Subsequently, the notion of *function* could be analyzed from

this point of view, and regarded as what bridges this aspect of an artefact to its physical properties (for more detail, see also Verbeek & Vermaas, 2012; Vermaas et al., 2011; and Vaesen, 2011).

Bearing these aspects in mind, it is worth referring again to some interesting clues in the literature, which support the 'dual nature' account of models more. For instance:

- In Morrison and Morgan's (1999) account, 'construction' and 'function' are two (of four) basic elements of models;
- Knuuttila and Voutilainen (2003) describe models as 'materialized' things that have their own certain 'intentional construction' and their own 'functioning' in a multitude of ways in scientific activities;
- The most interesting properties of models are, in Knuuttila's (2004) view, due to the way in which 'intentionally' and 'materiality' intersect in their diverse uses. She also stresses the 'variously-materialized' beings of models; and
- The 'purposefully-designed' aspect of models has been considered by Boon and Knuuttila (2009).

Thus, turning to the discussion line, the dual nature of models can be investigated more, benefiting from the literature. However, in order to avoid any complexity by talking of the 'physical' nature of models (for example, when speaking of software simulated models or the like), this has been replaced by the 'intrinsic' nature; this seems to fit the structural side of models better, without averting us from the main goal of the chapter (i.e., to describe the essence of models and various properties thereof). Thus, the next steps will respectively be devoted to excavating both the 'intrinsic' and 'intentional' natures of models, and after that their interrelationship will be analyzed.

4.6. The Intrinsic Nature of Models

As far as related to this nature, students can understand a number of features of models through dealing with some questions like:

- What are models made of?
- How can they be described in terms of size, weight, color, shape, materials, etc.?
- What components do they consist of? What connects these components together?
- What types of models are there?

Although not all such questions are meant to be addressed here, it is important to call the attention of teachers to the main points needed to be taken into account in this regard, that is, taking up the 'material' *structure* of models, and their various *types* (or *forms*).

1. *The 'material' structure of models* Before anything else, models have their own 'material' structure (i.e., they need inherently to be manifested through specific, variously materialized forms, sizes, colors, etc.). By using 'materialized' the intention in the literature is mostly to stress the specific human intention behind their formation (Morrison & Morgan, 1999; Knuuttila, 2005). However, what matters here is that models are constructed of single or complex combinations of different materials such as diverse types of wood, paper, metal, chemical, or other natural or artefactual objects; even mathematical models and computer simulations, in this respect, have their own materiality as well (Knuuttila & Voutilainen, 2003; Vallverdúl, 2014). Obviously, this chapter does not aim to characterize different sorts of materiality; rather, it emphasizes the significance of models' material structure as what foremost enables the world to be inspected through them. Students, in this sense, should understand why a model has taken a specific material structure, and as a technical artefact, what the characteristics

(including the shape, weight, size, color, and the like), positions and the interrelations of its different parts are. To do so, they are supposed to be able to manipulate (at least) some models and conceive the various constituents, logics, and relations that appear in the course of this manipulation, made feasible first and foremost by materiality.

2. *Different types (forms) of models* A noteworthy advantage of distinguishing the two natures of models is its application in studying different types of models in a less complex manner. This is because one might face many types of categorization in the literature based upon various criteria, such as models' diverse functions. However, these tools are regarded here only from the *intrinsic* nature point of view; the rest will be inspected through subsequent subsections of the *intentional* nature.

   One way of teaching about various types of models in this respect, as stated by De Vries (2013), is making students more familiar with different suggested typologies of these tools. For instance, Bertels and Nauta (1974) distinguish three types of *Concrete*, *Conceptual*, and *Formal* models: *Concrete* models in this account consist of materials (e.g., replicas and mock-ups); the *conceptual* ones consist of concepts (e.g., flowchart models used in design processes); and the *formal* models entail symbols (e.g., mathematical formula and computer software models such as CAD).

   There is also another option through which students get acquainted with various types of models; they can learn about many tools or representational methods used as models – such as *geometrical figures*, *diagrams*, *sketches*, *maps*, *physical objects*, *computer programs*, *number sequences*, *graphs*, *oral descriptions*, *written descriptions*, *mathematical structures*, *scale models*, etc. (see Vincenti, 1993; Morrison & Morgan, 1999; De Vries, 2013).

4.7. The Intentional Nature of Models

This section begins with a brief, but essential, discussion on the representational task of models (as alluded to earlier on), and, in line with scholars such as Morrison and Morgan (1999), and Knuuttila and Voutilainen (2003), argues and emphasizes first and foremost that confining the nature of models to only 'representational tasks' places excessive limitation on our artefactual approach to them: 'representation', though thought of as "one of the uses models are put to" (Knuuttila, 2004, p. 7), should not be entirely considered as the final intention behind modelling, at least in engineering enterprise. That is to say, engineers tend to use models to represent something, not for the sake of representing in itself but in order to attain further purposes. Hence, our dual-nature account favors the (pragmatic) multifunctional reflections on models; the reflections which regard models' representational task only as an artefact-using activity – among others – in the way of pursuing further goals (Knuuttila, 2004; 2005).

Nevertheless, a significant lack still remains in regard to these pragmatic reflections: they do not deliver a comprehensive detailed account of the 'further purposes' of modelling. For one thing, while some like Boon and Knuuttila (2009) concentrate predominantly on certain epistemic goals of models, some others such as France et al. (2010) are satisfied only with describing a number of managerial aims behind them; one could also place Vincenti's (1993) exemplars somewhere between these two approaches. Thus, the main question here is how to describe various intentions of modelling enterprises and to sort them out under an all-inclusive teachable account.

The attempt to address such a critical question here begins from the specific point of admitting the epistemic nature (of the function) of models, because in any case, as seen and deliberated on shortly, they are used ultimately to render a certain knowledge, though in diverse ways (Knuuttila, 2004). However, such an 'epistemic' function needs to be more clarified for its part. Therefore, one step is taken here by using the artefactual account of models and characterizing them specifically as 'techno-scientific artefacts'. However, this account can be further enriched by referring to the statements that concentrate on both 'scientific' and 'technological' intentions of using models and trying to expound their differences. The first belongs to Boon and Knuuttila (2009), in which they remark that:

> *The models developed in the engineering sciences should be distinguished from the models produced in engineering [in technological practice]. Whereas the latter usually represent the design of a device or its mechanical workings, models in the engineering sciences aim for scientific understanding of the behavior of different devices or the properties of diverse materials* (p. 693).

Such a claim can also be accompanied by later studies of others, such as the very interesting work of France et al. (2010). It narrates a fascinating story of how two biotechnologists used models – one as a technologist and the other as a scientist – and indicates that:

> *In technology models are a means to an end - that is used to test design ideas and outcomes to provide robust evidence to support defensible decision-making so that the outcome is fit for purpose ... [but, in] science a robust model enables one to predict and account for properties that had not been expected* (p. 390).

Therefore, all this brings us to a new point relating to models, which is that, in general, their intentional nature can be realized as *epistemic techno-scientific*.

Nevertheless, as the next step, this 'epistemic techno-scientific' nature still demands to be learned in a more specific manner, which is now not difficult to get to. Therefore, through improving De Vries's (2013) listing, two main types of epistemic intentions of making or using models are ascertained here: *supporting the development of*, and/or *communicating about knowledge and artefacts*, elaborated as follows:

1. *Support the development of knowledge and artefacts*[10] This constitutes the primary task of models' epistemicity. This is because they are fundamentally used to enhance their users' or builders' learning and embrace a wide range, from pure scientific understanding of diverse phenomena as well as developing relevant theories, to acquiring practical knowledge of how to design, build or optimize certain artefacts (Boon & Knuuttila, 2009). Such intentions can be realized through (at least) two ways or a combination of them:

   (a) *Straight Use* The tool-like characteristics of models enables them to be used in different fields of study such as (a) exploring or illuminating hypotheses, (b) reconnoitering, constructing, applying, as well as revising theories, and (c) gaining new understanding through various types of investigating the world or surveying and solving existing problems, etc. There are numerous examples indicating this aspect of models' epistemicity; for instance, one can regard how using a plane pendulum model can lead to measuring local gravitational acceleration more accurately (see for more detail Morrison & Morgan, 1999), how several ready-made sketches of different parts of an airplane can be employed in the course of the designing processes of aircraft (see for more detail Vincenti, 1993), or how designers make use of system representation models to determine the proper structure of subsystems through mental exploring (De Vries, 2013).

   (b) *Build and Manipulate* Beside directly using (ready-made) models, also the building and manipulating of them can in themselves render a valuable (source of) knowledge. Boon and Knuuttila (2009) make some

[10] This was stated in De Vries's (2013) account as 'support development of theories and artefact'. However, in our opinion, this does not deliver a sufficient description of this facet of models' epistemic functions. This is because there are times that models help us to gain certain knowledge not necessarily referred to as a type of theory; for example, when we tend to use models to understand the behaviour of specific material in chemistry research, we seek to develop our knowledge not necessarily leading to a theory.

good emphatic points in this respect explaining how interacting with models can provide particularly new know-how knowledge of scientific reasoning, artefact designing, and even of the models themselves. Also, Vincenti (1993, pp. 44-50) takes two significant epistemic roles of modelling into account, namely, helping designers to find out how to "increase the performance" and "decrease the uncertainty" of their products. It is also worthwhile, in this regard, to point to the case of intermittent designing, building, and manipulating various models of airplane wings and propellers to be tested in wind tunnels (Vincenti, 1993). In addition one can consider the exemplars of Nersessian and Patton's (2009) study, namely, *designing off-the-shelf vascular tissue replacements for the cardiovascular system and understanding the ways neurons learn in the brain*; where engineers engage with a multidisciplinary work of designing, constructing, manipulating, and modifying physical simulation models in the context of biomedical engineering, in order to reason about, make hypotheses on, and achieve an understanding of real biological phenomena.

2. *Communicate about knowledge and artefacts*[11] Models have another epistemic function, that is, for communicating with people including other engineers, teams, decision makers, students, customers, and so forth. In De Vries's (2013) account this can happen for at least two reasons:

   (a) *Educational* Models can be and are already extensively used for educating goals. Take for instance DNA or skull models employed in teaching biology, or molecule models made use of in teaching chemistry.

   (b) *Procedural* For this, De Vries (2013) draws on the common CAD models of houses that can be used by architects to communicate with customers

[11] This was stated by De Vries (2013) as 'communicate about theories and artefacts'. However due to the same reason in footnote 10, we replaced it with 'communicate about knowledge and artefacts'.

about their final products, or to illustrate their qualities in designing houses.

Nevertheless, this account is recommended to be improved by adding a third communicational intention for models, as follows:

(c) *Decisional* Models are also widely used to help in taking wiser decisions – particularly those of *managerial* types. One may point in this regard to the risk-mitigating role of models, both before and after releasing a technological outcome, which has been considered earlier on respectively in terms of *functional modelling* and *prototyping* (in NZC), and also explained by France et al. (2010) as follows:

> *Functional modelling provides an opportunity to test all aspects of design concepts prior to the realization of the technological outcome and is used to enhance risk mitigation by providing the means to minimize the unknown or unintended consequences of possible technological outcomes. Functional modelling allows for the exploration and evaluation of the design concept in order to make justifiable decisions regarding its future development … [whereas] … Prototype modelling allows for the testing of an outcome's fitness for purpose after it has been realized but prior to its implementation, and provides evidence for its acceptance, or the need for further development.* (pp. 383-384)

France et al. have also devoted an interesting part of their article to a very insightful case study of 'decisional' application of both functional models and prototypes in producing and releasing a special type of vaccine.

4.8. On the Relationship Between the Intrinsic and the Intentional Natures of Models

Turning back to the subject of artefacts in general, it is discussed in the literature that talking about 'physical' and 'intentional' natures in a separate manner does not suffice to deliver a comprehensive knowledge of them; there are still certain essential points that can be accounted for only through considering the 'relationship' between these two natures, and form a third type of artefact-related technological knowledge (for more detail see De Vries, 2003; De Vries & Meijers, 2013). Therefore, such a fact can be claimed to hold for models as well. However, this fact has been barely touched upon in the related literature; most has focused merely on the points that, as seen before, could be categorized under one of the two natures. Hence, this section has been devoted to connecting models' *intrinsic* and *intentional* natures, through referring to a clarifying point by De Vries and Meijers (2013), worthy of being extended to models as well. While reflecting on certain characteristics of the relationship between 'physical' and 'intentional' ("functional" in their terms) natures, they distinguish *users'* knowledge of artefacts in this sense from *designers'*, thus:

> *The users' version of this type of knowledge is of the following kind: S knows that [artefact] A's physical property p (or a combination of properties pi) makes it suitable for carrying out with A the action ACT … [while] … The designers' version of this type of knowledge is different: in order to let action ACT with A …, A should have physical property p (or a combination of physical properties pi). These two versions differ considerably. The user starts with the physical nature of the artefact at hand and from that seeks possible functions. The designer starts with desired functions and from that she/he seeks a suitable physical nature (properties).* (De Vries & Meijers, 2013, pp. 62-63)

Bearing this in mind, one can accordingly suggest these two views to be taken into account about models; in other words, students are supposed to learn both of these two ways of inspecting the relation between the intrinsic and the intentional natures of models, as follows:

1. *Users' view* This belongs to understanding how a specific property of the model at hand makes it suitable for serving certain action(s). This understanding can happen in diverse ways such as direct learning about, pondering on, or trying out ready-made models. For instance, students can be given a 3D simulation of a car, and be asked to explore how, and for which intention, or which section of a car-making factory, that model could be made use of.

2. *Designers' view* Here designers learn how to make useful models to realize their intended functions. To achieve such learning, students can be faced with various pre-defined functions regarding a model, and be asked to make their own, what they consider to be, relevant models. One may point in this regard to the example of asking them to think of, construct, and/or discuss their graphical simulations of a comfortable driver or baby car seat.

Be that as it may, there still exist some significant points to be deliberated on as to each or both users' and designers' views in this perspective. Chief among them could be considered thus:

1. *The matter of the specific design of models* This subject may be realized as the first and fundamental aspect which underpins the relation between the intrinsic and the intentional natures of models; this can be inspected from both the users' and designers' points of view. The first of these viewpoints touches on learning about the fact that each model's specific design enables it to serve certain intended goal(s). On the other hand, by taking the second standpoint, students understand about designers' concerns, that the model ought to have a specific design in order to satisfy certain purpose(s). In

addition, it is also supposed to be learned that it is the specific design of models which enables them to take their certain representational forms: a structural, functional, and/or behavioral analogy of physical objects, entities, processes used in experimental situations, and so forth (Nersessian & Patton, 2009).

2. *The matter of simplification in models* Simplification is an unavoidable step in the process of reaching to a model's specific design; it is tied to models' essence, that is to say, without making certain *simplifications* a model will not be a model, but an exact replication of the intended reality. Thus, students are recommended to properly understand and explore how simplifications can happen and appear in the specific design of a model, and relate it to a certain intention. *Abstraction* and *idealization* are, in De Vries's (2013, p. 123) opinion, the two particular methods in simplification:

> *[A]bstraction means that we leave out aspects of reality. We may, for instance, leave out air friction to produce a model for free fall motion. Idealization means that we make small changes to simplify the representation of reality. We may, for instance, replace a wobbly curve of measured values into a smooth one that fits a simple mathematical formula.*

Needless to say, abstraction and idealization defined in this way can take various forms and properties, which though beyond of the scope of this study, are strongly suggested to be reflected upon in later studies, and well thought-out when teaching in practice.

3. *The matter of iterativity in modelling* The next significant fact to be properly conceived – particularly when seen from a designers' perspective - is that what appears as the specific design of a model's structure has often not been brought about at once or in a linear and straightforward manner. Rather, it is mostly the result of certain iterative constructing and challenging efforts. That

is to say, a narrative of a continuous reasoning back and forward between (mental) theories, the intended functions and expectations, and the real phenomena, as well as an unceasing analyzing and assessing (trial & error), is frequently hidden behind connecting the final design of the model at hand to its intended function (Vincenti, 1993; Nersessian, 2002; Nersessian & Patton, 2009).

4. *The matter of adequacy of models* Approaching models as artefacts unavoidably makes them subjected to 'appropriateness' concerns from both the users' and designers' points of view. This is because, as discussed, models in technology are basically a particular means to an end (see how De Vries [2007] speaks of the means-ends reflection, and relates it to the knowledge of the relation between physical and functional nature of artefacts, in his terms), and then there are high expectations that they will suitably satisfy their intended purpose. Therefore, as mentioned by some authors such as Wimsatt (2006), France et al. (2010), and De Vries (2013), the evaluation of models in technology has, and should have, more to do with the matter of 'effectiveness' – i.e. the extent to which they can properly lead to defined ends – than those of 'truth', 'accuracy', or 'fitness'. This becomes even clearer when noticing that, because of using implicit or explicit simplifications, models typically ignore a number of variables, and simplify some interactions among them; that is to say, models are purposefully the source of bias, or full of inaccuracy in themselves. One can refer in this regard to the simulations used to learn certain medical treatments; the quality in these models in fact has to do with representing some essential elements and leaving out the others, using a suitable method (see Suárez, 2003; Frigg, 2006; Wimsatt, 2006; Contessa, 2007; Boon & Knuuttila, 2009).

This latter point also brings us to another noteworthy conclusion that "the adequacy of models is [consequently] highly context-dependent, and that their adequacy for some purposes does not guarantee the adequacy in general" (Wimsatt, 2006, p. 5). For instance, think of a basic conceptual model of a pilot cabin: it may be helpful for designing an airplane's body structure, while it may not be valuable at all when designing the very cabin which needs to consider more things in detail.

There is another relevant fact worth being reflected on here, that is, as argued by Boumans (1999), "the model-building process is the integration of several ingredients in such a way that the result – the model – meets certain a priori criteria of quality" (p. 91). In other words, models are typically developed through step-by-step building, manipulating, trial-and-error, and revaluating, in order to deliver a richer and more advanced content (Boumans, 1999; Boon & Knuuttila, 2009), and therefore this makes them "not justified merely by what they produce; rather, part of their justification is 'built-in' or internal to them" (Knuuttila & Voutilainen, 2003, p. 1488), and occurs in the course of the designing process.

5. *The matter of knowledge behind models* Each model, in itself, bears (from a user's view) or should bear (from a designer's view) a certain knowledge used to make it suitable for intended action(s). This knowledge must not be confined only to *theoretical* rationale (such as those which belong to mathematics, physics, chemistry, engineering sciences, etc.), because models do not entirely stem from theories (Morrison & Morgan, 1999); in addition, they comprise *experiential* knowledge as well (Boon & Knuuttila, 2009).

   The experiential knowledge here, as indicated by the title, can be conceived of as directly linked to the past experiences of the modelers; it derives through, and sometimes only through, modelling more and more, and certainly, the above-mentioned *iterative* efforts play a paramount role here. In other words, getting involved with the practice of modelling enhances the level of skills – i.e., the level of the 'know-how' knowledge, in addition to the 'know-that' one. This fact has been soundly narrated across different stories throughout the highly recommended book of *What engineers know and how* *they know it* (Vincenti, 1993), where the author draws on the significant role of iterative designing and trial-and-error in acquiring the know-how knowledge to be used for further designs. Though not focused on the concept of modelling, Vincenti's concentration on different instances of design and test of, for instance, wings, air-propellers, and flush-rivets in the aeronautical industry, exhibits the role of iterative modelling in the way of getting to the optimal level of experiential knowledge to model and design.

The subject of 'experiential knowledge' has another facet: it may lead to provided sheets, standards, models, and other applicable documents which could be made use of and referred to later on by other designers to develop their intended models. The aforementioned book affords some sample models in this regard as well; for example, the models of "NACA four-digit airfoil family from early 1930s" (p. 38), "Line drawings of airplanes tested from 1933 to 1941" (p. 90), and "[M]odel propellers used in the initial set of tests" (p. 149). The main feature of these sample models is, as emphasized earlier, that they have resulted from extensive trial-and-error tests in different situations, specifically in wind tunnels, not just from direct theoretical background.

All that said, the knowledge of modelling can be viewed from another angle as well, where the level of 'knowledge specificity' matters. In this sense, students should be aware that designing a suitable model to meet certain functions mostly necessitates, as put forward by Nersessian (2002, p. 151), both "highly specific domain knowledge" and "knowledge of abstract general principles". To explain a little more, as in the airplane case, one can observe that the certain design of wings or propellers are grounded in the modelers' both 'general knowledge', such as that of mathematics, physics, etc., and the 'knowledge specific to the intended domain of practice', such as the scientific details in designing wings or propellers.

4.9. Concluding Remarks, and Recommendations for Future Research

Considering models as techno-scientific artefacts contributes highly to improving the technological literacy of students who are expected to learn how to design, make, or deal with models. This perspective on models, supported by philosophical reflections, (a) yields a concrete rationale explaining the nature of models in an acceptable and reliable manner, and thereupon (b) proposes a well-structured reference enabling teachers to speak of various aspects and properties of models through a methodically-categorized approach.

Figure 2 provides a referable summary of such an approach starting with ascertaining two natures for models: the 'intrinsic' and the 'intentional'. Seeing from the 'intrinsic-nature' angle, students can become acquainted with the material structure of models as well as the various types of their appearance. On the other hand, the 'intentional nature' tells them that models are epistemic tools made use of, in different ways, to either support development of or communicate about knowledge and artefacts. Further, according to the 'dual-nature' perspective, having to do with the relationship between the two natures, students can acquire a number of useful insights as to some additional properties of models, such as their 'specific design' and 'adequacy matters', as well as 'the knowledge behind' making them.

That said, it is useful now to provide a starting point for future research as well by offering a suggestion as to how this framework can be used critically to analyze the approach of the two cases drawn upon at the outset of the chapter. One can see, for instance, that STL scarcely delivers any ideas about the nature of models, and it seems that has mostly focused on either the 'communicational' or 'development support' functions of models while neglecting many other aspects. The case of the NZC does not give a notable clue delineating the essence of models, either, and seems to be mainly confined to speaking of 'functional models' and 'prototypes';

both can be assigned to the 'decisional' space of the 'communicational' function of models.

