Review

Fostering Human Development Through Engineering and Technology Education

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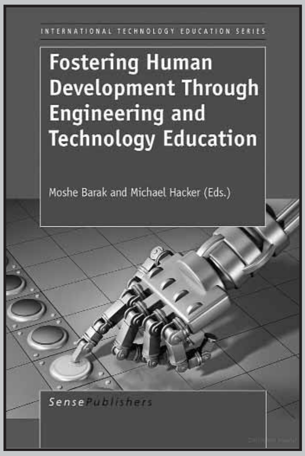

This is a publication in Sense's 'International Technology Education Series': a peer-reviewed series edited by Rod Custer and Marc de Vries. The book is a collection of invited essays, edited by Moshe Barak and Michael Hacker and grouped into four parts:

- Dimensions of Learning.
- Dimensions of Human Development.
- Cultural Dimensions.
- Pedagogical Dimensions.

Each part has between three and five chapters (15 chapters in total) that approach the general topic of the section from different angles.

Before getting into the detail of the book it is worth noting that the phrase ‘human development’ has two generally understood meanings: a biological sense relating to the process of biological maturity and a broader population sense relating to economic development, standards of living and so forth. I approached this book assuming, wrongly, that it was using the phrase in the second sense. As this led to a degree of initial confusion, for me, it is worth making clear that the primary scope of the book is the ways that engineering and technology education (ETE) can foster the first, biological sense. The introduction makes clear that the focus is:

> The role of ETE in developing students’ broad intellectual competencies, talents, knowledge and skills that will enable them to enjoy long, fulfilling and creative lives and contribute meaningfully to society and the economy. [pvii]

The introduction also notes the editors’ firm belief that ETE should shift “from teaching specific knowledge and skills to fostering students’ higher-order capabilities such as critical thinking creativity and problem solving”. For readers working in the current UK education policy climate this creates something of a tension, as, however much one might agree with this approach, we are being required to stake out the dimensions of our subject in terms of knowledge and skills. However this book helps make clear why, in the medium to long-term, a capability approach to the subject area is going to be required to place the subject on a more substantial and better-grounded footing.

Importantly, the book provides a sound and substantial response to the view expressed by the Expert Panel on the UK National Curriculum that they were ‘not entirely persuaded of claims that design and technology (…has) sufficient disciplinary coherence to be stated as (a) discrete and separate National Curriculum ‘subject.’ (DfE, 2011, p24).

Each chapter in the book stands on its own as a well-referenced and scholarly summary of an aspect of ETE education. Together the chapters build a compelling case for the importance of ETE in a modern curriculum designed to meet the needs of all pupils.

Part 1: Dimensions of Learning – a Theoretical Framework

The first of the four chapters in this part of the book, by Schunn & Silk, explores learning theories for ETE. The authors are clear that the kinds of learning they are interested in are broad components of behaviour (including fluency in procedures, strategic competence, adaptive reasoning and a productive disposition) as opposed to narrow knowledge and skills and they focus on those theories of learning that they consider to be most applicable to developing these aspects of ETE;

information processing, distributed cognition and cognitive apprenticeship. They argue that 'Given the complexity of what must be learned it is not surprising that a range of learning theories must be used to explain how this learning happens...' [p15]

Following a substantial introduction to information processing theory they conclude that teachers need to be very clear about the kinds of information they are expecting students to process and how it might impact factors like perceptual encoding, working memory and long-term memory demands while bearing in mind the long-term aim of developing fluent problem-solving capability and noting the impact of the learning environment.

While information processing focuses on the mental demands of learning, distributed cognition takes account of the whole body, the surrounding environment such as tools and instruments and even other people such as collaborators. The authors pay particular attention to the use of models and modelling as forms of distributed cognition that can aid learning.

The authors describe cognitive apprenticeship as a development of more traditional apprenticeship models that aims to both speed up learning and make it more robust. Two key elements of cognitive apprenticeship are making aspects of a task visible, for example by thinking aloud during the demonstration of a process, and varying task settings so that transfer to new situations is made more likely. The authors suggest that teaching should start with a global setting within which micro-tasks are set so their relevance is clear; this looks very much like the model of Design and Make Activities supported by Focused Practical Tasks that UK teachers are familiar with.

The second chapter by Dakers explores Activity Theory, describing its roots in Marxist theory, the contribution of Vygotsky and others to its development and the significance of Leont'ev in creating a full description. This description is thorough, detailed and very clear – though hard to summarise briefly in review. Dakers concludes this section of this chapter by emphasising the key point that activity theory is focussed on the analysis of activity in a particular setting rather than the actors themselves – noting that these actors can be elements of technological systems and/or humans. So a technological system or artefact has no inherent intentionality; this is supplied to it when a human actor uses it – in ways that may or may not match the designer's vision for it. The aim of Activity Theory is to "reveal the meaning behind the actions of the participants" [p25].

The second part of Dakers' chapter uses Activity Theory to develop a pedagogical framework for ETE by firstly critiquing a number of pedagogical models to show how they are flawed in their representation of the relationships between the various actors. He then builds on constructivist and social constructivist models to develop a pedagogical model that not only incorporates social constructivist ideas but, importantly, includes individual pupils as actors rather than the 'class' as a homogenous mass.

The key practical result of this analysis is to suggest a pedagogy in which individual pupils actively exercise agency in designing and making. When this happens:

> …teachers are no longer considered to be experts in some specific subject domain depositing pre-established information into the minds of the young (a form of enculturation that is closer to indoctrination). Rather they become proficient in facilitating learning about culturally meaningful activities that are considered useful to the learner (a from of enculturation that is liberating). [p31-32]

The chapter concludes by arguing that learning in ETE should include the development of intellectual skills as well as the acquisition of subject knowledge and skills and that a pedagogical framework built on Activity Theory enables this.

In the following chapter Barak turns the focus onto competence in cognition, metacognition and motivation and the role of ETE in developing these competences. He starts by discussing the notions of self-directed and self-regulated learning (SDL and SRL) and noting the importance of these abilities in supporting future independent life-long learning. He goes on to suggest that cognition, metacognition and motivation play key roles in supporting SDL and SRL and provides a clear, well-referenced description of each. He concludes that ETE:

> …has the potential of serving as one of the best frameworks education has for fostering these capabilities amongst students. But to what extent is this potential realised in our schools? [p38]

The second part of this chapter describes a series of interventions aimed at reforming Israeli high school ETE. The first intervention had as its aim to develop ETE teaching from a focus on facts taught through limited 'experiments' focused on component features, to a project-based approach. Following this a reform program aimed at fostering higher-order thinking in ETE was developed. The approaches used in these reform programs and the roles of the various participants are clearly described along with data on the responses of teachers to these reforms.

While it is clear from Barak's descriptions that the problems in high school ETE in Israel are rather different from the problems that can be found in UK settings, the conclusions of his work seem equally pertinent in both settings. He concludes that:

> …in order to realise the potential of fostering students' higher order skills in the technology class (…) it is essential to impart to the teachers content-pedagogical knowledge that relates particularly to achieving this end. (…) the current study also demonstrates that the aim of developing these skills can be expressed explicitly in the formal engineering and technology curriculum in such a way that teachers would (…) be willing to implement them [p52]

The fourth, and last, chapter in this first section of the book focuses on learning transfer. Johnson, Dixon, Daugherty and Lawanto note the now well-established difficulty that learners have in transferring knowledge learnt in one domain into a second domain. A review of the historical development of thinking about learning transfer concludes that, while how transfer occurs is contested, it is clear that the context of the learning environment is a critical factor.

Deeper examinations of the role of context (focussing on near vs. far transfer) and the cognitive effort required for transfer (focussing on automatic vs. mindful transfer) are followed by an extended examination of the kinds of cognitive strategies that might contribute to successful transfer arguing that:

> By placing greater importance on teaching cognitive strategies and skills, technology education students will be better prepared to transfer successfully their learning to new situation. [p58]

The cognitive concepts/strategies explored are metacognition, mental representations and analogical reasoning: If students are to transfer concepts to new situations successfully they need to understand how they understand the application of the concept, they need to hold a good quality mental representation of the concept (schemata, naïve theories and mental models are discussed) and they need to be able to reason analogically to explore the similarities and differences between two contexts in which the concept might be applied.