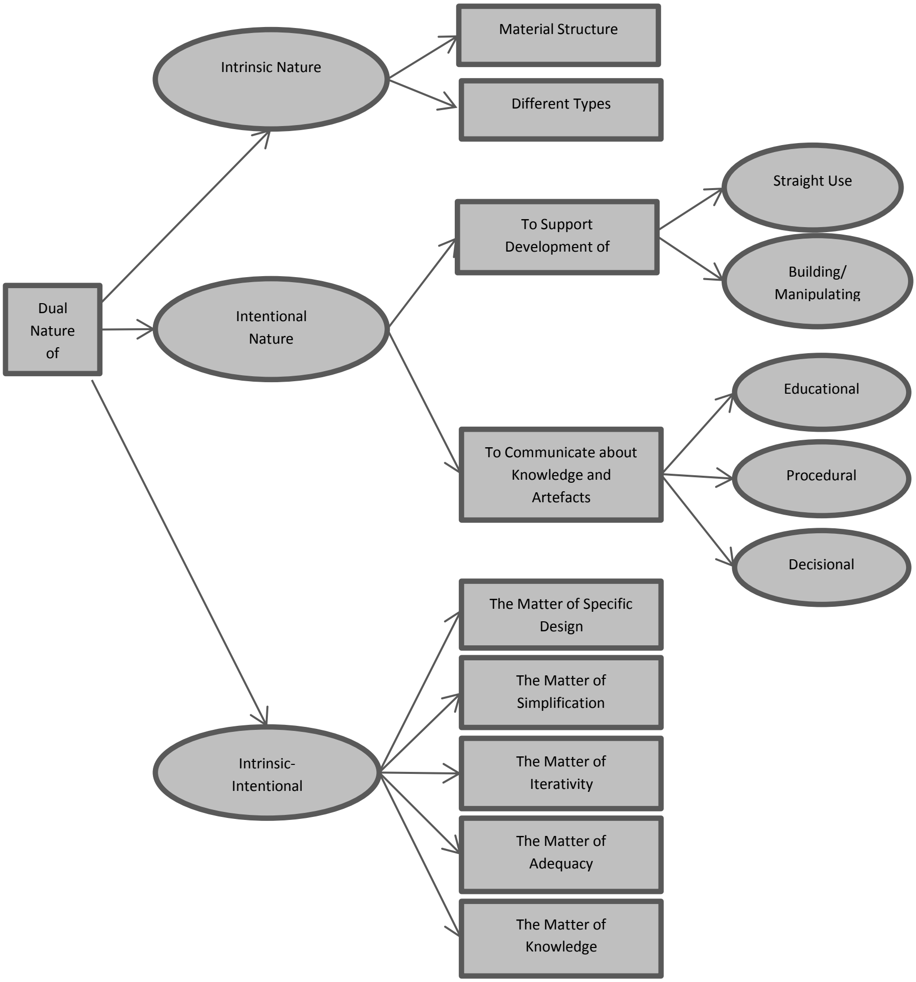

Fig. 2 Dual nature of models in a brief sketch

These are only some preliminary analyses as to the state of affairs of models in the intended cases, emphatically proposed to be tested and inspected in more detail in further research. Furthermore, the suggested approach of the current study can be applied in the same way to other long-term policy documents, such as those of Australia, England, and South Africa, in order to deliver a sound picture of their approach to models, and to provide the necessary rectifications in this regard.

Ultimately, the dual nature account of models – as deliberated on in this chapter – is not at all claimed to be a perfect reflection; there may definitely still be some points of improvement which would help to make this approach more effective. Therefore, we highly recommend that it be critically reflected upon, in the course of the above-mentioned feature research, to be enriched further so that it can provide more insightful contributions to learning about models.

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Chapter. 5

TECHNOLOGY DEVELOPMENT AS A NORMATIVE PRACTICE

a meaning-based approach to learning about values of engineering

DAMMING AS A CASE STUDY

RE-SUBMITTED PAPER :
Journal of Science and Engineering Ethics

	PRIMARY/SECONDARY SCHOOL STUDENTS	TERTIARY SCHOOL STUDENTS
OVERALL CONTENT	CHAPTERS 2&3	CHAPTER 6
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TECHNOLOGY DEVELOPMENT AS A NORMATIVE PRACTICE:

A MEANING-BASED APPROACH TO LEARNING ABOUT VALUES IN ENGINEERING; DAMMING AS A CASE STUDY

Foreword:

Normativity was discussed (in the course of Chapters 2 and 3) as being a significant concept for understanding the nature of engineering activities. Belonging to the *volitional* side of technology (as argued in Chapter 2), this concept has directly to do with ethics and technology. Nevertheless, this concept is not yet well developed within the literature of engineering education. The current training of future engineers, particularly at the tertiary level of their education, is confined to certain basic points and ideas regarding ethics, and even these have been the focus of many critiques and controversies in the area of philosophy of technology/engineering. Specifically, a considerable portion of these ideas and points is believed to be too abstract to be useful in the actual practice of engineering. Therefore, in line with the argumentation of the thesis, the current chapter attempts to provide a well-supported argument for education about ethics (and morality) in relation to the practice of technology development, the main activity of engineers. Technology development, in this perspective, has inherent normative rules that need to be understood and considered if one is to be a competent, practicing engineer.

5.1. Introduction

The practice of engineering has always been a source of ethical concerns. As a multidimensional practice involving technology development, it has complex interrelations with many other activities, and ethical considerations of its potential impact have been approached from various perspectives. Nevertheless, the literature of the philosophy of engineering/technology has included much debate over the establishment of concrete rationale(s) or framework(s) that could comprehensively describe 'engineering values' (see, e.g., Clift, 2011; Didier, 2009; Doorn & Fahlquist, 2010; Dupuy, 2009; Keulartz, 2009; Kroes et al., 2009; Mitcham & Briggle, 2009; Mitcham & Waelbers, 2009; Pitt, 2011; van de Poel, 2009; van de Poel & Verbeek, 2006; Stirling, 2011; Swierstra & Jelsma, 2006; and Waelbers, 2009). Such attempts become even more controversial when faced with differing perceptions of the complicated, multifaceted nature of engineering practice (Clift, 2011; Didier, 2009; Doorn & Fahlquist, 2010; Keulartz, 2009; Kroes et al., 2009; van de Poel, 2009; Waelbers, 2009), so that the idea of organizing an optimized, overarching view of the values entailed in technology development processes seems idealistic, inaccessible, and perhaps nothing more than a blind alley, in the opinion of some scholars (see, e.g., Didier, 2009; Keulartz, 2009; Kroes et al., 2009; Pitt, 2011; Simon, 1973, 1976, & 1996; and van de Poel, 2009). In view of that, the main question to be dealt with in this study is how to tackle such difficulties and contribute to organizing those values in an overarching view, based on a concrete, practical foundation.

We would like to embark on the discussion by stating that the field of 'engineering ethics' is, in fact, not old; it can be traced back to the 1970s (Doorn & Fahlquist, 2010). However, this area, typically perceived as a field of *applied ethics*, has undergone various critiques and modifications, in the sense of being tailored to actual practices (see, e.g., Clift, 2011; Doorn & Fahlquist, 2010; Lynch & Kline, 2000; Mitcham & Briggle, 2009; Mitcham & Waelbers, 2009; Peterson, 2009; van de Poel, 2009; Stirling, 2011; Swierstra & Jelsma, 2006). That said, one of the most common and earliest concerns as to the applicability of this applied ethics is related to its traditional focus on matters such as 'individual responsibilities in technological failures or disasters', 'blameworthiness orientation', and 'so-called whistle-blowing policies' (Didier, 2009; Doorn & Fahlquist, 2010; Durbin, 2008; Lynch & Kline, 2000; Pritchard, 2001; Pritchard & Holtzapple, 1997; Swierstra & Jelsma, 2006; Vanderburg, 2000). That is to say, this traditional approach concentrates mostly on 'wrongdoings' and less on 'the positive standards' that responsible engineers ought to follow; furthermore, it ignores the matter of 'collective responsibility' of various actors – the problem of *many hands* – in technological practices. Another drawback to the traditional approach is its lack of attention to *institutional* ethics, the fact that could lead engineers toward the 'trap of (hidden) duality' placing them against upper-level policy makers, particularly managers, whereas a main task of engineers is loyalty to the decision hierarchy of their organization (Boudon, 1979; Giddens, 1984; Swierstra & Jelsma, 2006).

The other parallel or subsequent approaches of applied ethics have also received considerable critiques by the philosophers. 'Codes of ethics', for instance, are considered to present significant difficulties in delineating the exact responsibilities of engineers in the face of real organizational issues and value conflicts (Clift, 2011; Mitcham & Briggle, 2009). Such codes, it is claimed, have their roots more in engineers' reflections on their practice than in those of the philosophers of engineering or technology (Mitcham & Briggle, 2009) and, consequently, do not have a stable base to view the state of values in different situations and explain them appropriately (Clift, 2011; Didier, 2009; Mitcham & Briggle, 2009).

In the same vein, '(instrumental) rationality', as well, is subject to significant concerns, particularly as to its limited assessment-based power in facing the multi-criteria practices of various conflicts or so-called *incommensurable* issues (Kroes et al. 2009; Simon, 1973; van de Poel, 2009). Likewise, there are other more or less similar arguments questioning the applicability of the approaches of 'statement of ethical principles for engineering', 'precautionary principle', 'efficiency', and so forth (Clift, 2011; Mitcham & Briggle, 2009; O'Neill, 2011; Stirling, 2009, & 2011; van de Poel, 2009).

That said, the current philosophical reflections on ethics of engineering/technology could scarcely address a comprehensive solution to the above problems, and the issue of reaching an overarching description, applicable in real practice, still remains. One can see, for instance, that van de Poel's (2009) respectful ideas as to the necessity of considering the matter of 'diversity' and 'genre-specificity' of ethical issues are still proposed in the line of the above-mentioned *rationalistic* approach; the worthy concept of 'value-sensitive design', proposed by van der Hoven and Manders-Hutts (2009), concentrates on a *preventive* approach tackling different values as much as possible in the design phase; Doorn and Fahlquist's (2010) innovative suggestion endeavours to enhance the state of ethical considerations through entering engineering ethicists into the research teams of technology development; Swierstra & Jelsma (2006) propose integrating engineering ethicists in the structural levels of decision making in companies; Lynch and Kline's (2000) prudent discussions lead to highlighting the necessity of incorporating ethics-oriented knowledge and skills in educational plans for engineering, etc. – however, the matter of providing a concrete rationale able to prioritize values and tackle the conflicts within actual practices of engineering is still a substantial concern.

In some recent discussions, this problem has been considered to have its roots mainly in the insufficient attention to the matter of *normativity* within a great part of customary approaches of ethical reflections on engineering and technology; the approaches, although leading to rich and cumulative insights, remain largely 'theoretical' and 'descriptive' in character and still need to be enriched more in the sense of 'practical' and 'prescriptive' orientations while, concurrently, taking the matter of *normativity* into serious account (Borgmann, 2006; van Burken & de Vries, 2012; Harandi et al., 2014; Mitcham & Waelbers, 2009; Jochemsen, 2006, 2013, & 2015). Accordingly, one can raise two relevant questions:

Given the complex and multifaceted nature of most technology development practices, how can we explore their nature and underpin a well-organized and applicable account that can prioritize different values and the raised conflicts within actual engineering practices?

And, *if such an applicable account is to be normative, what view can provide a concrete rationale for describing such normativity?*

These are the main questions this study aims to address.

This chapter is based upon a foundation of two correlative perspectives. The first is the necessity of approaching technology development practices – and their complexities – through a 'systemic view'. This will lead to the worth of underpinning a sound approach able to deliberate the nature and different aspects of such systems (Section 2). The second is the significance of sidestepping the customary view of modernity in seeing values and ethical issues as more or less *abstract, external subjective additives* to technological practices, the view predominant within various professional studies of applied ethics (Doorn and Fahlquist, 2010; Glas, 2012; Jochemsen, 2006; Pitt, 2011). This consideration suggests a normativity-based orientation which realises values as *internal objective norms* constructing the practices (Section 3). Passing through such foundational concerns, the main line of discussion of the chapter is dedicated to proposing technology development activities to be reflected upon as normative practices. Dooyeweerd's *Reformational Philosophy* will enable us to have a comprehensive view of various aspects of technology development, and suggest an overarching account to recognise and prioritize the different built-in values of such practices

(Section 4). Next, the study will concentrate on two considerable cases of 'damming': the inspiring case of Abbasi Dam, and the challenging case of Zayandeh Rood Dam. This field of engineering, as one of the most critical but controversial, multifaceted subjects of ethical concerns, will provide a rich background to illustrate the applicability of the account proposed in this study – particularly, in terms of contextual and historical views in considering value conflicts. Lastly, the chapter will end with some general concluding points as well as recommendations for further research.

5.2. Technology Development as a Systemic Multi-Aspect Practice

A foundational critique regarding most current approaches to engineering ethics is ascribed to 'black-box' thinking which barely penetrates the intricate nature of technological development practices. That is to say, the complex processes and manifold aspects and features of technological developments scarcely come into analysis in such approaches; the focus is mainly on analysing the consequences from the outside (Pitt, 2011; van de Poel & Verbeek, 2006).

In order to be able to address this concern, this study suggests that most technology development practices be understood first of all as multi-aspect systems – involving different peoples, institutions, companies, and infrastructural entities (Barkane & Ginters, 2011; Geels, 2002, 2004, 2005a, & 2005b; Geels & Kemp, 2007; Musango & Brent, 2011). Such typically 'socio-technical systems' have essential features, among which the following can be highlighted as relating to this research:

- They can have a complicated nature embracing numerous elements with an interwoven network of mutual relations, depending on various factors (Carlsson & Stankiewicz, 1991; Geels, 2002, 2004, 2005a, & 2005b; Georgieva, 2008).

- Such systems, although adapted to particular economic, political, or other social characteristics in the development phase, are of considerable potential, particularly in the case of large technological systems (LTS), to lead to a consolidation phase in society – a *momentum* (Hughes, 1969, & 1994), "difficult to change, creating an appearance of autonomy from its environment" (van der Vleuten, 2009, p. 219).
- They, in a level, construct socio-technical *regimes* comprising several *subsystems* of dynamic *actors* and *rules* (Geels, 2004, 2005a, & 2005b; Geels & Schot, 2007). The concept of *actor* in this account embraces a wide-ranging continuum of human actors and users, firms, industries, social groups, public authorities, research institutes, governmental organisations, etc., in a context of complicated interrelations and various features, perceptions, norms, and so forth. These *regimes* are consequently dominated by an extensive *subsystem* of subsequently different *rules*. These various rules do not, in fact, have an independent nature and function; they are defined and work in strict relation to each other (Geels, 2002, 2004, 2005a, & 2005b; Geels & Kemp, 2007; Rip & Kemp, 1998).

Therefore, such a wide-ranging perspective to the systemic nature of technology development practices undeniably calls for a concrete account capable of embracing the mentioned complexities of diverse aspects – including their various types of rules – in order to be able to recognise and prioritise the coexisting values of those systems.

5.3. Technology Development as a Normative Practice

The 'normative practice' view has great potential to yield a concrete account to address most of the above-mentioned concerns and deliberate and describe the complex nature of technology development practices. The root of this perspective on ethics can be traced back to the critiques on the efficiency and applicability of the customary 'predominant applied ethics' (PAE), the inspiring critiques which conform to the brief content of the introduction of this study, as well.

The predominant applied ethics, in the view of scholars such as Jochemsen (2006), suffers from considerable challenges, namely:

- Concentrating on dilemmas, instead of referring to a broader view of a good life;
- Dealing mainly with the application of ready-made theories to overcoming the raised dilemmas and crises and regulating and normalizing them, rather than tackling the probable ill-defined scientific and technological causes;
- Legitimizing the predominant developments;
- Ignoring the specific social contexts; and
- Rejecting the significance of worldviews in (ethical) debates

In quite a similar vein, Glas (2012) believes that such approaches to applied ethics – *principle-based* ethics, in his terms – in fact, "reduce moral deliberation to the application of general moral principles or rules to practical situations" (p. 4). For him, these predominant views have two crucial problematic weak-points: (1) they are too general to do justice to the particularities of intricate moral situations, particularly in highly technological contexts of practices, and, more importantly, (2) "by placing moral principles above or outside [a] practice, the impression was given that the moral dimension, instead of being a natural part of [that] practice, should be added from outside" (p. 4).

That said, the proposed 'normative practice' view benefits from a more concrete perspective in the view of the aforementioned scholars. As a *practice-based* approach (as opposed to the aforementioned *principle-based* one), this view is based upon a central tenet that,

> *ethics is not just a special kind of decision-making skill to solve ethical dilemmas the practitioner is confronted with. … Ethical issues [rather]*

> *should be placed in the context of the integral normativity of the practice as can be formulated in all the constitutive principles and rules … whose realisation requires the related virtues of the practitioner* (Jochemsen, 2006, p. 107).

The normative practice view has already been applied to some subjects of study and could deliver outstanding insights to explain the normative aspect of the intended practices and present an organized manner of understanding the nature and state of different values within them (see, e.g., Glas, 2012; Harandi et al., 2014; Hoogland & Jochemsen, 2000; Jochemsen 2006, 2013; van Burken, 2013; van Burken & de Vries, 2012). In the same vein, this view is capable of explaining the nature and different features of values in technological practices.

'Practice' in such a view implies the meaning intended by McIntyre (1981) in his development of the theory of 'social practices' as:

> *[A]ny coherent and complex form of socially established co-operative human activity through which goods internal to that form of activity are realised in the course of trying to achieve those standards of excellence which are appropriate to, and partially definitive of, that form of activity, with the result that human powers to achieve excellence, and human conceptions of the ends and goods involved, are systematically extended* (p. 175).

Through this definition, McIntyre has indeed attempted to present a meaningful, realistic description of humans' (collective) actions in which certain 'values' are being realised (Verkerk et al., 2007), avoiding the trap of the *individualistic* and *liberal* ethics customary in most current approaches to analysing the state of different values embedded in practices (van Burken & de Vries, 2012). For McIntyre, values have a meaning-based nature that relates to the 'internal goods' of practices, and, therefore, any ethical reflection on practices should be realised from the perspective of their inherent normativity, rather than being thought of as add-on components dependent on or constructed by outsider norms, rules, and obligations (van Burken & de Vries, 2012).

Two key points must be explicated at this point. First, the concept of ‘internal goods’ is different from so-called ‘goals’ typically set by and related to individual/collective actors. An internal good, in fact, is the *destination* of a practice; the *finality* which belongs to the very nature of that practice or, in other words, the core value and reason appreciated within society and for which such a practice mainly exists (Jochemsen, 2006, & 2013; polder et al., 1997, van Burken & Essen, 2010); needless to say, a finality “leaves space for a number of subjective goals which could be set within [its] specific practice” (Polder et al., 1997, p. 414). For instance, the meaning of a medical practice, as evident for society, is ‘giving care’ which resides mainly in the good caregiving itself; it is not just determined by the measurable effects of the practice on patients’ health and also not to be thought of as economic-oriented aims of the practitioners, such as profit or even earning a livelihood, although the practice may already lead to these results.

Secondly, the finality of a practice is realised well if a constellation of the ‘normative rules’ of that practice is simultaneously observed (Hoogland & Jochemsen, 2000; Jochemsen, 2015). That is to say, the competent performance of a practice is grounded in the ability to act according to the specific ‘rules’ that set up that particular practice and, at the same time, “define excellent practice and provide criteria to evaluate the activities of individual practitioners” (Jochemsen, 2006, p. 104). One should notice that the concept of ‘rules’ in this view does not refer so much to the ‘knowing that’ types of rules, which have to do with the capability of articulating the applied rules in an explicit manner. Rather, it implies primarily the implicit side, that is, the ‘knowing how’ rules. As such, these ‘rules’ have intrinsic normative natures so that they can even be followed without a permanent conscious decision of the practitioner when applied. Thus, a competent practitioner must have certain virtues in order to be able to adeptly observe the related normative rules of practice and, consequently, to effectively fulfil the practice's built-in finality. This is, indeed, the very way in which the meaning-based virtues of a practice are realised (Jochemsen, 2006, & 2015).

McIntyre's proposed account, nonetheless, is not by itself rich enough to describe the nature of such rules in more detail and to do justice to the complexity of practices. Needless to say, the values embodied in social practices are much more interwoven than explainable merely in terms of dualities such as internal/external and implicit/explicit norms (see, e.g., Verkerk et al., 2007; van Burken & Essen, 2010). As a matter of fact, as far as our intended practices – technology development practices – are concerned, there are two more significant points that must be taken into account.

Point 1. Technology development is mostly an extensive practice entailing a coherent form of sub-practices; consequently, as a whole, it has a main finality, the realisation of which is based on harmonious performance of those different sub-practices and, subsequently, their various sub-finalities. The same holds true regarding the embodied rules and virtues of the sub-practices, so that any significant tension or conflict among them (and their correspondent finalities) will not be likely to lead to a virtuous, desirable result (see, e.g., van Burken, 2013).

Point 2. The normative rules of a practice, as indicated by scholars such as Jochemsen (2006) and van Burken (2013), can be conceived as its 'rules of play' – formed based on specific normative principles, logic, and criteria. Hence, these rules are not very flexible to change or manipulation. They are typically shaped in the course of related 'socially established human activities' and can only be explained and realised from such a perspective on their particular features and co-relations. Dooyeweerd's *Reformational Philosophy* can play a critical role in recognizing and understanding the different types of such rules of play in terms of the *constitutive* and the *regulative* normative rules, as described later on.

The next subsection presents a broad explanation as these two points.