In exploring the implications of this for ETE, the author suggests a range of strategies that might enhance the chances of successful transfer; these include teaching metacognition, using concept maps to develop appropriate mental representations, using systems diagrams to allow the key features of a system to be abstracted, learning through analogical reasoning and ensuring that students have hands-on experience. They conclude:

> (ETE) can achieve significant success in promoting transfer if it is properly designed in ways that support learning beyond superficial understanding. [p68]

Part II: Dimensions of Human Development: Competences, Knowledge and Skills

In Part II the focus turns from how ETE is taught and learned to the content of ETE. The five chapters in this section focus on a concept-context framework for ETE, dispositions, creativity, motivation and skills for future careers.

In the first of these chapters De Vries starts by emphasising that ETE 'does have its own knowledge, different from science' [p76], while noting that defining that the core of this knowledge base needs to avoid:

> …ending up with an endless list of detailed knowledge elements that become easily outdated because of the dynamics of engineering and technology. [p76]

Observing that a range of methods could be used to identify a knowledge core for ETE, the bulk of the chapter reports on a Delphi study, conducted by De Vries and colleagues, in which 30 academics where asked what they thought were the core concepts in ETE. Five main core concepts emerged: Designing, modelling, systems, resources and values and, within these, a range of sub-concepts. The meanings of these are discussed in some depth.

The author goes on to note that these concepts are abstractions that only make sense when applied to particular contexts:

> What one sees in reality is, for instance, not systems, but cars, houses, mobile phones, fast-food stores, bridges etc. [p80]

Thus ETE requires a concept-context approach in which concepts are developed across a range of relevant contexts. The same Delphi study explored the contexts that might best support learning in ETE resulting (following a process that is well worth reading in full in the book) in the following: Shelter, Artefacts for practical purposes, mobility, communication, health, food, water, energy, safety – in other words a set of broad contexts that relate to basic human needs. It is recognised that these are rather abstract and ways of transforming them into more concrete settings are explored.

The chapter continues by discussing a concept-based and a context-based approach to using the concept-context framework to develop an actual ETE curriculum. It finishes by discussing the relationship between technological literacy and the concept-context approach, noting that conceptual understanding is just one element of technological literacy alongside skills and attitudes.

In the second chapter, in Part II, Williams explores dispositions as learning goals in ETE, where dispositions are:

> …patterns of behaviour that are exhibited intentionally and frequently, representing habits of mind. [p89]

The chapter starts by exploring the literature on dispositions in some detail, noting that much of this is relatively recent and driven by the inclusion of the idea in the USA Teaching Standards of 2008. This is followed by an exploration of the relationship between dispositions and notions of technological literacy that concludes by suggesting and exploring a set of dispositions that need to be developed for pupil success in ETE: Seek understanding, metacognitive, lateral thinking, carefulness, constructive, imaginative, take risks, make connections, critical.

How these dispositions might be taught is then discussed, emphasising that dispositions are cultivated rather than imparted, describing how such cultivation can take place within ETE, and the kinds of classroom environments that are most likely to foster the development of these dispositions, noting that:

> The multifaceted nature of design and technology lends itself to the nurture of integrated dispositions. [p98]

In the next chapter Barlex turns the focus onto creativity and how its development can be supported through ETE. He first provides an overview of the development of thinking about creativity in the context of the English curriculum, starting with the broad curriculum picture and then looking in detail at some recent key studies based in the English D&T curriculum.

Following this he explores the relationship between designing and creativity, focusing particularly on the kinds of design decisions that pupils are able (allowed) to make when designing and making, and then explores the ways that designing and making activities can be structured and supported to maximise the opportunities for creative responses. The special case of students working creatively when designing *without* making is examined and exemplified through the work of the Young Foresight project.

To illustrate how these aspects of creativity can be fostered through a specific curriculum structure, Barlex describes the curriculum framework developed for the Electronics in Schools Strategy, which developed a range of starting points for designing with different degrees of openness (or, looked at from the opposite end of the telescope, prescription) alongside a clear progression pathway for eight strands of technical knowledge and skill, where the intention was to support creativity in the development of both form and function.

Further sections of the chapter describe the work of the English Digital D&T programme and its Support Centres to develop creative approaches to designing and making with digital tools, examine the potential for D&T as a part of STEM activities to foster creative outcomes, explore the relationship between assessment and creativity and discuss the importance of a school developing a shared vision for creativity.

The chapter concludes by noting that there is much work to be done to fully embed approaches to teaching in D&T that will allow creativity to flourish.

The fourth chapter within Part II focuses on motivation. Ritz and Moye are particularly interested in how the contextual features of work in ETE can help motivate learning both within and beyond technical subjects. The chapter starts by exploring the literature on motivation and education, focusing particularly on the roles of self-efficacy, goal setting, individual interests, and the values that people hold. The authors then turn to the importance of context in learning and explore the importance of context for both cognitive and social development. Following a (long) list of social and cognitive skills that it is desirable for pupils to develop, the authors conclude that:

> …all of these points have the potential to be addressed when (…) students are completing engineering design problems presented to them in real world contexts. [p138]

Having explored motivation and context generally, the chapter turns specifically to exploring the literature on their relationship to ETE. Intriguingly they note (US) studies that indicate that experience in technology education raises scores in science, mathematics and social sciences.

The second half of the chapter details three practical examples of contextualised learning linked to ETE raising motivation and outcomes in, respectively, primary science (grades K-2; y1-3 in England), social studies (grades 3-5, y4-6), language arts (grades 6-8, y7-9) and mathematics (grades 9-12, y10-13). The authors conclude that:

> Principles of motivation and learning can contribute to student performance in ETE and the core academic subjects. If one analyses curriculum and instructional techniques, content and activities could be used to increase students' self-efficacy, goals, interests, and values – motivation. [p148]

In the final chapter in this Part of the book Liao:

> …focuses on a description of engineering concepts and tools that include applied science and mathematics examples in the context of 21st century careers. [p153]

The chapter starts by noting the kinds of skills that employers say they are looking for and the relationship of these to the kinds of outcomes that previous chapters have argued should arise from ETE. To exemplify this matching, one element of these skills, the ability to work with feedback control systems, is explored through detailed examples including the development of the heart pacemaker and the use of barcodes to automate IT systems and in the US postal system.

These examples note the importance of innovative design and the role of decision-making; the second part of the chapter explores these two aspects and starts by describing five possible future technologies (for example, guilt in robots and synthetic 'greenery') which support the development of a concept map for the design process i.e. a diagram that explores how the various elements of design activity relate to each other and suggests ways in which such a map can guide design work.

The author then turns to an exploration of decision-making set in the context of zero energy buildings and, specifically, the selection of an efficient air-conditioner. This concludes by noting that this required knowledge of concepts from physics, mathematics and engineering.

The chapter concludes with brief discussion of the societal impact of technology and the dangers of technological overkill.

Part III: Cultural Dimensions

The third part of the book contains three chapters that explore cultural aspects of ETE.

In the first of these Ginestié, reflecting on technology education in France, explores the cultural transmission of knowledge, through problem solving, relating to the tools, artefacts and knowledge associated with ETE. The chapter starts by exploring the cultural transmission of knowledge in terms of subject/object relationships, and how this approach leads to a particular view of technical objects;

> An object is technical the moment it brings a technique with it, a way of doing something with a view to fulfilling a set objective. [p172]

The author describes a study carried out by him and a colleague that explored the ways that pupils attribute technical characteristics to objects. This study suggests that children have a rather narrow view of what makes an object 'technical', largely limited to things with mechanical or electrical elements, rather than anything made by humans. And this tendency to categorise whole classes of synthetic objects as non-technical generally increases during the years of schooling, 'in contradiction to the aims of technology education in France'. [p175]. A further study of pupils' attitudes towards technology as a school subject is described and notes that pupils 'shy away from this academic discipline which is becoming "second rate" to them' [p176].

The chapter continues with an exploration of the kinds of 'pedagogical scenarios' that maximise student performance in technical activities, concluding that those that take a constructivist approach and encourage metacognition are most successful. The last part of the chapter examines with detailed examples, the characteristics of tasks that support constructivist learning.

The second chapter in this Part, by Markert, examines:

> …the extent to which cultural orientation influences our capacity as individuals to become technologically literate. [p194]

Noting research that shows the (low) extent to which US citizens (including children) are aware of their world, the author argues the case that ETE has the capacity to build global understanding. This is explored through a range of cultural perspectives including gender and religion (and secularism) as well as the dilemmas that technologies such as medicine can create. In summary:

> …the ceremonies, rituals, symbols and instructional strategies we use in our technology and engineering facilities must be gender neutral, unbiased and accessible to all. [p201]

The chapter goes on to explore what culturally relevant teaching for ETE might look like concluding that we need to:

> Develop technological literacy to enhance geographic literacy, leading toward a more expansive world view,

> through improved cultural competence, devoid of gender bias – all of which ultimately will foster human development into a sustainable future. [p203]

Kapp rounds off this Part of the book by exploring the cultural implications of digital connectedness on ETE, noting at the start that technology is a key part of culture and that education are intertwined and raising the question of how the culture of third millennium children effects educational provision. Reviewing the range of pedagogies that have been used in ETE, it is suggested that:

> …we now have an opportunity to learn from experience and introduce educational reforms that combine design-based methods, constructivist pedagogy and the technological acumen of third millennium students to create instruction that is meaningful, impactful and capable of engaging students both within and outside of the four walls of the traditional classroom. [p210]

The chapter examines the cultural lives of modern children and their teachers and discusses the implications for ETE, arguing firmly that ETE must take account of and include digital technologies both as tools to support learning and also as the objects of learning.

In exemplifying what this focus on new technologies might look like, there is a focus on simulation tools and software design along with discussions of the role of social media, web-based resources that can support learning, the use of e-portfolios and the potential for children's own technology (such as smart phones) to support learning. Oddly, for this reviewer at least, there is no mention of designing and making with modern digital tools such as CAD/CAM or the design of embedded control systems using microcontrollers.

Part IV: Pedagogical Dimensions

The last Part of the book also contains three chapters that examine the roles in ETE of project based learning, gaming and digital technologies.

Crismond focuses on the role of project based learning to scaffold learning in both engineering design and scientific enquiry. Following a brief history of the development of problem and project based learning approaches, the author considers some of the issues that arise when planning to use project based learning approaches in design focussed tasks in STEM contexts, concluding that such pedagogic approaches are 'not for the faint-hearted' [p239]. This is followed by a more detailed examination of some particular aspects of project based learning including a debate between constructivist and direct instruction approaches and a discussion of ways of scaffolding learning. A 'matrix of informed design', that contrasts how beginner and informed designers approach aspects of designing, is used to inform the discussion of two particular teaching strategies; the use of fair test experiments to develop design rules of thumb and the use of diagnostic troubleshooting to support ETE.

In the second chapter in this Part of the book Hacker and Kiggens look at the potential for games to stimulate STEM learning. The authors begin by summarising the research indicating the high degree of computer (including smart phone) use amongst young people, discussing the wide range of transferable skills that creating video games develop, outlining what it is about video games that make them so compelling and, via a summary of video game genres, introducing the idea of 'serious' video games (those who primary purpose is not entertainment) and their potential within education through a series of short case studies.

An examination of game development both as a tool for developing understanding and as a gender neutral activity is followed by a discussion of how gaming might be implemented to support ETE, supported through an extended case study of one such implementation. Readers may, or may not, like to hear one of the conclusions, namely that:

> First and foremost, teachers must be experienced players themselves and be fully inculcated in digital game-based learning pedagogy. [p265]

A short discussion of 'hybrid modelling' (supported by a detailed appendix), in which real-world and computer models are linked, is followed by a discussion on the impediments to implementation of gaming in the curriculum which summarise as issues to do with the image of gaming and those to do with teacher capability.

The chapter concludes with a proposal for institutionalising game-based learning.

The final chapter of this Part (and the book) argues that:

> …ETE provides an opportunity to e-examine curricula in the light of new technologies. [p283]

Pianfetti and Reese note both that society is experiencing rapid changes in technology and that this has significant implications for the content of ETE, citing bio-informatics, genomics, and nanotechnology as examples of new fields in which today's students might find careers.

Briefly reviewing the history of curriculum arguments in the USA and the place of ETE within the curriculum, they

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note something that will resonate with UK teachers of D&T:

> (As traditional ETE courses are eliminated), they are not being replaced by a modern, integrated technology education, but rather by an effort to compel students to take more traditional mathematics and science. [p284]

The authors argue instead that, firstly,

> …ETE has the potential for democratizing education by giving empowering tools to all members of an education community and allowing them to use those tools for their ends. [p291]

Secondly:

> …ETE can be a unifying pedagogical approach that embraces multiple tools and multiple curricula to bring us closer to a vision (that will) make the curriculum closer to the active life of the mind.

Reference

DfE (2011) *The Framework for the National Curriculum - A report by the Expert Panel for the National Curriculum review* DfE (London)