5.3.1. The Normative Structure of the 'Rules of Play'

In order to be able to recognise and analyse the normative rules of playing in a technological practice, we would like to make use of Hoogland and Jochemsen's (2000) approach, elaborated more in Jochemsen's (2006). Drawing from Dooyeweerd's ontological theory about the reality of things, their reflections propose that the essential 'rules of play' of a practice (respectively, the practices of 'medicine' and 'nursing') be defined and explained through distinguishing between a practice's *constitutive* and *regulative* sides, the approach later extended to different specific practices such as 'husbandry' (Jochemsen 2013), 'military service' (van Burken, 2013; van Burken & de Vries, 2012), and 'water management' (Harandi et al., 2014).

In Dooyeweerd's ontological account, the reality of things is subject to fifteen *spheres* (aspects) of meaning (properties) and laws. Things start to function actively from the first sphere, i.e. the *quantitative* one, and then go sequentially toward the next until it is finally qualified in a specific aspect, depending upon the nature of those things. For instance, as shown in Table 1, a rock is qualified *physically*, a tree is qualified *organically*, and an animal is qualified *psychically*. The concept of 'things' in this account also embraces all human practices; one can realise, for example, that the work of a company manager is typically qualified *economically* (see for more detail Clouser 2009). Furthermore, being qualified in each aspect means covering all previous spheres as well; for instance, the company manager's professional activities also embody the *organic*, *lingual* and *social* spheres.

The *constitutive* side of a practice is defined as the side comprising the rules that ground the structure of that practice, in terms of the rules, processes, and (inter)actions that form that practice as it is. In other words, this side has to do with the constellation of principles and norms that characterize a social structure of the practice, what it aims for, and concurrently establishes its boundaries (Glas, 2012; Hoogland & Jochemsen, 2013; van Burken, 2013; van Burken & de Vries, 2012). The constitutive aspect, actually, can be conceived of as the 'field of play' of a practice and consists of three types of normative rules:

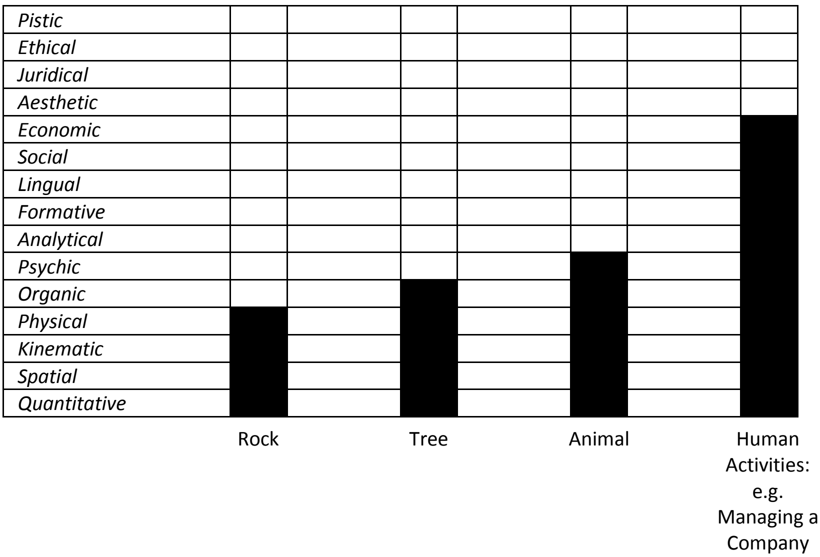
i) The *qualifying* rules which establish the finality (destination) of a practice and characterise it as it is. They are derived from the principle of the *qualifying* sphere of a specific practice.

ii) The *founding* rules related to the fundamental activities that form a specific practice in the sense of its structure and content. They pertain exactly to the *formative* sphere of that practice.

iii) The *conditioning* rules which formulate certain conditions of the context upon which a practice is performed, i.e., the rules of the *social*, *economic*, and *legal (Juridical)* spheres.

(Hoogland & Jochemsen, 2000; Jochemsen, 2006)

Table. 1 A schematic of things as qualified in Dooyeweerd's view (taken with some improvements from Clouser, 2009)



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To make this explanation clearer, it is worth drawing on Searle's (1969) chess metaphor. The main aim of playing chess is 'joy' – playing a game and having fun. Therefore, the matter of winning or losing is a secondary aim. Thus, playing chess is qualified by the 'joy' of its players, and, accordingly, its *qualifying* rules should be conceived as 'those which lead to such joy'. Regarding the *founding* rules of this case, however, they have to do with the activities of playing chess, i.e., the typical technical rules of moving the pieces. Finally, the *conditioning* rules are the rules which set the context in which the game is played, namely, the specific rules of the structure of the board.

Turning to the description line, the *constitutive* rules (along with the *formative* and *constitutive* ones) need to be complemented through an interpretive side – i.e., *regulative* side. This side, also referred to as the '*directional'* side, pertains essentially to the attitudes, motives, beliefs, and the normative convictions that construct one's worldview and shape one's interpretive meaning-giving framework (Hoogland & Jochemsen, 2000; Jochemsen, 2015; Polder et al., 1997). As a matter of fact, there is no neutral performance of a practice in this view, and the *directional* rules play essential roles in this regard. They, although not immediately apparent to us, "function strongly in the form of unwritten, sometimes even unspoken codes of conduct and customs, convictions on what is decent and indecent" (Jochemsen, 2015, p. 102).

Hence, in order to have a comprehensive image of a practice and make a concrete critique, one should take its *regulative* side, too, into explicit account; otherwise, one's image of that practice can itself be subject to divergent and relativistic analyses and interpretations, as seen in the case study section. That said, the *regulative* side of a practice has mainly to do with the topmost sphere of its reality, that is, the *pistic* aspect, and many culture-based differences in viewing, analysing, and assessing a practice can be attributed to this aspect of normativity.

Turning to the metaphor of chess, this side has to do with how one interprets the concept of 'joy' in such a game. That is to say, one may realize this 'joy' as either '(just) conquering', 'wining with a specific strategy', 'particularly-targeted practicing', or even 'simple, childish fun with one's children'.

Let us finalize this section by re-emphasizing the essential point that the competent performance of a practice requires the simultaneous realisation of all the above-mentioned normative rules.

5.4. Case Study: Damming as a Normative Practice

Damming, as an essential component of water management systems, has undoubtedly been one of the most controversial subjects of ethical concern. Rooted in ancient human history going back more than 3000 years (Gourbesville 2008), dams have been frequent centrepieces of multi-aspect systems, involving numerous aspects of both natural and socio-technical sides of ecosystems, and have led in many cases to multi-layered *seamless webs* of technological structures (as intended by Hughes, 1986), particularly in the modern era (Adger et al., 2005; Molle, 2007; Robbins, 2004; Sneddon et al., 2002; Worster, 1985).

That said, dams have been subject to different levels of achievements or failures in ethical terms (Molle, 2006; Molle & Mamanpoush, 2012); this fact makes their complex nature worth analysing in terms of their various normative features, particularly when taking into consideration the fact that most of the failures in damming have brought catastrophes on their ecosystems (Molle, 2006; Molle & Mamanpoush, 2012). Two cases have therefore been selected to be studied in this section: the Abbasi dam as an ancient but successful case of sustainable development, and the Zayandeh Rud dam as a modern but unsuccessful one. Both cases have been selected from Iran, a historically water-based civilization which has embraced many types of water infrastructures in the course of history.

5.4.1. A Brief Introduction of the Cases

The Abbasi flood-retarding dam (Fig. 1) was constructed among the mountains near Tabas city and on the Nahrain River (one of the most important water resources in that region) in the east of Iran. Most historians identify the Safavids (1501-1722) as the origin of this dam. Built in a valley, it consists of two brick arches and a body made up of stone and mortar. Resting on the mountains on both sides of the river, the lower arch width narrows to 35.2 meters in the lowest row. The distance between the top of the arch and the edge of the sharply pointed layer is 7 metres. An interesting detail of this dam is the form of the bricks' array, which is not limited to a certain width but is radially extended toward the mountains and has a very strong structure. The dam is decorated with stone engravings of antelope, which are a symbol of the 'appeal of water abundance'. Abbasi dam has attractive features for tourists and in particular attracts nature enthusiasts throughout the year. With a height of 60 metres, it is not only the oldest and the largest arch dam in the world but was also known as the tallest for 550 years. It has another distinction which no other dam can claim: the Abbasi dam's one-metre-wide crest is still the thinnest in the world (Emami et al., 2005).

To get a more detailed look at its functional features, we quote from 'Creative Harmony with Floodwaters by Value Engineering' (Emami, 2005):

> *The Abbasi flood-retarding dam is an illustrating example of water-oriented wisdom of the builders… The dam has protected the city of Tabas from floods of [the] Nahrain River for 600 years. To [avoid] construction of diversion tunnel[s], Iranian [builders] used to construct their dams on a brick arch in narrow canyons. The lower part of the dam was constructed during a dry season. This creative scheme has been used in many historical dams in Iran. At [the] Abbasi dam site, the lower part was not constructed so during floods the outflow from the dam was automatically regulated. The scheme is so elaborate that most of the engineers visiting*

the site believed that the dam was uncompleted or [that] it had suffered a wash-out because of the alluvium foundation… This is the first time that based on site visits by dam and flood experts and communications with the nearby villagers, the dam is called a flood-retarding dam. The dam site is located 100 m upstream of water springs that account for a considerable part of the base flow of the river. Consequently, it is unlikely that the main function of the dam is water storage, otherwise they should have constructed the dam downstream of the springs. A historical document indicates that the main function of the dam is controlling the floods.[12]

What qualifies this dam as an important civil technological building in the water resource management area is that, despite its great age, it is still stable and useful, and there has never been any indication that it has caused any problems, side effects, or environmentally harmful effects; it is, in fact, an exemplary case of sustainable development (Emami et al. 2005).

The next case, the Zayandeh Rud dam (Fig 2), is, however, completely different from the previous case: besides failing to accomplish its declared missions, this dam has also brought about many environmental problems. This case, indeed, has little relation to sustainable development in practice (see, Adger et al. 2005; Molle & Mamanpoush 2012; Molle & Wester 2009; Morid 2003; Murray-Rust & Droogers 2004; Wilbanks 2006).

The dam's name is taken from the river on which it is built – the Zayandeh Rud river, which means 'the procreator river' in Persian. This river, one of the largest rivers of Iran, is located in the Central Plateau of this country and, flowing from west to east, has been the lifeline of civilization in that extensive area. It irrigates

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[12] as a flood occurs, [the] reservoir fills and the discharge increases until the flood has passed and the inflow has become equal to the outflow. After this time, water is automatically withdrawn from the reservoir until the stored water is completely discharged (http://www.tabasenc.ir/abbasi-dam-creative-harmony-with-floodwaters-by-value-engineering/).

and makes possible many gardens and farms along the way; it is the main source of verdure and fertility in the large, well known, and ancient city of Isfahan and its region (Molle & Mamanpoush, 2012; Moradi, 2014; Murray-Rust & Droogers, 2004; Ranani, 2014).

Fig 1. The Abbasi dam[13]

The dam was built in the early 1970s, 110 kilometres west of Isfahan. This 2-arch dam has a 452×6-metre crest, a height of 100 metres, a maximum reservoir capacity of 1450 million m^2, and a useful reservoir capacity of 1250 million m^2. The maximum surface area of the lake behind the dam is about 54000 m^2. The dam was

[13] Retrieved from http://www.kojaro.com/2016/7/17/120574/shah-abbasi-dam/

established with the proposition of providing benefits to different water users, with the following objectives:

- To irrigate the Isfahan fields;
- To increase areas dedicated to cultivation and to provide more sources of revenue;
- To supply the water demand of some regional industries;
- To protect the city and especially its ancient bridges against the Zayandeh Rud river flooding;
- To supply electricity to Isfahan.

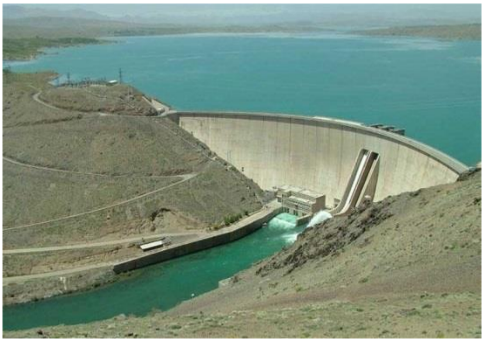

Fig. 2 The Zayandeh Rud dam[14]

That said, despite the fact that in the past one could see a large amount of water in the bed of this river entering into the Isfahan region (Fig. 3), the main bed nowadays is almost dry, and the 'procreator river' – once one of the most

[14] Retrieved from https://www.tasnimnews.com/fa/news/1395/01/26/1048789/%D8%B3%D8%B1%D8%B1%DB%8C%D8%B2-%D8%B4%D8%AF%D9%86-%D8%B3%D8%AF-%D8%B2%D8%A7%DB%8C%D9%86%D8%AF%D9%87-%D8%B1%D9%88%D8%AF-%D8%B5%D8%AD%D8%AA-%D9%86%D8%AF%D8%A7%D8%B1%D8%AF-%D8%AD%D8%AC%D9%85-%D8%A2%D8%A8-%D8%B3%D8%AF-%D9%81%D9%82%D8%B7-260-%D9%85%DB%8C%D9%84%DB%8C%D9%88%D9%86%D9%85%D8%AA%D8%B1%D9%85%DA%A9%D8%B9%D8%A8-%D8%A7%D8%B3%D8%AA

attractive and touristic settings of the region – is now suffering from various problems in its environment and the surrounding society, as elaborated later on.

Fig. 3 The Zayandeh Rud riverbed in the centre of Isfahan city is mostly dry[15]

5.4.2. Toward the Normative Practice View

Let us see how the normative practice approach can describe the selected cases and analyse different reasons for their success or failure. As seen, pondering the constitutive and regulative rules of the practice of dam construction in general will pave an appropriate path forward.

a) Qualifying constitutive rules of damming: One may, first of all, find the topic of damming rather controversial or far from accessible. That is to say, the ideas addressing the primary 'why' behind the construction of dams appear considerably divergent in real practice: some may relate it to 'increasing the economic growth of an area' (and consequently of the country) and, on the other hand, some may emphasize subjects like 'advancement of certain industry sectors' as a purpose. 'Gaining more political power or control' can also be, not surprisingly, set as the

[15] Retrieved from
http://lastsecond.ir/news/Zayandeh-Rood

main priority from the perspective of the political sector. Hence an essential question at this point is:

"What is the actual qualifying sphere of damming?"

One can draw on several definitions in this regard which extensively assert various reasons for damming. Poff and Hart (2002), for instance, begin their fascinating work *How dams vary and why it matters for the engineering science of dam removal* with the following paragraph:

> *Dams are structures designed by humans to capture water and modify the magnitude and timing of its movement downstream. The damming of streams and rivers has been integral to human population and technological innovation. Among other things, dams have reduced flood hazard and allowed humans to settle and farm productive alluvial soils on river floodplains; they have harnessed the power of moving water for commerce and industry; and they have created reservoirs to augment the supply of water during periods of drought* (p. 659).

Another statement by Farhangi (2002) articulates an eloquent definition:

> *Dams offer security against two extremes: Against a lack of water bringing drought, power failures, dried out river beds and falling groundwater levels, and against too much water, especially too much too quickly, in the form of raging floods causing devastating inundation to farmland and people's homes* (p. 47).

Some key phrases can be highlighted in such statements: 'to capture water and modify …', 'integral to human population', 'harnessing the power of water', 'allowed humans to settle', 'security against lack of water', and 'security against too much water'. These all can be said to be associated with a central concept regarding the *finality* of dam construction, that is, *welfare,* which belongs to the *juridical* aspect of Dooyeweerd's proposed spheres of temporal reality (see Basden [2011]). This being said, the normative rules of providing welfare should dominate all other objectives in this account.

b) *Founding constitutive rules of damming:* As previously discussed, this type of rule has to do with the *formative* sphere, in this case, all necessary techniques and skills of damming. Therefore, the rules essential to and used in planning, designing, constructing, assessing, maintaining, managing, and the like, whether written or unwritten, are the binding rules that can be described as the normative *founding* rules.

c) *Conditioning constitutive rules of damming:* These are the normative rules that dominate the context in which the damming practice takes place and can be of a local as well as global nature. The rules associated with matters such as environmental circumstances, official rules, governmental support, legal background, and so forth, as far as dam construction is concerned, belong to this kind of normative rule, which can be related to the *physical*, *social*, *economic*, and *juridical* aspects.

d) *Regulative rules of damming:* these rules, as discussed earlier on, are concerned with concepts such as 'attitudes', 'beliefs', and 'motives' behind the practice of damming; the rules which lead to an exclusive interpretation of the practice's *constitutive* rules, particularly concerning the *finality* – i.e., the *welfare* – of this practice. From this perspective, one can raise the following questions regarding how to view and interpret the concept of *welfare*:

- What is meant exactly by this welfare? How can different types of welfare, e.g., 'economic welfare' and 'safety welfare', be identified and distinguished from each other in this case?
- Whose welfare matters in damming? How should different people, particularly those on the upstream and downstream sides, be considered in

terms of benefit from such welfare? To what extent and according to which criteria is the welfare of some people allowed to be sacrificed for that of others?

- Is this welfare defined only in the sense of human welfare, or does it include the environment's welfare as well? To be more specific, how should the concept of 'sustainable development' be considered in this sense?

From Dooyeweerd's perspective, the *regulative* rules of damming, although having to do with the *lingual* aspect (when seen as explicit interpretations), mainly belong to the *pistic* spheres; these types of rules primarily arise from one's view of the world and the meaning of welfare in one's point of view (see, Basden [2011], and Dooyeweerd [1955]).

Now let us take a more detailed look at the intended cases in the sense of how they satisfy their inherent normative rules.

5.4.3. The Abbasi Dam and its Normative Rules

Applying the normative practice approach to the Abbasi dam yields a worthwhile insight as to why it can be considered an exemplary case of sustainable development. To begin with, it is worth taking a look at its *qualifying rule* – the *norm* of providing *welfare* – and interpret it through the *regulative* side: The main function of this dam was protecting the people against the seasonal floods of the Nahrain River, which was prone to become a terrible torrent threatening the local inhabitants' life. The dam was therefore built in such a way that it could control a natural disaster but without any serious conflict with its environment: its special shape leaves the torrents not entirely blocked, but controlled and retarded.

Furthermore, one can see that the other normative sub-practices (each with their own qualifying rules), have also been taken into account in designing and developing this dam: for instance, the role of communication and traveling through the riverbed for the people of the surrounding villages has not been affected, and the equitable distribution system of the water of Nahrain Qanat has been preserved (Emami 2005, 2014; Emami et al. 2005). These all, as discussed earlier on, pertain to *conditioning* rules that seem well considered in this case.

It is moreover worth mentioning another well-considered instance of *conditioning* rules, which has to do with the historical background of this context, that is, the role of *Mirabs* (plural of *Mirab*) in the water management system dominant in that zone. Mirabs were locally well-known and trusted people who had the responsibility of managing particular parts of a water system. Each Mirab, usually born in that particular region, was in fact a knowledgeable authority concerning water system issues as well as the various features of the lifestyle of people in his region. This Mirab-based system had been defined based on a systematically and gradually constructed mechanism over the course of many years, a fact that led Mirabs to play a significant role in making essential decisions as to renewing or modifying their related water management systems (see, for more details about Mirabs, Balali et al. 2011; Harandi, Nia, & de Vries 2014; Hossaini 2006; Mehraby 2010; Mohmand 2011; Molle & Mamanpoush 2012; Thomas & Ahmad 2009).

The *founding* rules of this case, also, can be seen to be dependent on the status of Mirabs and are defined and flow well in such a relation: the ‘managerial’ side of the necessary knowledge and skills, certainly including the tacit ones, is directly formed and run through the Mirabs’ direct influence, and the purely technical side as well (i.e., the rules concerned with the process of designing and constructing the dam) come into being within such a supervisory chain.

To recapitulate this case, one can observe that the intended *welfare* is attained through simultaneous adherence to its constellation of normative rules, so that one does not disturb (pre)established practices (Fig. 4); this fact has led the dam to be a sustainable development, as concerns both the environment and human nature: “[it] is a dam for all generations and no one could imagine any limitation to its useful life, unless it were sacrificed in human development programs and drowned in the reservoir of a new dam" (Emami et al., 2005).

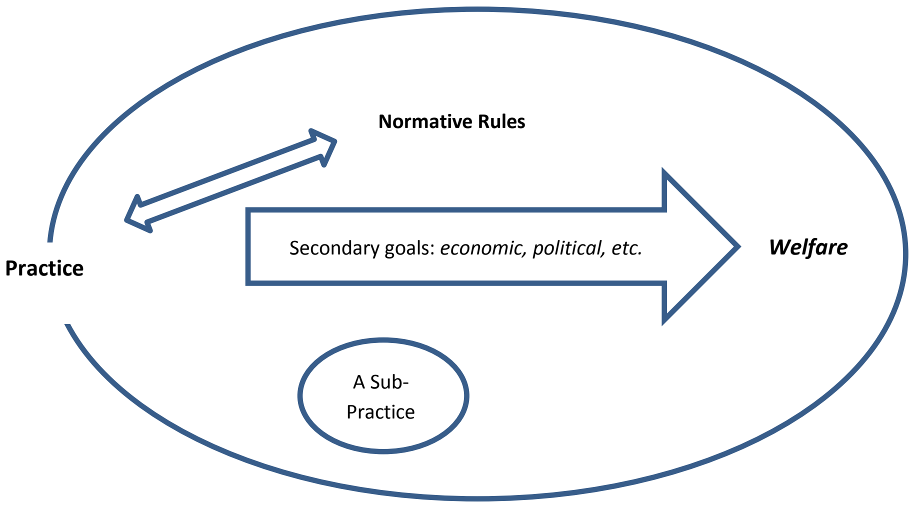

Fig. 4 A normative practice as it applies to for the Abbasi dam (taken with some changes from Jochemsen [2013])

5.4.4. The Zayandeh Rud Dam and its Normative Rules

The Zayandeh Rud dam (along with its river and basin) as a modern technological structure[16] has been subject to many challenges and has raised numerous problems in relation to the surrounding nature and human life (Khatounabadi, 2014). This extensive, multi-layered, multi-sectoral, multi-causal, and complex system of numerous variables (Biswas, 2004) has been organized in such a way that it could not satisfy its intended major missions and has conversely brought about considerable difficulties for different types of regular users – the downstream

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[16] Completed and came to use in 1970 https://fa.wikipedia.org/wiki/%D8%B3%D8%AF_%D8%B2%D8%A7%DB%8C%D9%86%D8%AF%D9%87%E2%80%8C%D8%B1%D9%88%D8%AF

users in particular – as well as the environment, not to mention future generations (Harandi, 2016; Molle & Mamanpoush, 2012). The troubles of this dam are mainly attributed to an inadequate understanding of all the interacting sub-systems of such a complex infrastructure. From the development's inception, this confusion has led to significant consolidated conflicts and regular tensions over matters such as river rights, involving actors such as the state, farmers, factories, and others (see, for more detail, Harandi [2016]; Molle & Mamanpoush [2012]; Molle & Wester [2009]; and Molle et al. [2009]). These tensions appear unresolvable through customary technical or managerial approaches, or through simply engaging different stakeholders of various backgrounds, aims, and even immutable views and values in dialogue and closer cooperation (Harandi, 2016). However, analysing the case through examining its normative rules will yield insights about the case from the perspective of what it *ought* to be, as compared to what it currently *is*.

Let us begin this with considering the *welfare* (the *qualifying* norm) in this case, through taking its probable interpretations (*regulative* norms) into account. The main problem seems rooted here and is reflected in inconsistent approaches to realising the multi-purposed set of intentions regarding this dam. That is to say, the chief *welfare* in this case, as a social normative practice, should have been defined in the sense of *appropriateness and due for all* (Basden, 2011), serving not just *me* and *mine*, but *we*, *us* and *them*, indeed the *whole,* including nature. Unfortunately, this finality has been violated and sacrificed at the expense of certain sectoral goals.

The sectoral goals defined in the course of establishing this dam included a 'joint electricity-irrigation scheme' (Harandi, 2016). Besides 'protecting the people of the Isfahan region against floods or droughts', the dam was meant to 'provide electricity for both people and industries', 'found a well-irrigating system for farming', 'supply drinking water, as well as water needed by the steel factories, refinery, and power plants in the area', 'transfer the water to the other zones', and so forth (Harandi, 2016). These goals, however, are qualified at quite different levels of reality. For instance, while the practices of 'protecting people against floods and droughts' and 'providing drinking water' are qualified *juridically*, the practices of factories and their owner companies are typically qualified in an *economic* sphere, as is the practice of farming. Nevertheless, the problem that has arisen here is that most of the mentioned goals have not been articulated in a well-ordered manner consistent with the finality of *welfare* in the sense of 'due for all justly' (Basden, 2011); that is to say, one can observe numerous cases of prioritizing the economic (or political) goals of companies and the state above the normative *welfare* of the case with respect to people and the environment (Fig. 5). This fact has led to frequent droughts in the riverbed and consequently, many problems for the environment and the society of the region (Khatounabadi, 2014; Ziaei, 2014a).

A just welfare founds its core normative rules in relation to those of the *foundational* and *constitutional* and therefore needs to be examined from this view also – recalling the significance of the simultaneous realisation of the entire constellation of normative rules. This consideration reveals some further aspects of the difficulties mentioned in the case that can be elaborated according to Figure 5.

The construction of the dam with its multi-sectoral goals has failed to conform to its *constitutive* norms, particularly those belonging to the Zayandeh Rud river. This river, tied to a historical context of sociocultural norms, used to be the main source of verdure and fertility of the Isfahan region and played a critical role in supporting the farming (sub-practice) of the people of that region, as well as other traditional livelihoods (Harandi, 2016; Khatounabadi, 2014). The use of this water in this particular sociocultural context was long governed through the wisely structured system overseen by a Mirab, as elaborated by Molle and Mamanpoush (2012):

The river was managed by a Mirab and six assistants selected by 33 boluk representatives, with the help of appointed maadi salars, heads of each of the main run-of-the-river diversion canals (maadi) that were branching off the river. These managers were paid by users, proportionally to the amount of water received, and were dispensed with if their service was judged to be unsatisfactory (p. 287).

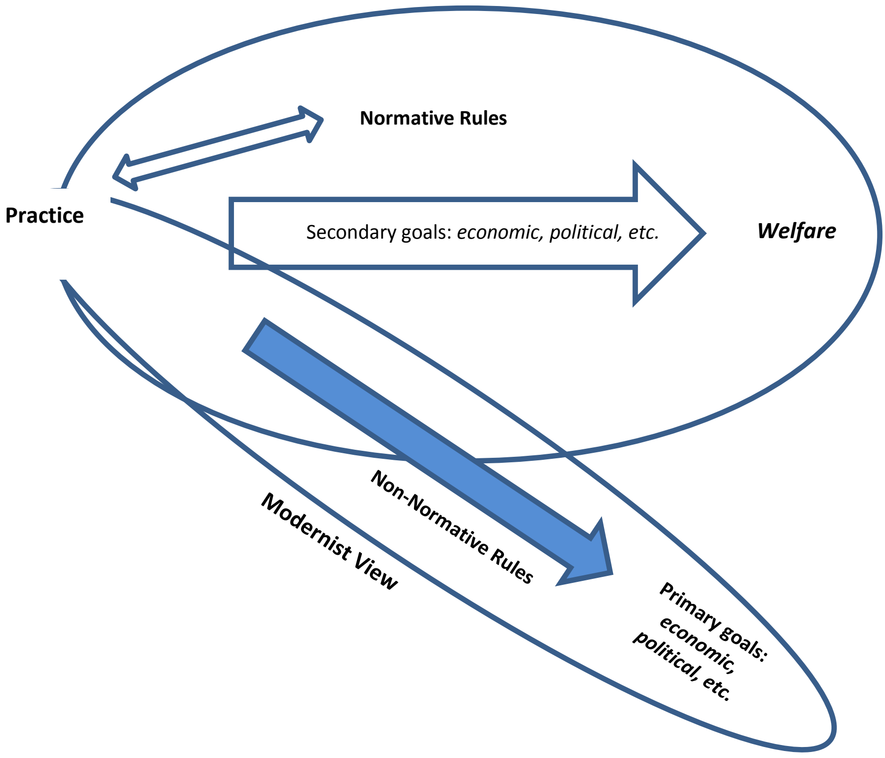

Fig. 5 The Zayandeh Rud dam has violated the normative rules

A Mirab must also "prevent the powerful from trespassing on the weak with regard to the shares of water" (Spooner, 1974, p. 151), and "referee water disputes with the confirmation and approval of the local leaders" (Molle & Mamanpoush, 2012, p. 287). This, as a matter of fact, allowed the governance of this river system to be placed entirely in the hands of local people; it was a democratic governance in which the state-related governors rarely had a direct role (Hossaini, 2006).

It is worth mentioning that the Mirabs' managerial practice also followed the Civil Code of Islamic Law. This code played a significant role in establishing a just norm for water rights:

> *The Civil Code … gives priority to established owners of land over newcomers and upstream over downstream users of water. Prior appropriation rights [as well] were protected by a clause stipulating that the use of water by newcomers should not impact on the interest of existing users (Molle & Mamanpoush, 2012, p. 291).*

Some of these norms were locally regulated and "governed to a large degree the access to, and use of, water in irrigation within what was a complex organization of supply in an uncertain physical environment" (McLachlan, 1988, p.71). However, the case of the Zayandeh Rud dam was subject to many top-down policy and governance rules from the very first stages of its design and construction. This was in line with the modern view of the Iranian state regarding governance of water resources through a centrally integrated, government-based system. This view emerged in the field of water management with the Land Reforms of the 1970s and pushed aside many local traditions and norms which had evolved over the course of many decades and even centuries (Harandi et al. 2014).

The *foundational* rules – the *formative* norms – of the described system had long been linked to these traditional norms and background, in terms of both technical and managerial competencies. For instance, one can point to one of the most essential policy documents governing such norms, *Sheikh-Bahai's edict (Tumar)*. Sheikh-Bahai, a renowned Iranian scientist from the Safavid era, developed[17] a comprehensive set of rules known as the *Tumar* that wisely considered many necessary guidelines and particularly local norms – including geographical, social, and technical ones – to be applied to both the design and governance of water management systems, along with the general (not regionally specific) knowledge and skills necessary for each of those domains. One can see, however, that the *Tumar* and much of the other local knowledge and skills pertaining to designing, constructing, maintaining, and managing such water infrastructures has been ignored in devising and establishing the Zayandeh Rud dam (see, for more details in this respect, Harandi 2016; Hossaini 2006; Molle & Mamanpoush 2012; Moradi 2014; Nasr 'e Esfahani 2014; Ziaei 2014b).

In summary, the Zayandeh Rud dam can be understood as a case of inconsistent and conflicting norms. Its internal mission is not satisfied, but violated, through its existing form of governance. The next section will propose further suggestions for tackling these issues.

5.4.5. The Normative Practice View: Toward Tackling the Case of Failure

The Zayandeh Rud dam has been subject to many conflicts in the course of its management and use, stemming, as already discussed, from its intricate engagement with diverse actors and stakeholders having different expectations and desires. 'Negotiating' over the conflicts seems to be an ineffective, abstract solution to the problem; in negotiations, the parties seek to regulate a win-lose discursive framework to maximise their own benefits from the existing limited water (Harandi, 2016). Some concrete criteria are necessary to make the problems clearer and delineate the governing rules and their conflicts. Such a framework is needed to manage the competing sectoral perspectives and the anticipations of

[17] Jelveh Nejad (2014) believes that the *Tumar* was developed before Sheikh-Bahai and only improved or approved by him.

each stakeholder. Otherwise, the more interests that are represented, the more issues will arise and the more complexity must be overcome (Coughlin 1999; Harandi 2016).

Taking the normativity of technology development practices into account could provide practical insight into how to tackle or prevent the failures of the Zayandeh Rud dam case or similar cases. The problem has its roots, as mentioned earlier, first of all in diverse views on the aim of establishing the dam. That is to say, while the welfare of the people and protecting the environment should be considered to be its ultimate *finality*, this mission has been sacrificed to the economic gain of some powerful stakeholders, such as industries, or to political aims to convey the river water to particular planned developments, with the intention of greening the surrounding deserts, electrifying the country, spreading irrigation projects, and increasing agricultural outputs (Bouguerra, 2006; Harandi et al., 2014; Molle & Mamanpoush, 2012).

This problem, it should be noted, is attributed to the *modernist* interpretation of welfare, a utopian dream of subduing nature and mastering water for human prosperity, which emerged strongly beginning in the mid-19th century (Bouguerra, 2006; Harandi et al., 2014; Molle 2006, & 2009). One can see this view manifested in many approaches to dams or their river basins. Nehru, when commissioning the massive Nagarjuna Sagar dam, spoke of dams as the ‘modern temples of India’. The Orange River Project was heralded as changing the desert face of South Africa into a paradise. Churchill stated that rivers should perish gloriously without a single drop of them reaching the sea. The dominant view of the beginning of the twentieth century in Spain was based on the Spanish motto that not a single drop of water should reach the Ocean without paying its obligatory tribute to the earth to make the country rich. Fidel Castro emphasized that not a single stream or river should be left undammed. Zemin (the president of China) related the Three Gorges dam of the Yangtze river to the daring vision of Chinese people for a new horizon and better future during their reform era, and so forth (Molle 2006).

These modernist views of dams and other water management projects did not set out to isolate such infrastructures from nature but gradually led to the dominance of regulative norms which did not qualify welfare in the juridical sphere of "due for all, far beyond me and mine, beyond 'we, us, and them' within our ken, to the whole" (Basden 2011, p. 18). It downgraded such qualifying norms to satisfy the tenets of productivism and utilitarianism and consequently, replaced the respect for nature and society as a whole with that for the sectoral demands typically belonging to the government and industry (see, for more detail, Harandi et al. 2014, and Molle 2009).

The modern approach of governing hydrological systems, founded in Iran's 1968 Land Reforms, influenced the dominance of both the *conditional* and *foundational* normative rules as well and in fact, swept them away in a dramatic manner. The normative rules of devising and managing water systems on the basis of local resources and indigenous knowledge and "implemented according to precise technical- and societal-tuned mechanisms" were substituted by the centrally-oriented regulations of the hierarchical governance systems of the state or state-based institutions (see, e.g., in Harandi et al. [2014]; this is how the conventional Mirabs were replaced by the Mirab Company in the Isfahan region.) The problematical issue is that the new water management systems – particularly the new hydropower dams – are (components of) massive 'distributed systems' which, as typical post-modern technologies, embrace a diversity of conflicting technical, sociocultural, or environmental interests and contingencies. For that reason, from a 'system view', such massive distributed systems escape central control – not only technically, but also socially and politically. This makes it difficult for actors to appropriate the benefits of their interventions and to influence technological developments in the 'right' direction (Georgieva 2008; Rip & Groen

2005), and, hence, "the idea of a single institution (e.g., the government) that controls the entire process of technological development becomes a myth" (Georgieva 2008, p. 112).

We would like to end the analysis by making two complementary points:

First, although the discussion is based on delineating the normative rules of technology development, the analysis of the failed case attributed its problems mainly to its underlying modern thinking. This is not a surprising finding, and the reason lies in the fact that the normative practice view is primarily based upon McIntyre's account of the concept of practice, where he explicitly introduces himself as an ethicist against the current modern ethos (McIntyre, 1981). Needless to say, the proposed approach to realising the normative rules is also a 'meaning-based ethics' product of Dooyeweerd's ontology, believing that 'meaning precedes existence' (see, for more detail, Jochemsen 2006; Clouser 2009).

Secondly, one might raise a doubt about the applicability of the above analysis to tackling failures such as the Zayandeh Rud dam, in the sense that amending the dominant rules may not be entirely possible, or that further analyses in this line may lead to the conclusion that there is no possibility for amelioration of the case, and removing the dam may be the only option. We concur with this concern, that is to say, it is not always possible to solve such huge problems in their entirety and, in these cases, we may need to resort to either solving them partially or at least preventing them from being extended. The latter option was recently highlighted in some European water management policies. It must also be borne in mind that dam removal has recently been undergoing further study and has been put into practice, although this is not feasible in many cases (Lindloff, 2000; Poff & Hart, 2002). That said, what is intended in the philosophical descriptions is to illuminate or discover some new aspects or provide a concrete base of argumentation to perceive the subjects of study. In addition, damming is merely one case among many technological development cases, and the Zayandeh Rud dam is merely one case among many dams. The normative practice view is a holistic perspective to understand the inherent normativity of technology development as a whole and can be applied to different cases in various fields which may be much easier to tackle.

5.5. Concluding Remarks

The normative practice approach to understanding different aspects of the practice of technology development can lead to valuable insights regarding various values within the complicated and multi-layered systemic essence of engineering activities. This view, in other words, can contribute to productive discussions about the controversial subject of prioritizing ethical and moral issues in engineering practice, discussions that used to be considered a blind alley in the view of some scholars of ethics and technology.

The normative practice view of technological development, in fact, extends the area of reflections upon normativity of technology to its *volitional* aspect. These reflections were typically confined to the realm of epistemological perspectives on the nature of technology, related to understanding different features of technological knowledge (see, e.g., de Vries 2003, 2005, and 2010; de Vries and Meijers 2013; Meijers and Kroes 2013; Sarlemijn 1993), or the analyses examined some partial aspects of technology, such as the character of technological 'artefacts' (Franssen 2013; Vaesen 2013), 'risks' (Möller 2013; Peterson & Espinoza, 2013), 'environmental considerations' (Sandin 2013), 'processes and functions' (Radder 2009), etc.

The proposed normative practice view, which stemmed from a meaning-based worldview, considers the values of a practice as built-in components of its coherent nature, the normative rules (standards of excellence) to be understood and considered in the course of related engineering activities, in order to achieve the intended finality of that practice. The qualifying, formative, and conditional normative rules constitute a practice and define a significant part of its concrete form and the regulative rules that direct that practice and give a specific meaning to its intended finality. The approach as a whole can be considered as a perspective less likely to be captured in the trap of relativistic ideas and judgements regarding the moral and ethical issues in the course of technological developments. Applying such a perspective to the case of damming, as one of the most controversial fields of serious concerns regarding technological developments, could yield insights as to the matter of success or failure in such cases, as related to ethical issues. These issues are not easily solvable, due to the profound impact of the modern view and its accompanying enormous technological momentum.

So far, the thesis has approached the content to be educated about engineering and technology. The next chapter, however, takes up the practice of improving engineering education as a whole and attempts to analyse the different features of such a practice and the probable obstacles of it at the tertiary level of engineering education.

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06

Chapter. 6

CAPTIVITIES OF ENGINEERING EDUCATION

a context-based reflection on the mechanical engineering programme at Sharif university of technology in Iran

RE-SUBMITTED PAPER :
European Journal of Engineering Education

	PRIMARY/SECONDARY SCHOOL STUDENTS	TERTIARY SCHOOL STUDENTS
OVERALL CONTENT	CHAPTERS 2&3	**CHAPTER 6**
SPECIFIC ISSUES	CHAPTERS 4	CHAPTER 5

CAPTIVITIES OF ENGINEERING EDUCATION:

A CONTEXT-BASED REFLECTION ON THE MECHANICAL ENGINEERING PROGRAMME AT SHARIF UNIVERSITY OF TECHNOLOGY IN IRAN

6.1. Introduction and Research Questions

Reforms to current systems and methods of engineering education have recently been receiving considerable attention in the literature. One can see numerous concerns, points, and suggestions in this relation raised from different perspectives (see, e.g., Holt 2001, 2002; Badley 2003; Splitt 2003; Memarian 2012a, 2012b, and also many relevant papers articulated as well throughout books such as *Philosophy in Engineering* [Christensen, Meganck, and Delahousse 2007] or *Engineering in Context* [Christensen, Delahousse, and Meganck 2009]). There have also been certain long-term policy documents developed in this line such as *The Engineer of 2020: Visions of Engineering in the New Century* (National Academy of Engineering 2004) and *Grand Challenges for Engineering* (National Academy of Sciences 2008). These contribute to the delivery of clearer accounts of visions or guidelines that need to be reflected upon in engineering education.

Very little has, however, yet been written about the contextual issues – in terms of many social variables that hinder the process and/or the efficiency of making such reforms. Indeed, it appears that current efforts have mainly focused on what may be called *the scientific captivity* of engineering education, which means being locked into the supremacy of the culture and discourse of sciences and losing touch with the more practical aspects of engineering activities (Goldman 1991; Johnston, Lee, and McGregor 1996).[18]

This may have roots in the fact that these regular perspectives typically have Western origins, and therefore reflect the most common concerns of engineering education in countries such as the USA, England, the Netherlands, Denmark, France, and those with fairly settled infrastructures of technology and education; a characteristic which does not necessarily always hold true when it comes to some other countries such as certain Asian ones. The latter, as observed in this chapter, have a different problematic aspect that needs to be taken into account: engineering programmes in these countries, besides being bound by science-oriented approaches, are concurrently confined by a broader dominance of challenging contextual backgrounds and infrastructures. This has brought about a second type of issues which can be labelled as the *contextual captivity* of education.

Sharif University of Technology[19] (SUT), one of Iran's best technical universities[20], has been taken as an illustrative case in this regard because its mechanical engineering programme is a good example of being engaged with both types of the mentioned captivities. That is to say, studying this case gives a way to unfold the different problems involved in the way engineering education is being reorganized in an attempt to improve the efficiency of its current science-bound curriculum. In other words, this inspection reveals, in several ways, when reforming the current educational system, there are situations that it is not enough to concentrate solely on the matter of 'scientific captivity'. There may also be some

[18] Goldman (1991) discusses this issue, but from an engineering-in-practice perspective, as an *intellectual* captivity.
[19] http://www.sharif.ir/web/en
[20] http://ur.isc.gov.ir/Default.aspx?Lan=en

impeding factors that belong to a broader, but encompassing, area of 'contextual captivity' that must be given due consideration in educational reflections.

Thus, the main research question was: 'How can the current mechanical engineering education at SUT be improved, considering the probable captivities?'; the question which finally, as elaborated on later, tied in some ways the enhancement of the quality of this 'science-bound' strand of engineering programme, at SUT, to its contextual confinements.

The research question was meant to be addressed by the staff members of SUT, because the study was intended to concentrate on the perspective of academia. In other words, although incorporating the related ideas of industry could be interesting and yield insights, the mission of this study was to focus on academia; this would allow the research to achieve a more focused, better elaborated, and less complex description of the multifaceted aspects of the intended case and to provide a clearer analysis of the proposed ideas for improvement, from an academic viewpoint.

The study proceeded accordingly on the basis of interviewing eleven (of the forty-four) reputable staff members at SUT's Faculty of Mechanical Engineering[21]; as informed and experienced teachers of one of the leading engineering universities of Iran, their ideas were presumed to be a very important contribution to evaluating the success of their graduates as effective engineers in practice and to discover any related concerns that these teachers had in this respect.

The main research questions were therefore formulated into the following three open-ended questions:

1. How do you, as staff members, define the characteristics of your ideal newly-graduated mechanical engineers?

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[21] The interviewees were selected based on the snowball sampling method in which 'the researcher samples initially a small group of people relevant to the research questions, and these sampled participants propose other participants who have had the experience or characteristics relevant to the research. These participants will then suggest others and so on' (Bryman 2012, p. 424).

2. What reforms are needed to educate them, in order to acquire such ideal characteristics?

3. What are the barriers to making the desired reforms?

The first question was a fundamental one seeking the interviewees' exact attitudes to mechanical engineers and the way of educating them, in terms of the relevant definitions and the role that these engineers need to take and play in practice. Indeed, it seemed essential to know foremost what the aim of mechanical engineering education is, and which characteristics are expected to be acquired by the students. Talking over this question led the inspection to come up with the first level of the problems, that is, those of 'the existing complex and inconsistent contextual 'attitudes' towards mechanical engineering.

Therefore, regarding the points raised by discussing the first question, the next query explored the respondents' ideas as to the effectiveness of the current educational content of mechanical engineering courses, as well as their suggested modifications. This inquiry though had more to do with the 'scientific' captivities, as discussed in many of the above-mentioned Western-based reflections, at the same time opened up another outlook to the infrastructural issues and barriers, approached and deliberated on more by the third question.

By asking the third question we investigated whether we can hope or expect to enhance the quality of mechanical engineering education only through taking the guidelines and putting the suggested points of the former two questions into action. The staff members put some critical concerns forward in this respect and particularly talked of several specific problems of both the industry and academia in Iran, which led to another extensive deliberation of the 'contextual' captivities of engineering education in this country.

Finally, as summarized in the concluding section, placing all the discussions together yielded a worthy understanding of different types of captivities of (mechanical) engineering education at SUT, and by extension, in countries similar to Iran. Some recommendations for further studies to complement this one are also proposed at the end.

6.2. Method

The study is based on performing a qualitative research method entailing four substantial stages:

i. Undertaking a *semi-structured* interview[22] with the teachers, along with a voice recording, to examine their perspectives and interpretations of their engineering contextual issues. A significant advantage of this type of interview, performed here by the performers of the study, is that, though having some main questions as the interview guide, it provides a flexible space for discussion for the interviewees and encourages them to ramble around whatever is relevant and important in their opinion (Bryman 2012).

ii. Providing full transcripts, without any manipulation of the original voice, in order to pave the way for enhancing both the accuracy and the quality of research (see Heritage 1984, p. 238)

iii. Using the QCA (Quantitative Content Analysis) method to analyse the provided data and yield a well-organized illustration to realize the different aspects of engineering education issues. This stage entailed the critical part of identifying the relevant 'themes' as well as employing all three types of 'coding' – i.e. the *open*, *axial*, and *selective* codings (see Bryman 2012, p. 569) – and organizing them in different forms of tables, as seen later on.

iv. Analysing the tables and extracting a well-organized illustration of those analyses to describe engineering education captivities in the Iranian context.

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[22] In this type of interview, as explained by Bryman (2012), '[t]he researcher has a list of questions or fairly specific topics to be covered, often referred to as an interview guide, but the interviewee has a great deal of leeway in how to reply. Questions may not follow on exactly in the way outlined on the schedule. Questions that are not included in the guide may be asked as the interviewer picks up on things said by interviewees. But, by and large, all the questions will be asked and a similar wording will be used from interviewee to interviewee' (p. 471).

There are three critical points as well that are worth being touched on here. First, the process of research from the stage of coding to that of analysing was not a linear or one-way effort at all; rather, it was a recursive procedure of constant movement backwards and forwards between those two steps, so that the initial coding led to the results which proposed again the need for new codes and data, and so on (see Bryman 2012, p. 566). Second, in the meanwhile, the hidden content of the raised perceptions too has been strictly considered; the elements such as 'tone' or 'emphasis' on different words or phrases of the interviewees' speeches have been taken seriously into account throughout the stage of identifying the main themes and codes and even while categorizing and analysing them. Lastly, the study benefits from an adequate degree of validity and reliability, in particular, because the mentioned iterative attempt has been performed by three researchers in different stages of working separately and together, and the findings are consequently the result of a high degree of agreement (around 80%) among them.

6.3. Analysis and Conclusions

Now let us take up our three questions more elaborately, bearing in mind that from now on the phrases of 'mechanical engineering' and 'mechanical engineer(s)' have been respectively abbreviated to 'engineering' and 'engineer(s)'.

6.3.1. Question 1: How do you define engineering? What is your ideal newly-graduated engineer?

As mentioned earlier, it was foremost very important to us to get the staff members' views in response to this question. This was because having a definite idea about the concept of engineering and what an engineer is expected to be, immediately after graduation in particular, was an essential step towards the necessity of reconsidering what engineers learn, compared to what they should learn, in academia. Hence, we first asked the interviewees to present their ideas about definitions and the related descriptions of engineering. It is worth noting that here we were, in fact, just seeking the explanations based on the respondents' own knowledge and real experiences, not necessarily those in textbooks and literature.

Responding to this question, the teaching staff discussed various points and attitudes; some reflected on the concept of engineering from a holistic perspective, and some took a more atomistic view, too, focusing on the characteristics of an ideal engineer. So, by accumulating and analysing these opinions, we could get to a two-sided model; one side, the *macro* one, considers different dimensions of the context of engineering as a practice, and the other, the *micro* side, mostly describes the relevant features that engineers are expected to have. What follows presents a more detailed result in this regard.

6.3.1.1. The 'Macro' Side:

This side of seeing engineering (Fig. 1), extracted from the interviewees' viewpoints, interestingly contemplates three aspects of engineering context, and has been actually formed based on how we may define the professional situation of engineers (briefly sketched in Table 1a[23]). These three aspects can be examined in more depth, as below:

i) *The 'orientation' of the educational system:* this aspect looks at the ways through which the engineering educational systems view or should view engineers, in the sense of their future profession within a *practice-research* spectrum. Here we can see the ideas such as that which was frankly stated by interviewee number 2 (I2) that:

> *it must be ascertained that do the universities anticipate a graduate to be engaged with more practical activities of close connections with*

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[23] We would like to declare that all the tables of this chapter are only summarized versions that have been organized according to what is needed to be discussed here. They are only the collection of some of the most important, among many, points and opinions which have been addressed by the interviewees.

industry, or do they aim to support him/her to perform more scientific research as an academic researcher in the future?

This aspect in fact reveals, in one way, that we may define engineering based on where the engineers are aiming to go: the more practical area of the industry or the more theoretical area of research (Table 1a; rows 1-4).

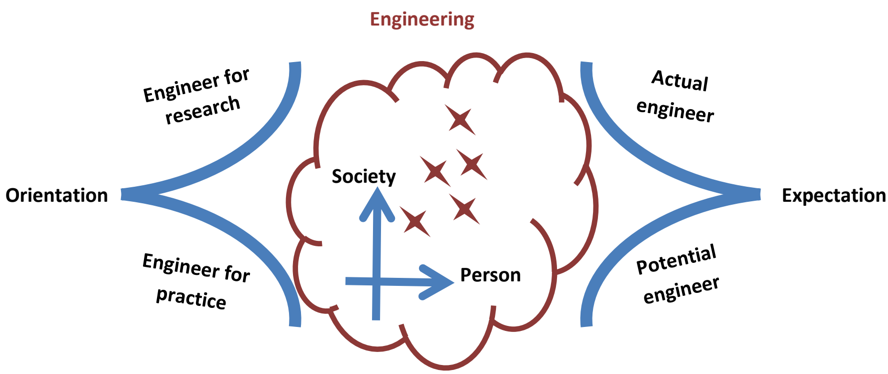

Fig.1 The macro side of seeing engineering

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ii) *The 'expectation' of the educational system:* this relates to the extent to which vocational capabilities are expected from a new graduate. The necessity of considering such an aspect gets clearer when we face the common view of Iranian industries, as opposed to that of its academia, which assumes that the new graduates have to be *actual experts* to carry out all the required engineering activities. This contrasts with the interviewees' opinions as to universities' mission to deliver *potential experts* which is described by *I3* as 'who are able to constantly improve themselves in the course of practice' (see, in brief, Table 1a; rows 5-7); the latter suggests that engineers have to *learn how to learn* – discussed later on – and this account differs from that of learning everything in a few years of engineering education in academia (Table 1a; row 8).

iii) *Relativity to 'individuals' and 'societies':* this facet stresses the flexibility and, in fact, the relativity of engineering definition, based on diverse situations. The staff members stated, in one way or another, two pivotal points in this respect. Firstly, as people are distinct in their talents and competencies, each person can best suit a specific field of engineering (Table 1a; rows 10-11). Moreover, societies and their various demands are dynamic over time, so the problems that the engineers are supposed to engage with are changing continuously (Table 1a; rows 9 and 12).

Thus, this aspect states that the definition of engineering, and what an engineer should be, varies depending on (1) individuals' qualifications, and (2) society's wishes and requirements. That is to say that we do not, and should not, need to train all the engineers, even the engineers with the same fields of profession, in entirely the same way. For one thing, some of them may be more talented in managerial works, some in commercial, and some others in laboratories.

6.3.1.2. The 'Micro' Side

This standpoint focuses on more detailed characteristics of engineers: the characteristics concerning a certain level of *Knowledge*, *Skills*, and *Attitudes* required for, and expected from, an engineer. These categorized features, as shown in Figure 2, could be explained as follows:

Table 1a The 'macro' side of the interviewees' viewpoints on engineering

Row	Interviewee(s)	Meaning Unit[24]	Label
1	I8 , I10	The professional future of an engineering graduate can be either working in industry or doing research.	approaches of education system to training engineers
2	I2 , I6 , I8 , I11	Today in Iran, the educational system is aimed at training students for higher education, not necessarily for solving industry's actual problems.	
3	I8, I10	Changing the approach of educating engineers towards engineering practice in industries.	
4	I2 , I7	Depending on universities' missions, different goals are considered: training engineers or scientists.	
5	I2, I3	It is not logical to expect an engineer to solve a problem at a glance.	expectations of education system by engineers
6	I4 , I6	Industries expect universities to train actual technologists so that a graduate is able to carry out engineering functions more effectively, immediately after graduation.	
7	I2 , I3	Engineers should be trained in a way that they can analyze engineering problems well and find solutions in due time, not necessarily at once.	
8	I2, I6, I9, I10	During their study, engineering students should learn how to learn.	
9	I2, I9	A society has various engineering needs and requirements. So engineers with various abilities are needed.	relativities of engineering definition to individuals and situations
10	I7, I9	As engineers have different talents and interests, engineers have and should have different qualifications.	
11	I2 , I7 , I9	We should have more optional lessons for engineering students of various talents, so that they can choose among them according to their potential and interests.	
12	I3	Applied subjects and fields of engineering change over time. Therefore, according to society's need in each period of time, engineering can have different definitions.	

24 'Meaning units' are usually as described by Elliot & Timulak (2005) 'parts of the data that even if standing out of the context, would communicate sufficient information to provide a piece of meaning to the reader. The length of the meaning unit depends on the judgement of the researcher, who must assess how different lengths of meaning unit will affect the further steps of the analysis and who also should adopt a meaning unit size that is appropriate to their cognitive style and the data at hand' (p.153).

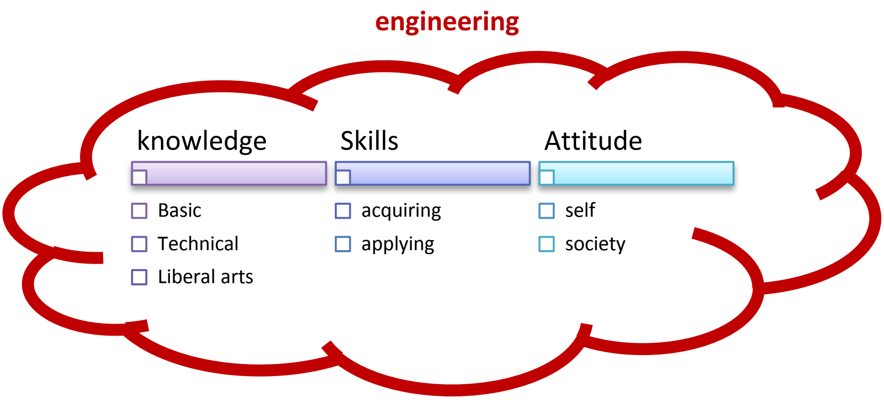

Fig. 2 The micro side of seeing engineering

i) *Knowledge:* the required knowledge for engineers can be divided into three distinct branches: (1) *Basic Knowledge* of sciences such as mathematics and physics; this knowledge is not only an essential prerequisite for problem solving, designing, analysing related issues and so forth, but also gives students a sharper mind and therefore they become more creative and skilled; (2) *Technical Knowledge* as to, for instance, various methods of analysing, designing, modelling, and problem solving of relevant fields; and (3) *Liberal Arts*, that is knowledge on social and cultural issues, for example. The interviewees seriously believed that, apart from the technical visions, engineers should also have other significant visions to overcome the ever-emerging challenges of our sociotechnical environment. One may point to 'ethics' as one of the most agreed and closer-to-mind examples of this branch (Table 1b; rows 1-13)

ii) *Skills:* by aggregating the different suggested skills we ended up with two main branches for them: (1) *the skill of acquiring knowledge* which refers to, as portrayed by I2, 'the qualification of learning how to learn required knowledge and become a self-advanced engineer'. This branch emphasizes that in today's ever-increasing technology, engineers should acquire the skill of identifying and grasping their contingent knowledge; they should learn, for instance, how to explore numerous proper books, papers, and online resources to enhance their knowledge, or how to work with various professional (or general) software to advance more efficiently; and (2) *the skill of applying knowledge*; described, for instance, by *I10* as 'the capability of using pertinent knowledge with adroitness when facing different engineering problems'. Actually, this type of skill was of the same significance compared to 'acquiring' one in the respondents' view. Let us make it clearer through an example: compare one engineer with a high-level knowledge of design, who cannot use it when facing a real design problem, with another of a slightly lower level of knowledge but a higher skill in analysing and solving the problem. There is no need to explain why the second engineer would be preferred most often (Table 1b; rows 14-25)

Now, prior to going any further and talking about 'attitudes', we would like to stress a (by-product) conclusion here: evidently, 'knowledge' and 'skills' interrelate together, and skills are nothing but the abilities of acquiring and applying the basic, technical, and liberal arts knowledge. Figure 3 shows this with the relevant examples within a matrix framework.

iii) *Attitudes*: A third type of characteristics exists which complements the above-mentioned two. From this point of view, engineers need to obtain appropriate attitudes during graduation; attitudes towards both *themselves* (as engineers) and their *society* (Table 1b; rows 26-31). Remarkable points were proposed by the professors in this respect that some of the more striking ones of them can be pointed out as below:

- Having a broad outlook regarding their to-be-acquired knowledge and their composition when facing various real problems ('self').
- Daring to not be captured in the bounds of their current knowledge ('self').

Table 1b The 'micro' side of the interviewees' viewpoints on engineering

Row	Interviewee(s)	Meaning Unit (Engineers need to learn about)	Label
1	I1	Statistics	Basic knowledge
2	I2 , I3	Physics	
3	I2 , I3, I6	Mathematics	
4	I1	Advanced methods (e.g. Finite element methods)	Technical knowledge
5	I6	Experimental methods	
6	I11	Analysis, Design, and Actualizing mechanical systems	
7	I5	Analysis, Design, and Study of forces	
8	I2, I3, I4, I7, I8, I10, I11	Economics	Liberal arts
9	I1, I2, I4, I8, I10, I11	Management	
10	I11	Entrepreneurship	
11	I7	Art	
12	I2, I3, I7, I8	Legal, social, and cultural issues	
13	I2	System analysis and system thinking	
14	I2, I4, I9, I11	Software using and coding	acquiring/applying skills
15	I2, I4, I8	Familiarity with industry's space & hardware	
16	I2	Laboratory	
17	I2, I6, I9, I10	Learning how to learn	
18	I3, I5, I10	Problem solving	
19	I10	Critical and logical thinking	
20	I1, I7, I10	Report and document development	
21	I1, I7, I10	Entrepreneurship and self-confidence	
22	I1, I3, I7, I10	Public relations and communication (e.g. presentations, negotiations, and professional interactions)	
23	I7	Getting updated (about the professional field)	
24	I3, I7, I11	Creativity & innovation	
25	I2, I3, I5, I7, I9	Ethics	
26	I1, I5, I11	Having a broad outlook regarding their about-to-be-acquired knowledge and its composition when facing various realistic problems	attitude to self
27	I11	Daring not to be restricted by the bounds of their current knowledge	
28	I8	Believing in the necessity of being acquainted with the relevant industries	
29	I7, I9	Understanding the importance of the welfare of people and their prioritized needs	attitude to society
30	I11	Believing in the necessity of self-improvement in order to properly respond to the community's needs	
31	I2, I3, I5, I7, I9	Having ethical considerations about their environment	

- Understanding the importance of welfare of people and their prioritized needs ('society').
- Having ethical considerations about their environment ('society').

In fact, what could be concluded here is that graduates need to have a proper, holistic view of their real world and their roles and interactions within it, and this will not be obtained unless they learn properly how to look at themselves and their society.

		Knowledge		
		Basic	Technical	Liberal arts
skills	acquiring	e.g., Statistics	e.g., Finite element method	e.g., Economics
	applying	e.g., Experimental research	e.g., MATLAB software	e.g., Commercialization

Fig. 3 The micro side matrix: the interrelation of knowledge and skills, with some relevant examples

At this moment, before turning to the second question, it is worthwhile to have a summarized view (Figure 4) of the ideas mentioned regarding the first question: the staff members believed that one of the most primary concerns in relation to reforming engineering education in SUT is the lack of a well-organized, acceptable definition as to the aim of training engineers in the context of Iran. This concern should be reflected from two aspects: the 'macro' and the 'micro' sides.

From the macro view, we have the following problems to be solved:

- The orientation of education is very vague and chaotic; while it seems that the main goal of engineering education should be training more effective practical engineers for industry, the education in SUT, like most other Iranian universities, is captive to only producing researchers.

- Moreover, what academia expects its newly-graduated engineers to be, i.e. potential experts, does not conform to the expectation of industry, which would prefer to take actual experts from universities.
- The system of education is under the dominance of the perspective that ignores both students' talents and society's needs in its plans.

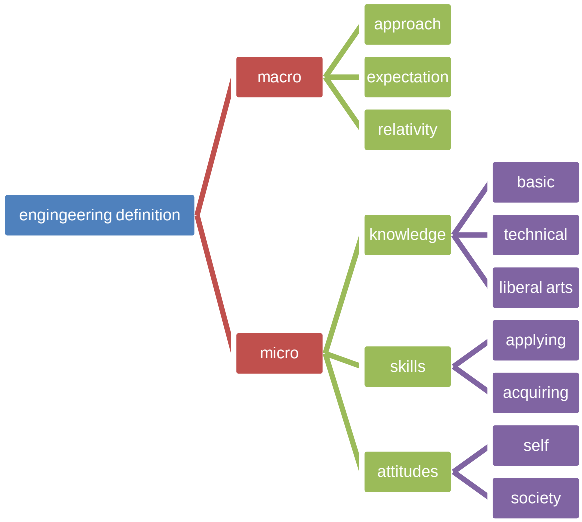

Fig. 4 Dimensions of engineering definition

However, as to the micro view, the main problem is that education has been confined to science-bound approach to the 'Basic' and 'Technical' types of engineering knowledge; also, there is almost no room for learning about 'Liberal Arts', or acquiring relevant skills, and attitudes, in the curriculum.

6.3.2. Question 2: What reforms are needed for educating engineers, to acquire such ideal characteristics?

In fact, this question had more to do with the micro aspect, and the interviewees in this stage were in some sense asked to describe the properties of their sought-after curriculum.

However, in order to move further, we need to ascertain three types of courses in SUT's engineering curriculum:

- *Generic* courses which can be related to the field of 'Liberal Arts' category (see Figure 2): those such as History, Persian Literature, General English, and Physical Education, not directly related to the field of so-called engineering knowledge and skills.
- *Basic* courses such as general Mathematics, Physics, and Chemistry that provide the fundamentals for engineering knowledge.
- *Specialised* courses such as Statics, Dynamics, Fluid Mechanics, Thermodynamics, Materials Science; these directly belong to the specific knowledge of mechanical engineering. These types of courses, which conform to the 'Technical' side of engineering knowledge (see Figure 2), are further classified into *Compulsory* and *Optional* ones.

(for more detail, see http://www.mech.sharif.ir/96)

Turning back to the main line of this question, the staff members' opinions in this relation could be categorized into three parts; the ideas about (1) re-planning *Non-specialised*, i.e. Basic and Generic, courses, (2) re-planning Specialised courses, and (3) implementing the re-planned courses.

As to re-planning the Basic courses, the respondents believed them to be reduced in volume. The courses such as Mathematics and Physics, in their opinion, are in fact filled with unnecessary, time-consuming topics, which though useful before, are no longer very helpful for today's engineers, and can be diluted now; not to mention the numerous overlaps across their contents (Table 2a; rows 1-3).

The same idea was held for the Compulsory Specialised courses; these would be confined only to a sufficient level of knowledge needed for mechanical engineering, not more. This idea can be associated to the above-mentioned emphasis on engaging students with the approach of 'learning how to learn', in our ever-changing technological world and required skills (Table 2a, rows 1-3).

The opinion concerning shrinking the content of both the Basic and Compulsory Specialised courses has in fact two significant benefits; it (1) provides some room to place more useful materials, and (2) enables the teachers to focus on increasing the quality of educating fewer but more useful subjects. However, this must not cause the importance of learning these types of knowledge to be neglected, as they in fact form sharper and more logical minds for engineers, and help them to acquire more analytical thinking skills that are crucial for conducting engineering activities. Moreover, students need to be well aware of what happens behind the (procedures of), for instance, software put to use in different stages of problem-solving and designing; this helps them to analyse the problem-solving processes and resulted outcomes in a more efficient and creative way (Table 2a; rows 4-9).

Turning to re-planning Optional Specialised courses, most interviewees argued in favour of having a richer content of such subjects, in quantitative terms; that which lead, in their opinion, to having graduates acquainted with a deeper level of knowledge as to a wider range of relevant topics. Some moved even one step further, and proposed the idea of organizing different *packages* of these courses to be selected freely by students, according to what they think fits well with their potential and aspirations. This latter, as argued by I8, 'would help students to become more knowledgeable and professional in a specific field of their individual-related requirements, rather than learning some sparse, superficial, and diffused information'. That said, the significant point underlined in this regard was the importance of society-related considerations (discussed in Question 1); these types of courses need to be changed, amended or updated, according to the state and real needs of society (Table 2a; rows 10-12).

Table 2a. The necessary reforms in the engineering curriculum structure and content, from the interviewees' perspective

Row	Interviewee(s)	Meaning Unit	Label
1	I2, I4, I5, I7, I10	Their current volume of Basic and Compulsory Specialized courses is much more than needed and is very time-consuming.	the necessity of diluting Basic and Compulsory Specialised courses
2	I11	There are many overlaps between the current contents of Basic and Compulsory Specialized courses.	
3	I1, I2, I4, I5, I6, I8, I10, I11	The current volume of Basic and Compulsory Specialized courses needs to be diluted to the essential and adequate (general knowledge) level.	
4	I2, I8, I10	Diluting the current volume of Basic and Compulsory Specialized courses provides more room to put in more useful materials and courses.	the benefits of diluting Basic and Compulsory Specialised courses
5	I2, I3	The quality of Basic and Compulsory Specialized courses needs to be increased.	
6	I2, I10	Diluting the current volume of Basic and Compulsory-Specialized courses enables the teachers and students to increase their focus on the quality of learning.	
7	I1, I2, I3, I10	It is essential for engineers to acquire an appropriate level of Basic and Compulsory Specialized types of knowledge.	the significance of Basic and Compulsory Specialised courses
8	I1, I2, I3, I10	The Basic and Compulsory Specialized courses shape sharper and more logical minds for engineers.	
9	I1, I3, I10	The Basic and Compulsory Specialized courses help engineers to acquire more analytical skills for problem solving.	
10	I2, I3, I5, I9, I11	The current volume and diversity of Optional Specialised courses needs to be modified, enriched and updated.	the necessity of modifying and enriching Optional Specialised courses
11	I1, I2, I8, I9	Some specific industry-oriented (packages of) courses need to be placed in this category. This will yield more knowledgeable and professional engineering graduates.	the necessity of modifying and enriching Optional Specialised courses / the benefits of modification
12	I1, I2, I3, I6, I8	The Optional Specialised courses should be modified based on the current needs and contingencies of society, in the first place, and the world afterwards.	the necessity of modifying and enriching Optional Specialised courses / the importance of considering social needs
13	I4, I5	The current Generic courses contain many unnecessary topics and materials.	the necessity of redesigning Generic courses
14	I2, I4, I5	Generic courses need to be redesigned to increase their quality and effectiveness.	

However, the teaching staff's ideas about enriching the content of the Optional Specialised aspect of the curriculum, such as the courses of Fluid Mechanics and Material Science, actually had roots in their main concern in delivering more capable (potential) experts to the industry. Therefore, these ideas are interestingly accompanied with those which emphasized enriching (modifying, and not necessarily increasing) the content of Generic (Liberal Arts) courses in parallel; engineers in this sense need to know, much more than before, about subjects related to, for instance, management, economics, communication, and so on (Table 2a; rows 13-14).

The final set of opinions as to the second question had to do with the ways of implementing such intended re-planned courses, whether specialised or non-specialised. The interviewees believed that teaching needs to become more interactive in its method; by the way, the 'theoretical' parts of lessons should be accompanied more by relevant 'practical' parts such as 'having lab- or portable-lab-lessons', 'engaging with experimental topics', 'taking more serious field trips', 'using more real-life examples', 'cooperating with industries to have field experts' presentations of actual topics', 'learning software along with theoretical issues', and the like (Table 2b).

Table 2b Ways to implement the re-planned Specialised or Non-specialised courses from the interviewees' perspective

Row	Interviewee(s)	Meaning Unit	Label(s)
1	I2	Increasing both the quantity and quality of practice-based courses	more interactive and practice-based learning
2	I2, I11	Increasing the volume of creative laboratory-based activities	
3	I6	Engaging with more experimental topics	
4	I2, I4, I9, I10	Taking more serious field trips and projects	
5	I1, I2, I4, I5, I9, I11	Learning and using software in designing and analysing in more effective ways	
7	I2, I4, I10, I11	Engaging with more realistic and practical problems	
8	I2, I10	Learning from industry's field experts	

6.3.3. Question 3: What are the barriers to making the desired reforms?

This question faced more challenging ideas, by the respondents, in the sense of getting deeper into analysing the infrastructural issues of engineering education. The staff members addressed this concern from a perspective other than, but absolutely related to, what was considered in answering the first question. They alluded, in this respect, specifically to two types of barriers hindering reformation; those related to the 'inefficiently-settled dynamic' of the interrelation of academia and industry (Table 3a), and those concerned with 'resistance against change' within academia itself, or its governmental supporting organizations (Table 3c).

Now let us go through the first aspect, i.e. the problematic connection between academia and industry. We would like to categorize the staff members' various opinions, in this regard, into three parts; these have to do respectively with (1) industry, (2) academia, and then (3) their interrelation. This would help us to conceive the inefficiency of such a dynamic, in a more organized way, in that the first two parts yield an insight into the third one.

6.3.3.1. On Industry

The industries in Iran, as a developing country, are suffering from some problematic general issues that are holding back the improvement in the engineering education system. Chief among them are:

(a) Many industries, like the automotive industry, have realized themselves as the followers, not leaders or even sturdy competitors. This problem was described for instance by *I2* as:

> *these industries have no serious motivation to plan and move independently towards the cutting-edge level of technological knowledge and innovation. Even in the far more successful fields of industry, such as oil which is the main income source of Iran's GDP, the primary goal of technological development plans can be seen as above;*

at best these plans are just attempting to get the newest technologies in their industry, instead of competing in advancing the frontiers of technology.

(b) Basically, most industries have been established on the basis of importing their technologies and the related structures from western countries, through getting various licenses and the like, and in a form somewhat independent of Iranian universities. Once again, the automotive industry is a good example in this regard.

(c) Most industries are engaging with profitability concerns, and are seeking to overcome these types of evolving issues in today's world of hard competition. Hence, they barely invest in long-term plans because ROI[25] is more predictable in short-term ones. They prefer instead to concentrate on cutting their costs, and finding a way to buy cheaper tools and equipment, rather than pursuing the big profits of the far future, through devoting a large amount of money to making the best use of the engineers' real potential, in order to get more technological innovations.

(d) So-described industry should not be expected to have a very vibrant existence, to generate much competitive science and technology; it would not believe or feel the necessity of approaching universities in order to progress more and more.

(see, in brief, Table 3a; rows 1-5)

6.3.3.2. On Academia

Universities of Iran, in general, and SUT, in particular, have their own characteristics as well from the respondents' point of view:

[25] Return on Investment

Table 3a The inefficiently consolidated dynamic of the interrelation of academia and industry, according to the interviewees

Row	Interviewee(s)	Meaning Unit	Label
1	I1, I2, I8, I9, I11	Many industries have defined themselves as followers, not leaders or competitors (e.g. the automotive industry).	inefficiencies of industry
2	I1, I2, I8, I9, I11	Many industries do not intend to move toward the cutting-edge level of technological innovation (e.g. the automotive industry and the oil industry); they are far behind academia in this sense.	inefficiencies of industry / inefficiencies of the industry-academia interrelation
3	I1, I5, I8, I9,	Most industries import their technologies and structures from the West, rather than local universities.	inefficiencies of industry / inefficiencies of the industry-academia interrelation
4	I4, , I5, I8	Most industries have been established and developed independent of universities.	inefficiencies of industry / inefficiencies of the industry-academia interrelation
5	I1, I5, I9, I11	Most industries are engaging with profitability concerns, short-term plans, cutting costs, etc. instead of development, investment in innovation, long-term plans and so forth.	inefficiencies of industry / inefficiencies of the industry-academia interrelation
6	I2, I9	The engineering education method in Iran is very traditional; it is difficult and costly to optimize it.	inefficiencies of academia
7	I2, I7, I8, I11	Most universities have no clearly defined mission regarding industry; they are typically postgraduate-oriented and independent of industry.	inefficiencies of academia
8	I4, I9	The subject of internship is not seriously taken into account.	inefficiencies of academia
9	I5, I6	The postgraduate-oriented approach of academia paves the way for graduates to go to foreign universities (and later industries).	inefficiencies of academia
10	I2, I5, I8	The context of competition in industry does not seem fair or sufficiently inspiring for highly-qualified graduates.	inefficiencies of academia / inefficiencies of the industry-academia interrelation
11	I6, I7, I8, I11	Academia's budget is to a large extent supplied by government, not industry.	inefficiencies of academia / inefficiencies of the industry-academia interrelation
12	I11	Any formal contract between industry and academia would be risky for industry.	inefficiencies of academia / inefficiencies of the industry-academia interrelation
13	I8, I11	Teachers are appraised in a traditional form, based on their academic publications, not according to their effective connection with industry.	inefficiencies of academia / inefficiencies of the industry-academia interrelation

(a) Their engineering education method is still very traditional; what has made the graduates, at least those of SUT, successful in the industry is to a large extent 'the elegance of students' themselves, rather than 'the method of educating' them.

(b) The mission of universities regarding technology has not been clearly defined, so there is no pressure on them to supply industry's need for engineers.

(c) Nevertheless, some universities, such as SUT, have recently started to improve their education; this does not conflict with the previous point, because the manner of optimizing the settled traditional approaches and methods is very time consuming.

(d) However, one of the most problematic issues in improving the education system is the fact that replacing the old method with a new, and more industry-oriented, one is very troublesome and costly.

(e) The next challenging point relates to the story of *industry internships;* this subject is not taken seriously in academia itself, let alone industry.

(f) Another robust contextual issue is that, unfortunately, the existing trend of education in universities, including the SUT, is more towards postgraduate education, rather than engaging with industry (discussed above). Such an approach, for its part, has roots in and leads to other problems; it is grounded in the dilemma of industry's unwillingness to absorb potential experts (discussed above), and paves the way for these engineers to approach foreign, mostly Western, universities (which usually welcome talented and successful students from Iranian top universities) to do their Master's or PhD, and then serve foreign industries.

(see, in brief, Table 3a; rows 6-13)

6.3.3.3. On the Relationship Between Academia and Industry

Regarding the above-mentioned points, the relationship between academia and industry in Iran suffers from the following issues:

(a) As both academia and industry have been mostly established on the basis of importing from Western countries, they are greatly independent of each other, rather than being constructed and developed through a localized and inter-relational form.

(b) Therefore, they have not been developed based on their mutual needs. Industry does not (need to) believe in the role of universities and potential expert engineers, to develop itself in a more effective way. Instead, it fulfils most of its needs, in terms of technological knowledge and experience as well as actual experts, from somewhere other than universities, such as importing from other countries, in easier ways.

(c) Even in the very limited situations of industry's approach to academia, in order to take the needed engineers, there are two problems to be noted: (1) the underlying aim of industry is mostly to gain or to copy certain existing technologies, rather than creating or innovating new ones, and (2) consequently, as stressed by I2, 'the context of competition is not fair or inspiring for those candidates who are potentially more qualified and talented; this makes them less interested in devoting their time and energy to such unpromising competitions'.

(d) On the other hand, an essential need of universities – i.e. its budget in general – is to a large extent supplied by government, and industry has a very minor role here. This leads engineering education programmes to be organized in such a way that they disregard the real needs of industry.

(e) Further, Iran's academia is usually at least one step closer to the cutting edge of technological knowledge, as compared to its industry. This does not have a good consequence for graduates' enthusiasm to approaching industry, nor does it motivate academia to make significant improvements in engineering education plans.

(f) In the so-defined state of interrelation, any formal contract between industry and university would be very risky – particularly for the latter – in terms of cost, time, credit, etc.

(g) In addition, the appraisal system of teachers is very traditional and based on their teaching experience, published books and papers, and the like. Teachers are barely evaluated according to their ability in making good connections with industry, in terms of any achievements in absorbing significant projects and funds from it.

(see, in brief, Table 3a; rows 2-5, and 10-13)

All that said, what is proposed by the professors is not confined only to the above-mentioned 'is' type of descriptions of the context; they had also certain ideas, in this relation, raised from the 'ought' point of view (see, in brief, Table 3b). They believed several amendments needed to take place in the manner of improving the contextual system of engineering education. The following are the most significant points in this regard:

(a) A serious improvement needs to take place in both academia and industry; they need to reach a mutual understanding about each other's current situation and the necessity of collaboration towards successful growth. Such an understanding will result in a natural (reinforcing) relationship, which will not need much of the current external inefficient forces.

(b) The mission of universities, and SUT in particular here, needs to be clarified more so that they know their ultimate aim for engineering education (as mentioned earlier, each university needs to have a definite goal specifying either that it wants to deliver practical engineers or researchers to society;

that of SUT should be training potential-expert engineers, in the interviewees' opinion). Such an outlook would provide universities with a primary roadmap to re-plan their educational structure and content. This can also help as guidance for students who intend to enter industry after graduation; they will prepare themselves regarding what industry needs and expects. The industries, too, should reciprocally enhance their approach to more innovation and creativity. They need to move towards more independence in technological research and production; therefore, national issues of technology development should be their first priority, and then they need to have a global view of today's competitive market. They should also improve their current managerial view which expects engineers to be experts immediately after having graduated; this needs to be replaced with the long-term perspective which regards them as potential experts who need to grow and become real experts in the course of their experience within industry, based on their fundamental knowledge acquired in academia.

Table 3b. The interviewees' opinions about the 'ought's of the interrelations of academia and industry in order to be more efficient

Row	Interviewee(s)	Meaning Unit	Label
1	I1, I2, I3	Industry should move towards more innovation in design and production.	'ought's for a more efficient relationship between industry and academia
2	I2, I5, I6, I7, I8, I11	Universities, particularly SUT, need to change their current postgraduate-oriented education system; they should move more towards industry.	
3	I2, I3, I4	Industry needs to modify its thinking; it requires potential expert engineers, not actual ones.	
4	I2	Industry should first take national needs more into account; an international outlook should be in second place.	
5	I2, I4, I7, I8, I9, I11	Both industry and academia need to know and supply each other's real requirements more efficiently: industry needs potential well-trained engineers and academia needs promising projects and funds.	
6	I5, I6, I8, I11	Industry-oriented education prepares more knowledgeable engineers for specific professions within industry.	
7	I5, I11	Teachers' scientific assessment and promotion should be tied to their effective connection with industry.	

(c) Universities should believe in the need for industry. Teachers' scientific progress and qualification, as well as their official promotion in this perspective too should tie with their success in identifying and capturing the real demands of industry, as well as providing relevant technical solutions to meet them. Furthermore, universities such as SUT should shift their approach away from research, in terms of taking both their subjects and funds, towards industry, and local industries are of the first priority. Although this may have more to do with their postgraduate level of education, it will certainly be accompanied by a great impact on the culture and the system of education, to be more industry oriented in the engineering education level. Approaching industry has another profit too for universities; engineers can focus on specific industries and this enhances their situation to find a proper career.

(d) What is designated about the 'is' (current) and the 'ought' (ideal) situation can be illustrated in some sense through Figures 5(a) and 5(b); they together reveal what types of the expected relations have been missed in the existing situation of the described system, and what types of them should be excluded (the filled arrows represent the existing relations, in contrast to the dashed arrows which stand for the non-existing ones).

As already discussed, barriers against making reforms in engineering education are not confined only to the dynamic of interrelation of academia and industry; there is another aspect of obstacles as well that relates to the educational system itself, namely, 'resistance to change' in two levels: (1) (some) teachers, and (2) the official system.

With regards to the first level, in the interviewees' opinion, there are (as usual) some teachers who do not like to change; this may have different reasons such as:

- Being satisfied with the current approach
- Believing engineering as a discipline is limited to design and analysis tasks
- Avoiding risks and difficulties of linking to industry

- Difficulties in updating their course material
- Not having a clear sense or view of the future of new approaches to engineering education

(see, in brief, Table 3c; rows 1-5)

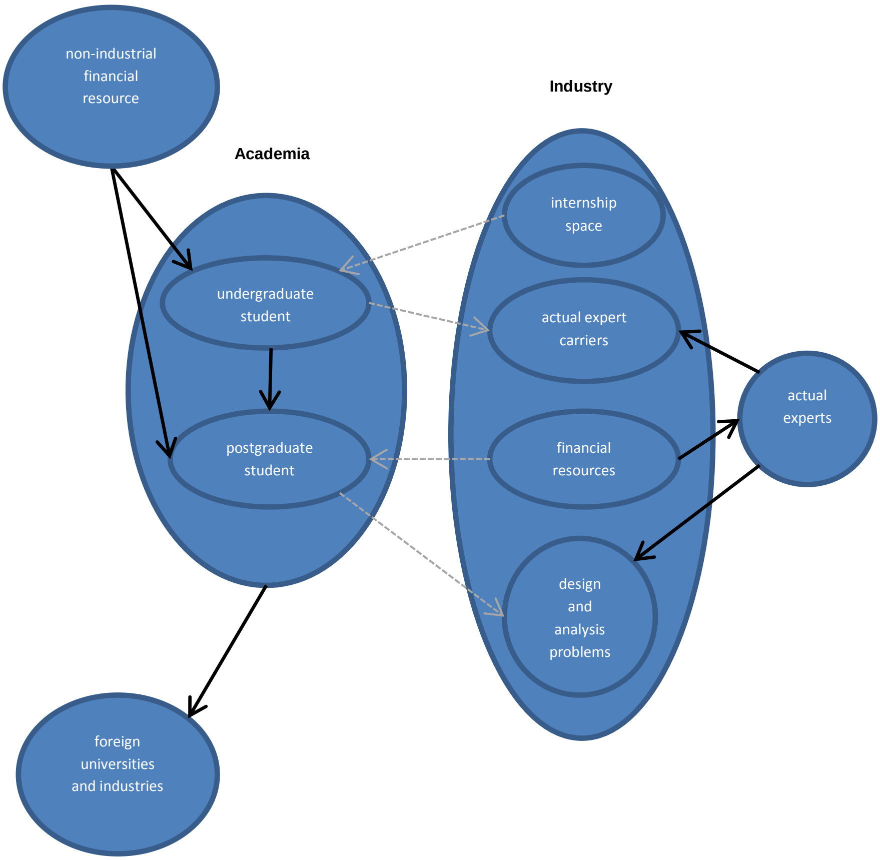

Fig. 5(a) The 'is' state of the interrelation of academia and industry in Iran

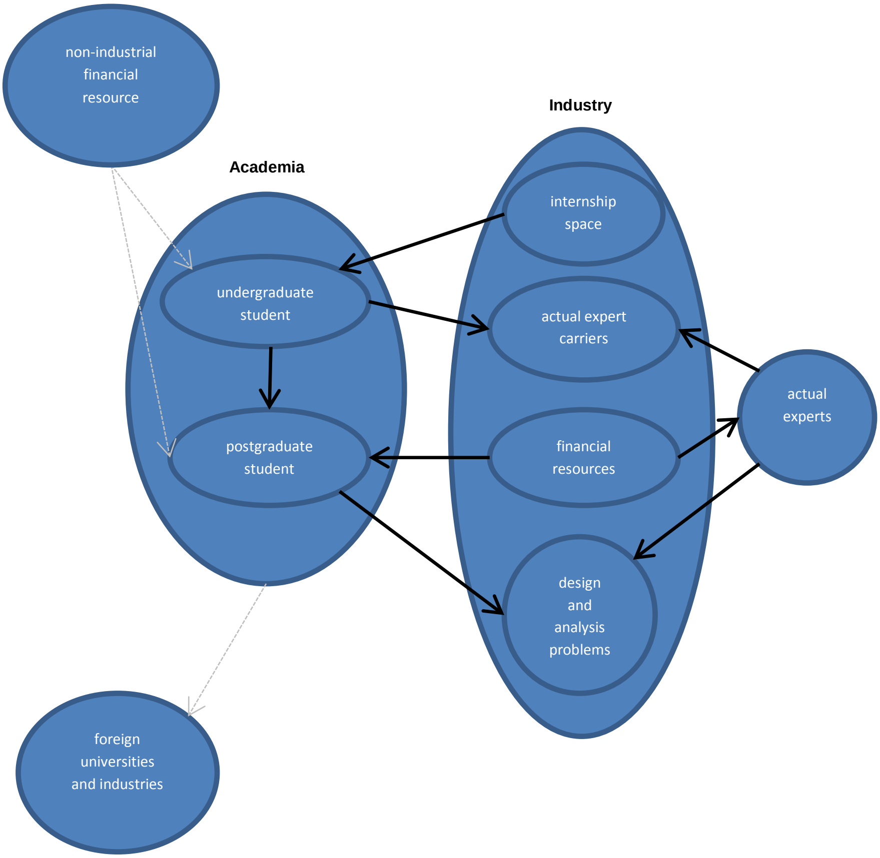

Fig. 5(b) The 'ought' state of the interrelation of academia and industry in Iran

This type of resistance, though serious, is not very hard to tackle. However, the situation gets more intricate when it comes to the second level that has to do with the resistance of the official (structure of the) system. As a matter of fact, Iranian universities are not very independent in defining or organizing their education contents, programmes, and methods; they should follow the approved documents issued in this relation by the Ministry of Science, Research and Technology of Iran. This makes the academia less flexible in changing their routine approach and the resulted methods; making any reform needs to be accompanied by the support of the Ministry (Table 3c, row 6).

That being said, the point worth mentioning here is that fortunately the significance and the necessity of making some reforms in engineering education has become clearer for the Ministry in recent years. However, what makes having such support difficult to implement is the complex and huge bureaucratic procedural flows in the official structure of the Ministry. In other words, the matter of contextual obstacles here is of the bureaucratic type.

Table 3c. Resistance to change within academia and its governmental supporting organizations

Row	Interviewee(s)	Meaning Unit	Label
1	I2, I9	Some teachers are satisfied with the current approach.	teachers' resistance to change
2	I2, I4	Some teachers believe that the engineering discipline is nothing but engaging with design and analysis.	
3	I5, I7, I8, I9, I11	Some teachers are conservative; they avoid any risk or difficulties of change.	
4	I8	Some teachers do not have a clear or well-imagined view of the future of new approaches and its requirements and needed plans.	
5	I4	Some teachers are very zealous and are biased towards the superiority of engineering against other disciplines or fields of study.	
6	I4, I7, I8, I11	Any change in the university education system or method should be approved by passing through the complex bureaucratic system of the Iranian Ministry of Sciences, Research, and Technology.	official system's resistance to change

Now, it is worthwhile to put this expounded discussion about the barriers beside the previous questions. This whole yields an insightful view to what flows in the context of engineering education in Iran and specifically in SUT, and its relation to the world of practice and industry. Therefore, let us end the study with the concluding remarks and recommendations in this relation.

6.4. Discussions and Recommendations

Planning to reform the current engineering education programmes is not easy to perform, nor does it only have to do with the scientific captivity of the current curricula. Rather, our study on SUT revealed that these programmes could be actually engaged with a contextual type of captivity, encompassing the first one, and they both required to be reflected upon in relation to each other. As a matter of fact, in contrast to the former which holds for many US and European technological universities, and consequently has been taken far more into contemplation, the latter more concerns some non-Western universities which have quite complicated and poorly consolidated interrelations with the industry sector(s) of their countries, and has not been seriously considered until now.

The chapter attempted to address both types of captivities in the area of mechanical engineering in Iran, from the perspective of academia. It was based on extensive interviews carried out with eleven staff members in SUT's Mechanical Engineering Faculty. Firstly it set out to establish a definition of a desirable newly-graduated engineer. Most respondents believed that it is difficult to find a common picture of (the qualifications of) newly-graduated engineers in the Iranian context, particularly in its universities and industry. The interviewees considered this problem from different angles and declared that if such inconsistencies cannot be tackled, other attempts will be abortive.

The second step considered the desired modifications needed to ensure that the newly-graduated engineers comply more closely with the expected criteria. Here, staff members generally thought that the current curriculum should be released from the constraints imposed on it by the existing theoretical working-on-paper approach. They suggested (i) lightening the load of the Basic and the Optional Specialised courses while at the same time increasing their quality; (ii) providing, on the contrary, more space to enrich and update the content of the

Generic and Compulsory Specialised courses; and (iii) making all courses more interactive and more relevant to actual practice.

Finally, the study touched on the significant fact that developing a desired curriculum has to do with many other significant infrastructural issues and barriers that impact on the Iranian context of engineering, in both education and practice. The third question therefore attempted to take up these points. The interviewees emphatically pointed in this respect to a significant number of problems within academia and industry as well as their interrelation. They also spoke of different types of resistance to reforming engineering education. The main concern that emerged in various discussions was that, when making any plan to reform mechanical engineering education in Iran, the role and state of contextual variables should be taken into consideration.

This could all provide a useful contribution to the recent studies that have hardly considered the issue of contextual captivity beside the scientific one. A short review of them illustrates well that they have mostly taken up the science-bound related issues of engineering content and have attempted to deliver their various solutions from this perspective; research which deals with topics such as:

- different aspects of engineering sciences and how they differ from mere applied sciences
- specific features of engineering knowledge
- diverse characteristics of design in engineering
- the implementation of liberal education in engineering studies
- issues of sustainability, the environment and ethics
- religious and political values in engineering
- new visions and skills for engineering
- globalisation in engineering
- system engineering

- new technological contexts of engineering; IT, cyberspace and virtual reality

(see for instance various texts within well-known published documents such as National Academy of Engineering 2004; Christensen et al. 2007, 2009; National Academy of Sciences 2008; Meijers 2009; The Royal Academy of Engineering 2010, 2011)

Even the studies which have touched on the 'context' of engineering have examined it mainly in terms of its industrial side; those, for instance, examining the humanitarian context of engineering (Mitcham & Muñoz 2009), highlighting the interrelation of engineering and various institutions and organizations (Delahousse 2007, 2009), considering the social aspects of technology (Kroes & Van de Poel 2009), or dealing with environmental, ethical, religious, or political considerations on engineering (Didier 2007, 2009; Van de Poel 2007, 2009). However, very little education-based perspective has been devoted to the subject of 'context' in the sense of tackling different captivities in education caused by poorly consolidated interrelations between the various parts of society, particularly its industry and academia.

Therefore, the approach adopted in this contribution could potentially open up a broad field of study for those interested in reflecting on engineering education from the wider view of society, within or across countries. That is to say, various points are supposed to be considered, particularly in some non-Western countries where different societal variables may have created specific situations need to be reflected upon in more detail, in order to reach a wiser perspective. This will help underpin more successful plans in engineering education in these contexts and move the barriers of knowledge forward.

It is also worth mentioning that such a study can be complemented with further research of this kind, but from the industry's perspective. Exploring different features of mechanical engineering in actual practice within industry of Iran, for instance, could yield many insights from the perspective of experienced engineers or other significant actors of industry. This could shed light on the industrial context as well as lead to some complementary ideas in two ways: (1) through identifying the current gaps in the curriculum, to deliver more qualified graduates in terms of an appropriate level of knowledge, skills, and attitudes needed for the real practice of engineering, and (2) through providing more information about the real problems and, particularly, the bottle necks of the interaction between engineers and industry, to be reflected upon and prioritized in policy making decisions.

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07

Chapter. 7

CONCLUDING REMARKS AND RECOMMENDATIONS

CONCLUDING REMARKS AND RECOMMENDATIONS

> *"The exciting future of engineering is beyond technological labels (e.g., mechanical engineer, electrical engineer, and chemical engineer) where isolated training falls to a more powerful profession of broadly educated "holistic engineers" – engineers who manage, lead, and understand complex, interdisciplinary systems that bring the power of engineering thought to issues spanning and connecting technology, law, public policy, sustainability, the arts, government, and industry. The end of technology as engineering's sole focus allows a future where the engineering profession actively grows and evolves, bringing the very best of science, technology, and innovation to serve the complex challenges of our 21st century lives."* (Grasso & Burkins, 2010)

> *"We came to recognize that our initial thinking about the keys to educational reform was wrong. The key variables weren't pedagogical. They weren't financial. They weren't curricular. They weren't research. They weren't any of the usual things we've always talked about as the engines of change. The variables were deeply emotional and cultural."* (Goldberg & Somerville, 2014)

This thesis began by raising the significance of making reforms in engineering education, in order to foster knowledgeable engineers who can deal with their increasingly technological work. It was shown that this significance has already been emphasized through a body of research, and that attempts to address the issue using various approaches have been made. Continuing in this line, the body of this thesis has endeavored to examine different features of the issue from an innovative perspective, taking advantage of philosophical reflections upon engineering/technology. It stressed the necessity of basing reform plans upon delivering a comprehensive understanding of engineering/technology and provided substantial insights and practical points to be considered in this regard.

7.1. Recapitulation: A Brief Sketch of the Findings

The study commenced with asking a central question, that is, "*In what respects do the current approaches to engineering education deliver a comprehensive image of engineering/technology and the socio-technical style of the future work and life of engineers?"* The examination was then conducted at two different levels of education: *primary/secondary* schools, in which students need to acquire an appropriate but general image of technology, and the *tertiary* level, that deals with engineers in training who require rather in-depth understanding about different aspects of engineering practice. The central question was split into five sub-questions, each taken up in a separate chapter, recapitulated as follows.

7.1.1. On the Primary/Secondary Levels of Education

Sub-question 1: Do standards for Technological Literacy render an adequate image of technology?

The research began from this overall inquiry into the state of engineering/technology education at the pre-university level, on the basis of the existing common-sense about the significance of fostering technologically literate students from the very beginning level of their education. The American case of *Standards for Technological Literacy* (ITEA, 2007) was a relevant candidate to be examined in this respect: this standard, the most extensive standard of technology education, has attempted to present an updated view of the knowledge that students need for encountering the technological world. It is therefore relevant to this thesis to examine how this standard has taken the nature and various features of technology into account.

The first step of our innovative approach enabled us to develop a solid framework for tackling that concern. That is to say, by drawing from the philosophy of technology and making use of Mitcham's perspective, our approach could deliver a framework which embraces a sizeable number of significant concepts and concerns to be learned about technology. Technology, in this approach, has four essential aspects to be considered: *object*, *knowledge*, *process*, and *volition*, each of which contains specific notions and features. Such a perspective also revealed the significant shortcomings of the studied case, particularly in terms of the *knowledge* and *volitional* sides of technology, and, more specifically, the essential notions such as *models* (and *modeling*) and *normativity*. All in all, the study yielded an extendable contribution that could be applied to other standards of technology education as well and lead to practical insight as to those cases' holistic approach to technological literacy.

Sub-question 2: To what extent could the specific approach of The New Zealand Curriculum foster a comprehensive understanding of the nature and various features of technology?

The New Zealand Curriculum is a relevant case for extending the domain of the aforementioned approach and gaining additional insights for this line of discussion. The main authors of the *Curriculum* claim that it is an approach based on the philosophy of technology, and more specifically, that it matches Mitcham's perspective. This is a fairly similar vision to our own in terms of structuring the base of technological literacy plans; therefore, examining it could lead us to complementary ideas as to our approach. On the one hand, we could analyze that case and see how well it satisfies our framework's view and, on the other hand, this application could extend the domain of our results about the concepts and concerns to be learned about technology and the according necessary amendments; in both respects, analyzing this case could make our research more reliable and insightful.

In the course of this study, the findings revealed that a significant number of the problems found in the American case are shared by the New Zealand case as well: although the *New Zealand Curriculum* is a worthy movement toward technological literacy and embracing novel points, the understanding of technology it presents needs serious enrichment, particularly as related to the *knowledge* and *volition* sides of technology, and more specifically in terms of subjects such as the state and various attributes of *models* (and *modeling*), and the matter of *normativity* in technological practices.

Considering the outcomes of grappling with the first two sub-questions, the research moved further toward a narrower, but more profound, examination into the significant but ignored concepts of *models* and *normativity*, as intended in the course of addressing sub-questions 3 and 4.

Sub-question 3: How can one deliver a comprehensive account as to the nature and various properties of 'models' designed and used in engineering practice?

The main issue found in teaching about *models* in the earlier studied case was that it is confined to partial views. One could see that STL focuses mainly on some functions of models, such as *simulating*, *prototyping*, *testing*, *simulating*, and *communicating*, and NZC, as well, views *models* merely from the perspectives of *functional modeling* and *prototyping*. We discussed that such restricted views, based on philosophical reflection, do not do justice to describing the nature and various properties of *models* and, consequently, do not deliver a comprehensive understanding in that respect to students.

Incidentally, it was discussed that the issue of learning about models is not confined to the primary/secondary level. It has been made clear that even in the tertiary level the principal focus of engineering students, in the course of designing and making use of numerous models, is on how to simulate their idea and/or design their relevant model, in order to be able to evaluate or justify their idea, communicate about it, etc. Students in the latter level pay scanty attention to the nature and various features of the very knowledge necessary to deal with models or acquired from such activities (see, e.g., Boon & Knuuttila, 2009; Brockman, 2008; Knuuttila, 2005).

Proposing that *models* be considered *techno-scientific artefacts* was the core idea that came from addressing the sub-question. This idea was yielded by exploring the philosophical reflections on models. Models in this respect are thought of as artefacts with a dual nature: the *intrinsic* and the *intentional* natures, realized in relation to each other. This account led to a solid rationale for explaining the nature of models, and to a well-ordered structure for describing their various properties and functions. Approaching models through such a concrete and wide-ranging perspective was the main suggestion of this contemplation that could be applied to engineering/technology education standards, plans, and curricula, at both pre-university and university levels of engineering/technology educations. This perspective extends the customary view of seeing models from the mere *process* side of technology to the realm of epistemological – i.e., *knowledge* side – considerations as well.

7.1.2. On the Tertiary Level of Education

Sub-question 4: How does one deliver a concrete educational account about the normativity in technology?

The lack of sound attention to the *normativity* of technology was another major issue of the studied standards. This issue, as discussed in this thesis, has much to do with the *volitional* side, particularly so-called *ethical* concerns regarding technology, although so far taken into philosophers’ consideration mostly from the knowledge side.

Pondering the concept of *normativity* was an appropriate point, for our thesis, to turn to the tertiary level of engineering education, where engineers are mostly pushed toward the so-called *specialized* subjects and courses, and the *volitional* side of technology has been blurred in the course of increasing thrusts to various types of technological developments, although the matter of fostering ethically-informed engineers has been recently taken into special account by philosophers of engineering/technology.

It was argued that technology development is essentially a *normative practice*, and what matters in this respect is highlighting the fact that this *normativity* is inherent to such practices, not an outside set of rules. This account, which goes against the most customary view of ethics, makes a great impact on the mindset of learners. They will not see the moral and ethical considerations as external rules to be recognized and incorporated in the practice the view that has always made technology prone to many *relativistic* approaches and *heterogeneous* judgments about how to prioritize various technological norms and rules and apply them to the different parts of engineering practice. Norms and rules are, rather, constructed upon more concrete foundations, and what matters, therefore, is learning well about how to identify, comprehend, and analyze the essence of such foundations.

It was also reasoned that Dooyeweerd's (1955) ontological approach could play a significant role in this respect. This approach, emphasized in the inspiring book *Teaching about Technology* (de Vries, 2005) is worth learning about, and was shown helpful in realizing the nature of things and identifying the type of their inherent governing norms.

Ethics, consequently, is supposed to be realized on the basis of considering the two types of *constitutive* and *regulative* normative rules, each entailing their inherent norms, specific to each practice. Such an approach could lead to wiser comprehension as to analyzing different types of technological practices, even the complex and multilayered socio-technical ones, in the sense of ethics – a claim confirmed well in the course of studying the ethics of damming as one of the most controversial fields of modern sociotechnical practices. We could present a clear description, in terms of the normative *constitutive* and *regulative* rules of this practice, as to why the case of the Abbasi dam became a prominent exemplar of a sustainable development for centuries, and why the Zayandeh Rood dam failed in attaining its design missions and caused many problems to its environment and people in less than half a century.

Sub-question 5: How can the current engineering education at the tertiary level be improved, considering the probable hindrances?

One way of dealing with this question would be choosing some well-known policy documents or curricula for this level of education and seeing how they have taken certain aspects, concepts, and concerns of engineering/technology into account, as was earlier done for the primary/secondary level. However, improving the quality of engineering education at this level, in the sense of delivering a more comprehensive perception about various aspects of the practice of engineering, turned out to be more complicated than expected, and our studies in this respect revealed some more profound issues to be tackled. Moreover, the subject of extending engineering students' view of the different features of their professional practice and socio-technical environment had already been considered in a wide variety of research, and this might make the inquiry not particularly novel.

It was pointed out that engineering education, although related to academic systems and approaches, is simultaneously related to the numerous external variables as well: the specific features and characteristics of the broader context of the encompassing society, particularly the industry. This necessitates a concurrent attention to two types of hindrances, which were focused upon in this part of the study by interviewing a number of staff members of the selected case of engineering education.

The first type of hindrance had to do with the main approach of the existing, typical curricula – bound to science-oriented materials and implying an image that what engineers do is an application of theoretical science. This type of problem was supposed to be tackled through improving the content of education in three aspects: *attributes*, *knowledge*, and *skills*. However, there is a second type of obstacle raised in so doing: the contextual issues rooted in the broader context of social variables, particularly those of the complicated interrelation of academia and industry, which impose themselves on the area and approach of the education.

The Iranian case of mechanical engineering education at Sharif University of Technology is an appropriate case for this study. As a non-western university, it contains several kinds of issues related to its specific context, a poorly-established context of industry, in the sense of the quality of coordination with academia. This case is obviously just one among many others, and what was intended in the related study was to draw attention to this critical angle of view of reforming engineering education plans. That is to say, the study should not be considered to be confined to that case, or non-western contexts; this perspective could be applied to a western context as well.

7.2. An Overall Look at the Contribution: A Holistic Approach to Educating Holistic Engineers

At this point we would like to turn to an overall look at the thesis by highlighting an essential point, that is, the contribution of this thesis should not be confined to analyzing certain cases and amending them in terms of enriching some concepts; nor are its narrower targeted concerns confined to some partial problems to be addressed. The main aim of the thesis, rather, has to do with the necessity of setting a broader outlook for engineering education, that is, delivering a concrete image of different aspects of engineering practice.

This contribution, overall, proposes *a holistic* approach to *holistic engineering education* (the term suggested in Grasso & Burkins [2010]), and also paves an innovative way for doing so. In one respect, it draws attention to some considerable deficiencies within two well-known standards of education, namely their failure to provide a comprehensive understanding of different aspects of technology. The issues will most likely be reflected in other known standards as well, in one way or another.

In a more detailed respect, it also highlights the lack of appropriate attention to some critical concepts within the studied standards. More specifically, it was strikingly clear that the major concepts of *models* and *normativity* have not been taken into serious account in the selected cases, and this could therefore be expected to be even more problematic in less extensive standards and educational policy documents. The special perspective of this thesis on the concepts of *models* and *normativity* can be used effectively to address their relative absence in various plans of engineering/technology education at both the pre-university and university levels.

Furthermore, this thesis has attempted to convey a complementary but critical concern for improving the tertiary level, specifically that reforming engineering education plans is not likely to be possible through simply proposing more technology-oriented educational content. The current structures and systems of education are typically rooted in various complexities of their context. This combination of factors and their intricate interrelations need to be subjected to a deeper analysis, in contrast with most proposals concentrating on the material side of education. The role of context is not exclusive to the studied case or those of similar universities; rather, it should be expected to apply to most universities across the world and therefore needs to be approached from a much broader viewpoint than most customary attempts.

The special approach of this study, as compared to some major and more conventional ones, is what enabled us to suggest appropriate changes. As a matter of fact, the concern of fostering more knowledgeable engineers has received much attention during the past decades – particularly regarding ever-progressing technology and socio-technical systems – and has already been subject to certain considerable approaches that differ based upon how they conceive of the nature and/or the priority of the problem(s) to be addressed. What follows presents a brief sketch in this regard:

1) Some attempts intend to analyze and describe the ever-increasing rate of technology development. These types of reflections, although of educational use in the training of engineers, have mainly to do with empowering people in general and adjusting their mindsets so that they can envision and be equipped to deal with the complications of fast-changing technology (at least in their perspective). This approach, which has received the attention of works such as *The engineering 2020: Visions of engineering in the new century* (NAE, 2004) as well, is highlighted and elaborated in studies such as Kurzweil (2005), Mbe (2015), and Shanahan (2015).

2) Some studies, on the other hand, have concentrated on providing various philosophical backgrounds describing the nature and different features of technology, socio-technical systems, and engineering phenomena. This approach, however, is mostly followed in the area of the philosophy of engineering/technology and finds little direct interrelation with the customary engineering education. Philosophical works such as Christensen, Delahousse, & Meganck (2009), Meijers (2009), Michelfelder, McCarthy, & Goldberg (2013), and Pitt (2011) are examples of this.

3) There exists a sizable approach, nevertheless, which has more specifically to do with the practice of engineering education. It emphasizes the necessity of, and focuses on, restructuring and improving the current standards and curricula of engineering/technology education, in order to empower future engineers to track, analyze, and comprehend the various features of the socio-technical practice of engineering. This approach appears in most recent standards and policy documents, aiming, in one way or another, at proposing more comprehensive and relevant educations about technology/engineering at either primary, secondary, or tertiary levels. Such an orientation can be seen in the earlier-mentioned standards of the primary/secondary level (see 1.1), as well as works such as *The Engineer of 2020; parts I and II* (NAE, 2004; 2005), *Grand Challenges for Engineering* (NAE, 2008), *A Whole New Engineer: The Coming Revolution in Engineering Education* (Goldberg & Somerville, 2014), *Engineering for a Changing World: A Roadmap to the Future of Engineering Practice, Research, and Education* (Duderstadt, 2008), and *Holistic Engineering Education* (Grasso & Burkins, 2010), in relation to the tertiary level.

The innovative aspect of the suggested line of this thesis, however, lies in connecting the latter two approaches. This thesis has focused on fostering more knowledgeable and effective engineers (the second approach) by taking advantage of philosophical reflections upon engineering/technology (the third approach) – a combined approach leading to a more concrete and reliable foundation for engineering education reform plans, which are typically built upon empirical feedback and learning (The Royal Academy of Engineering, 2012). We believe that the suggested approach is able to open a valuable perspective to engineering education and improve it in a number of respects.

The next point we would like to address is about a significant objection raised by some teachers or education planners, which is pointed out in the sixth chapter of the study. They claim that improving the content of engineering education at the expense of dropping some science-based courses or in terms of enriching their curricula with technology-based content is neither a wise nor a feasible suggestion. Students, in this contrary view, need to acquire extensive understanding about the scientific basics supporting the foundational knowledge and skills of engineering in practice, and the ordinary length of an engineering education (around 3-5 years) does not allow them to absorb other types of learning concurrently. In order to answer this objection, we need to make it clearer how the thesis relates to reforming the science-based curricula of engineering education. First, improvement in this approach does not necessarily imply dropping some courses. What matters here is making them as efficient as possible, and this can be accomplished by lightening them, as well. Although some courses may be dropped entirely, others may just need some partial reduction in this approach. Outdated and obsolete materials could be pruned out at this level of education. Secondly, the central decisions on reforming engineering education, according to this view, are not in the hands of the teachers, who are typically resistant to dramatic changes. Such decisions should instead be made and brought into application by the main board(s) of directors. They are the ones responsible for taking an overall look at the effectiveness of education in their university and reflecting upon ways of improving it. There is no convincing argument that the current material of education should be entirely prioritized over more practice-based educational content. One can consider, for instance, the case of reforming engineering education in Eindhoven University of Technology in the Netherlands, which was approved by the university's board.

7.3. Limitations of the Study

The study presented here, although it attempted to satisfy the main research question with concrete inspections and argumentation, had its own limitations in doing so. First of all, drawing from the philosophy of engineering/technology and examining the points, concepts, and concerns raised did not always lead to homogeneous ideas about a specific subject. For one thing, one could see that the realm of considerations about ethics contains many different and even incommensurable opinions, rooted in diverse assumptions or world views, not easy to combine or compare in order to arrive at conclusive points. Even the suggested account of the inherent normativity of practice is based upon Dooyeweerd's *non-reductionist ontological* approach, which itself might be challenged.

The next difficulty encountered in the research had to do with the matter of reliable and accurate interpretation. That is to say, since the research was largely underpinned by analyzing the literature, documents, and verbal opinions, understanding the exact meaning, or the underlying implicit intentions, became intricate at times.

Finally, we would like to refer to the problem of linking the mindset of philosophers to that of the researcher or policy makers in the area of education. There is much in-depth philosophical thinking on different aspects of concepts that have little relation with the necessary content and material in engineering education. These types of considerations require illumination in order to be applicable to the field of engineering/technology education for non-philosophers.

7.4. Recommendations for Future Research

Based on the argumentation line of this thesis, we would like to suggest the following subjects for extending the sphere of considerations of this research:

7.4.1. From Philosophy to Education

- The study performed on the concepts of *model* (and *modeling*) for the primary/secondary level can be broadened to embrace the other necessary notions as well. Concepts such as *the know-how aspect of technological knowledge*, *evaluation*, *aesthetics,* and so forth, were revealed in the thesis but have not been taken up thoroughly in the studied cases and, although not as important as *models* or *normativity*, can be a subject for further philosophical explorations.

- The concept of *model* (and *modeling*) itself seems to have great potential for study, including at the tertiary level. Although it may appear at first sight that students at this level grapple enough with making and using different types of models, the background surveys of this thesis revealed some significant question marks as to the learning acquired in this way. That is to say, *models* seem to be typically perceived at this level of education as intermediary tools, to gain an understanding. Consequently, the matter of acquiring insights as to their own specific nature and various features barely receives any educational attention.

- The customary standards or other types of policy documents at the tertiary level are also recommended for further study – particularly regarding the state of the *volitional* aspect. Most engineering education standards and curricula appear to have predominantly inclined toward specialized courses, and according to this perspective, engineers are expected to become well-informed and well-skilled experts regarding the various technical types of analyzing and designing activities. This approach, although it has many proponents, seems to have led to considerable ignorance regarding social issues, especially those related to *morality* and *ethics*. This is indeed a significant concern worth reflecting upon, in terms of relevant questions about what engineering students need to learn about the volitional side of their practice. Moreover, this question can be addressed from the 'how' view as well, because engineering education plans have their own limits in terms of available time, cost, and teachers, and these may need to be addressed through some innovative compromises regarding the necessary material of education.

- The proposed account for *normativity*, for its own part, can pave the way for reflections on *morality* and *ethics* to progress further – from abstract and/or theoretical views towards more realistic insights about the complex and multilayered socio-technical activities of engineers. This approach can lead to additional insights regarding *sustainable development,* from both global and local perspectives. Furthermore, the suggested account would be considered a broad view that can be the subject of more focused reflections upon certain aspect(s) of technological practices. For instance, the matter of *locality* has great potential for further elaboration and explanation.

- The *contextual issues* of engineering education also can be a subject for further research. For instance, as pointed out, the reason that the *social* and *contextual* obstacles to reformative plans for engineering education have barely received any explicit considerations – particularly in the sense of the interrelation of academia and industry – could be attributed to a significant fact: most reflections upon engineering education (re)planning have a western background and have evolved in a context of fairly well-established correlations between academia and industry, as compared to non-western backgrounds. These sorts of obstacles, nevertheless, are not specific to the latter contexts; they are, rather, a global issue, which manifests to varying degrees across different situations, and, accordingly, should be taken into account (see, e.g., the brief discussion over this issue in the US [NAE, 2005]). Thus, one can propose that this issue be examined for western countries as well as for non-western ones. Such attempts in combination can lead to an insightful set of reflections upon various types of *scientific/contextual captivities* (as defined in Chapter 6), which need to be approached, recognized and overcome.

7.4.2. From Education to Philosophy

- Although not made explicit in the thesis, its underlying research revealed an interesting point worth mentioning here: contrary to the presented approach of this study, in the sense of using the insights of the philosophy of technology/engineering to enrich the discipline of educating about them, there exist some well-considered notions in the area of education that have not been examined in the former types of reflections. For one thing, while the process of *production*, a pivotal component of most engineering activities, receives a substantial place in the studied standards, one can find barely any philosophical reflections about such a significant process. If philosophers are to extend the sphere of explorations into the nature and various features of significant aspects of technology/engineering, the concept of *production* is no doubt a substantial candidate in this respect; production is the essential step of engineers' practice without which the technical activities can be said to be meaningless.

7.5. The Final Word: On the Further Uses of the Proposed Approach

The area of philosophical reflections upon technology/engineering can present a rich field of various insights into the area of engineering education, particularly in the sense of its 21st-century characteristics. The environment of engineering is undergoing great changes in different aspects of its socio-technical essence, and a Kuhnian *paradigm shifting* appears to be happening for the current contexts of engineering (Goldberg, 2010). This fact accordingly needs to be considered in the course of transforming engineering education plans, and, as argued in the interesting book *A Whole New Engineer* (Goldberg, 2010), philosophical reflections can play an increasing role in this respect.

> *Kuhn argued that scientists turned to philosophy of science [science in the opening moments of the 20th century] as a way of both understanding*

> *the crisis of thought they were going through and as a way to help other scientists make the transition to the new thinking. … [T]he rapid pace of technological change in the opening moments of the 21st century is as disorienting to engineers as those earlier times were for scientists. It is in this spirit that I think philosophical reflection is particularly important for engineers right now. … The signs are clear that the old paradigm is breaking down and the new ways of thinking about what it means to be an engineer are emerging form the pace, scope, and sweep of technology in our times.* (Goldberg, 2010, p. 156)

It is worth emphasizing that such an approach should not be seen as being at all limited to a so-called *analytical* perspective, which may seem more directly related to different aspects of technological practices. One can appreciate the benefits of the *continental* view, also – particularly when it comes to learning about the *volitional* side of technology.

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SUMMARY

This thesis deals with the matter of making reforms in engineering education, and it highlights the significance of delivering a more comprehensive image of technology and its different aspects in the course of training students about technology and engineering. The innovative contribution of the thesis lies in its approach of taking advantage of the philosophy of engineering/technology.

The thesis conducts its examination at two different levels of education: *primary/secondary* schools, in which students need to acquire an appropriate but general image of technology, and the *tertiary* level, where future engineers require rather in-depth understanding about different aspects of engineering practice.

This research emphasizes that training well-informed engineers begins at the primary/secondary levels of education. What matters at this level is providing students with an appropriate level of understanding about technology in general, a point which has already been highlighted within a number of current educational standards and policy documents.

The reflections of the thesis on two well-known standards, *The American Standards for Technological Literacy* and *The New Zealand Curriculum* (along with its *Technology Curriculum Support)*, reveal their significant issues in delivering a comprehensive image of engineering/technology; the initiated four-side framework, based on the ground of philosophers reflections on technology, plays a significant role in such an inquiry.

The American case, although it does pay considerable attention to many aspects of technology, turns out that is still subject to some serious critiques: it does not yield an adequate perception of the *knowledge* and the *volition* sides of technology, and there also exist some shortcomings in addressing the other sides in this standard. Moreover, the case needs to be enriched in terms of more specific concepts such as *models* (and *modeling*), and *normativity* of technology, in relation to the neglected aspects.

The New Zealand case, too, has its own challenging points, and although it notably considers some aspects of technology, its main structure scarcely leads to a sound understanding of the *knowledge* and *volition* aspects of technology. The concepts of *normativity* and technological *models* again are two important related concepts that need more profound consideration in this case.

Both studies correspondingly receive necessary recommendations for improvement, in the sense of addressing the critiques raised. However, the thesis also attempted to go further, toward more focused perspectives on the concepts listed within the developed framework, in order to address some shortcomings there as well. It begins by concentrating on the notion of *models* (and *modeling*). The standards have mostly approached the notion of *modeling* through the lens of 'technology as *practice'* – conceiving of *models*, for the most part, as tools serving various types of production activities, a view which neglects other aspects of models, particularly the nature and different features of the *knowledge* acquired from them. The proposed account of the thesis – i.e., considering models as *artefacts* with a dual nature – leads to a well-ordered description of them from an all-inclusive perspective.

The thesis continues at this point to the tertiary level of engineering education and extends the line of argumentation to the education of yet-to-be engineers, who need to acquire a deeper understanding (as compared to that of the preceding levels) of what they will most likely experience in the socio-technical environment they will soon be entering.

The earlier study on *models* (and *modeling*) would be an interesting candidate for extending the domain of discussion to the tertiary level. *Models* are playing an increasing role and representing various types of advanced and complicated structures in today's engineering practices. Although students at the tertiary level have expectedly more engagement with models (as compared to the previous level), the issue mentioned previously applies to this level too: *models* are generally dealt with from the *process* side of viewing technology, and their nature and different features – from the *knowledge* perspective – are still neglected at this level. However, we preferred to address the next outstanding candidate of those ignored in the studied cases – the concept of *normativity* of technology – in order to examine its place in tertiary level education. This extension of the research domain could lead to a more elaborated contemplation in terms of analyzing and enriching the content of concepts to be learned. Moreover, the concept of *normativity* pertains directly to the significant notion of *ethics* (as one of the most essential fields of philosophical studies about technology and engineering practices) and belongs to the *volitional* aspect of technology, which itself has received scant attention in most specialized engineering education plans. Inspecting ethics through the lens of *inherent normativity* was an innovative contribution that, through focusing on the case of damming, attempted to deliver a concrete view as to how to perceive and deal with the complex nature of ethical issues in the course of numerous, complicated engineering practices.

The argumentation line of the thesis ends with turning again to overall considerations on the content of educational plans, from the tertiary level perspective. The discussion points out that educational plans at the tertiary level are principally confined to *science-oriented* approaches that see technology through the lens of applied science and do not provide students with adequate information as to many real features of what they will experience in their future technology-based profession. It is argued that tackling this misleading approach, however, may not be feasible, because the structure of engineering education at this level has firm roots in its underlying context, particularly in terms of the interrelation of academia and industry. Such established interrelations are likely to raise considerable contextual hurdles (captivities) to improving the education of engineers. The non-western case studied yielded interesting results and practical insights as to recognizing such obstacles and dealing with them.

The thesis concludes with highlighting an essential point, which is that the contribution of the thesis should not be confined to analyzing certain cases and amending them in terms of enriching particular concepts, nor are its more targeted concerns confined to partial problems to be addressed. The main aim of the thesis, rather, relates to the necessity of establishing a broader outlook for engineering education, that is, delivering a concrete understanding of different aspects of engineering practice. This contribution overall proposes *a holistic approach* to *holistic engineering education* and paves an innovative pathway for doing so through further studies of the subjects proposed.

SAMENVATTING

Dit proefschrift behandelt de behoefte aan hervormingen in onderwijs in techniek en ingenieurskunde. Het laat het belang zien van het aanbieden van een breed beeld van technologie en haar verschillende aspecten, voor de opleiding van leerlingen en studenten over technologie en ingenieurskunde. De innovatieve bijdrage van dit proefschrift ligt in de aanpak om gebruik te maken van de techniekfilosofie.

In dit proefschrift wordt op twee verschillende onderwijsniveaus onderzoek gedaan. Als eerste op het niveau van basis- en voortgezet onderwijs, waarin leerlingen een adequaat, maar ook algemeen beeld van technologie dienen te krijgen. Als tweede op het niveau van hoger onderwijs, waarin toekomstige ingenieurs een diepgaand begrip over verschillende aspecten van de ingenieurspraktijk nodig hebben.

Dit onderzoek benadrukt dat de opleiding van goed geïnformeerde ingenieurs begint op het niveau van basis- en voortgezet onderwijs. Op dit niveau is het belangrijk om er voor te zorgen dat leerlingen een adequaat begrip van technologie in het algemeen opdoen; iets dat al in meerdere, huidige eindtermen en beleidsdocumenten is onderstreept.

In dit proefschrift worden twee bekende verzamelingen eindtermen tegen het licht gehouden: de Standards for Technological Literacy in de Verenigde Staten en The New Zealand Curriculum (met het bijbehorende Technology Curriculum Support). Hierdoor zijn belangrijke problemen aan het licht gebracht met betrekking tot het aanbieden van een breder beeld van techniek en ingenieurskunde, waarbij een aan de techniekfilosofie ontleend raamwerk een belangrijke rol speelt.

Uit de analyse van de Amerikaanse casus blijkt dat, ondanks de grote aandacht die in de eindtermen wordt besteedt aan veel aspecten van technologie, deze nog steeds onderhevig is aan enkele ernstige kritieken: het levert namelijk een ontoereikend beeld op over de kennis en waardegerelateerde aspecten van technologie en er bestaan tekortkomingen in de aanpak van andere aspecten van techniek/ingenieurskunde. Bovendien dienen de eindtermen verrijkt te worden met meer specifieke concepten zoals 'modellen' (en 'modelleren') en 'normativiteit' in technologie.

Ook de casus van Nieuw-Zeeland heeft zijn eigen problemen, en hoewel het rekening houdt met bepaalde aspecten van technologie, leidt de hoofdstructuur nauwelijks tot een goed begrip van de kennis en waardengerelateerde aspecten van technologie. De normativiteit van technologie en technologische modellen zijn weer twee belangrijke, gerelateerde concepten die meer, diepgaande aandacht behoeven.

Overeenkomstig deze resultaten, worden voor beide casussen de nodige aanbevelingen voor verbetering van de kritiekpunten gegeven. In dit proefschrift wordt echter getracht dit verder door te trekken naar meer gefocuste perspectieven op de concepten van het ontwikkelde raamwerk, om andere tekortkomingen ook aan te kunnen pakken. Als eerste wordt aandacht besteed aan het begrip 'modellen' (en 'modelleren'). De eindtermen benaderden het begrip modellen met name door de lens van 'technologie als praktijk'. Hierbij worden modellen voornamelijk als hulpmiddelen beschouwd, dienend voor verschillende productieactiviteiten, waardoor andere aspecten van modellen worden genegeerd, in het bijzonder de aard en verschillende functies/kenmerken van de kennis verworven door modellen. Het voorstel in dit proefschrift, om modellen als ‘artefacten’ met een tweeledige aard te beschouwen, leidt tot een overzichtelijke beschrijving van modellen vanuit een allesomvattend perspectief.

Vervolgens gaat het in deze thesis naar het niveau van ingenieursonderwijs, het hoger onderwijs. Daar wordt de eerdere redenering uitgebouwd naar de opleiding van ingenieurs die, in vergelijking met leerlingen in het basis- en middelbaar onderwijs, een diepgaander begrip dienen op te doen over wat ze zullen ervaren in de sociaal-technische omgeving waar ze toe zullen gaan behoren.

De voorgaande studie over modellen (en modelleren) is een interessante kandidaat voor het uitbouwen van de redenering naar het tweede onderwijsniveau. Modellen spelen een steeds grotere rol en stellen verschillende typen geavanceerde en gecompliceerde structuren voor in de ingenieurspraktijk vandaag de dag. Hoewel studenten in het hoger onderwijs naar verwachting meer betrokkenheid hebben op modellen (in vergelijking met leerlingen in het basis- en middelbaaronderwijs), is het eerdergenoemde probleem ook hier van toepassing: modellen worden in het algemeen bekeken vanuit de proceskant van technologie, en hun aard en verschillende kenmerken – vanuit het kennis perspectief – worden nog steeds verwaarloosd op dit onderwijsniveau. Toch gaven we er de voorkeur aan om aandacht te schenken aan het concept van ‘normativiteit’ van technologie om de plaats daarvan in het hoger (ingenieurs-)onderwijs te onderzoeken.

Deze uitbreiding van het onderzoeksdomein leidde tot een nader uitgewerkte beschouwing in termen van analyse en verrijking van de inhoud van de concepten die geleerd dienen te worden. Bovendien heeft het begrip ‘normativiteit’ direct relatie met het belangrijke begrip ‘ethiek’ (als een van de belangrijkste onderwerpen van filosofische studies over technologie en ingenieurspraktijken) en behoort het tot het waardengerelateerde aspect van technologie, dat zelf maar weinig aandacht krijgt in de meest gespecialiseerde ingenieursonderwijs-programma’s. De benadering van ethiek door de lens van intrinsieke normativiteit is een innovatieve bijdrage die, door een focus op de casus van het bouwen van dammen, een concreet beeld biedt op hoe men de complexe aard van ethische problemen kan bekijken en aanpakken in de loop van talrijke, ingewikkelde ingenieurspraktijken.

Het betoog in dit proefschrift eindigt met een terugkeer naar de algemene overwegingen over de inhoud van onderwijsprogramma's, gezien vanuit het perspectief van het hoger onderwijs. De discussie wijst erop dat onderwijsprogramma's in het hoger onderwijs voornamelijk beperkt zijn tot wetenschappelijk georiënteerde aanpakken, die technologie bekijken door de lens van toegepaste wetenschappen, en studenten niet voldoende inzicht aanreiken over de vele kenmerken van wat ze zullen ervaren in hun toekomstige, op technologie gebaseerde beroepen. Er wordt aangetoond dat het aanpassen van deze onevenwichtige aanpak echter wellicht niet haalbaar is, omdat de structuur van ingenieursonderwijs op dit niveau sterke wortels heeft in de onderliggende context, met name wat betreft de relatie tussen de academische wereld en de industrie. Dergelijke gevestigde relaties zullen waarschijnlijk aanzienlijke, contextuele hindernissen opleveren voor het verbeteren van de opleiding van ingenieurs. De niet-Westerse casus (Iran) leverde interessante resultaten en praktische inzichten op over het (h)erkennen van en omgaan met zulke obstakels.

Dit proefschrift sluit af met het onderstrepen van een essentieel punt, namelijk dat de waarde van dit proefschrift niet beperkt is tot het analyseren van casussen en het verbeteren ervan door verrijking met bepaalde concepten, noch zijn de meer specifieke aandachtspunten beperkt tot partiële problemen die aangepakt dienen te worden. Het hoofddoel van dit proefschrift, daarentegen, heeft betrekking op de noodzaak van een breder perspectief voor ingenieursonderwijs, dat wil zeggen, het leveren van een concreet begrip van verschillende aspecten van de ingenieurspraktijk. Het proefschrift stelt een holistische benadering voor ingenieursonderwijs voor en kan leiden tot verder onderzoek naar de voorgestelde onderwerpen.

ACKNOWLEDGEMENTS

It is not easy to do justice in words to the valuable support of those who helped me to complete my Ph.D. However, I trust that all those whom I would like to acknowledge understand the limitations of words.

I would like to begin by expressing my deep gratitude to my wonderful promoter, Prof. Marc de Vries, who taught me a new way of contemplating research. His strict supervision and insistence on rigorous, qualitative work, although very time-consuming for us both, resulted in my absorbing a great deal of knowledge and was well worth the time spent in light of the research I accomplished.

In addition, I appreciate the support of all of my colleagues and friends in the Science Education and Communication section of the TNW Faculty, particularly Maarten van der Sanden, Martin Jacobs, Claudia Westhoff, and Leonie De Kluijs, and in the Philosophy of Technology section, specifically Prof. Peter Kroes and Prof. Ibo van de Poel, for their valuable help during my work at Delft University of Technology.

I would also like to offer my profound thanks to Dr. Taqavi at Sharif University of Technology, who fanned the first sparks of my philosophical thinking about technology and connected me to Delft University of Technology; my brilliant teachers in the Graduate School of Management and Economics at Sharif University of Technology, who helped me learn to analyse different features of the technological world that surrounds us; my colleagues from the Iran Society of Engineering Education, particularly Prof. Jabehdar Maralani and Dr. Memarian, who supported this attempt and provided insight and expertise that greatly improved some parts of the research, although they may not agree with all of its interpretations or conclusions; and Dr. Sohrabpour, deputy of the head of the National Elites Foundation of Iran for his valuable and constructive suggestions and cooperation during the planning and development of this research work. Their willingness to give their time so generously has been very much appreciated.

I wish to extend my thanks to the following staff members of the Faculty of Mechanical Engineering of Sharif University of Technology in Iran for their respected advice and assistance with the 6th chapter of this research: Dr. Alasti, Dr. Arjmand, Dr. Bahadori Nejad, Dr. Behzad, Dr. Behzadipour, Dr. Firoozabadi, Dr. Meghdari, Dr. Movahhedy, Dr. Saadat, Dr. Seif, and Dr. Zohoor.

I am also grateful to my many good Iranian friends in Delft who helped me cope with the difficulty of the work and were supportive of my stay in the Netherlands, in addition to my good friends in Tehran.

Finally, I would like to extend my acknowledgements above all to the bright stars of my life: my family, specifically, my father, my mother, my gracious and compassionate spouse, and my beloved children, who have always shown me the true meaning of a beautiful life.

About the Author

Mohammad Mahdi Ghaemi Nia was born in Iran in 1981. He studied *Mathematics and Physics* in high school and then entered the field of electrical engineering for his Bachelor studies. Despite his prior practical experience and interest in the technical aspects of his profession, he found himself more attracted to the holistic aspects of technology and the technological world. He completed an MBA, with a strong focus on strategic planning discourses. He next spent several years within the industry, examining and applying what he had learned in academia. With the practical experience gained in various domains of the technological world, he returned to academia in 2011 to continue his studies in technology policy at Delft University of Technology in the Netherlands. Since that time he has devoted his research to preparing engineers for the future of ever-advancing technology, and to provide them with useful and updated insights as to the features of the profession that await them. At the time of this book's publication, he has begun a postdoctoral project on how technological companies approach spotting trends and analysing the future of their area of technology, and how they empower engineers to face and deal with this dynamic reality.