Chapter 5
The Pedagogical Ecology of Technology Education: An Agenda for Future Research and Development

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In order to explore pedagogy for future technology education, this chapter weighs up the need to consider what we already know about effective pedagogical models for technology education with what might be required of technology education in the future, and how these goals might be addressed. The social, economic and cultural realities of this century are undergoing such radical changes, including technological transformations, that a thorough revision of teaching and pedagogical approaches is necessitated. The agenda for the future should include a great deal of research and development into addressing questions related to individual, group and social diversity. To pursue this agenda, a research and development pedagogical ecology framework is proposed that includes conceptual, contextual, pedagogical resources, and planning and implementation dimensions.

Introduction

Discussing teaching and pedagogical issues in the context of the future of technology education (TE) is a challenging task. On one hand, it could be argued that valuable pedagogical approaches and models have already been identified and defined over recent decades as a result of systematic research. In this case, the challenge in the near past has been, and will surely be in the near future, not theoretical or conceptual but practical: how to **implement** the already consolidated pedagogical models and solutions in educational systems worldwide. Or in different wording, why what has already been proven as appropriate in research contexts and limited scale implementations has not been widely adopted, and what is required for this to happen. On the other hand, a contrasting perspective suggests that the social, economic and

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cultural realities of this century are undergoing radical changes, including technological transformations, thus demanding a thorough revision of the goals and means of TE in general, and of teaching and pedagogical approaches in particular.

This chapter attempts to integrate the contrasting perspectives with the aim of exploring the main pedagogical issues and challenges to be faced in TE in the near future. It should be clear from the outset that it is difficult to discuss pedagogical issues in isolation from content-related and curricular issues within which pedagogies are developed and implemented. Many of these are explored in detail in other chapters in this book. I will try, however, to refer to these aspects only when required and as background for the elaboration on the main pedagogical issues.

Pedagogical Issues and Challenges in Technology Education

Before elaborating on specific issues related to TE, let me depict briefly the general framework concerning learning and pedagogy within which the specific issues are discussed.

In this chapter I advocate for a meaningful integration of several theoretical standpoints in support of a view of **learning as a complex system**. This systemic phenomenon compromises factors and processes related to the individual's cognitive and affective states (e.g., existing knowledge, schemes and beliefs; developmental stage; cognitive and learning style; perception of environmental—physical and human—traits; motivational foci), as well as to the world's states (e.g., others; social and cultural—including material—landscape; events, processes, contingencies and demands; and affordances of the socio-cultural context). No single theoretical standpoint (e.g., individual-centred constructivism[1] or social constructivist approaches) can grasp the complexity of the intricate relationships among individual and social factors affecting learning and cognitive development. As Rogoff and Chavajay (1995) have suggested,

> . . . individual, social, and cultural levels are inseparable. Analysis may focus primarily on one but not without reference to the others as if they can exist in isolation [. . .] the aim is to understand the developmental processes involved in activities involving individual, interpersonal, and community/cultural processes. (pp. 872)

[1] Constructivist pedagogies are based on a theory of learning—constructivism—that claims that learning results from the active involvement of the learner in meaning-making and knowledge construction (rather than from passive transmission/reception of information). New knowledge is constructed by the learner upon her/his previous knowledge schemas and resources. Roughly, two broad approaches towards the knowledge construction process have emerged: psychological constructivism, focusing on the ways meaning is constructed in the individual's mind; and social constructivism, emphasising the role of social and cultural forces affecting the meaning construction process. Constructivist pedagogies aim to facilitate and support learners' active participation in knowledge construction by means of unique methods and learning environments (e.g., inquiry and design tasks, building kits, productivity or modelling software).

Along these lines, Perkins (1993) proposes a "person-plus" view (in contrast to a person-solo view) for understanding cognitive growth and learning processes in terms of the dynamic synergy between the individual traits and the human and physical surrounds. In addition, Salomon (1993) addressed the need to "overcome the situational determinism I see in the radical view of distributed cognitions and the intrapersonal determinism in the radical solo view of cognitions" (pp. xviii), adopting an integrative and interactive perspective about the co-evolvement of intra-personal and inter-[personal, social, cultural] developments.

Stemming from this theoretical stance, pedagogical solutions are developed following clearly defined principles:

- Learner-centred approach: the learner is not only the primary target of the pedagogical process, but also the main engine driving it
- Knowledge is gradually constructed by the learner as a result of meaningful interactions between existing knowledge and schemes and new triggering and challenging demands embedded in the pedagogical situation (O'Donnel 2012). The creation of perceivable challenging gaps between existing and required knowledge are regarded as powerful pedagogical means for supporting knowledge construction processes.
- Knowledge is also gradually constructed by the learner as a result of meaningful interactions with a rich and conceptually challenging environment (Richardson 2003). The context, characteristics and conditions of the environment in which learning takes place (e.g., social, cultural or geographical properties and materials) offer both affordances and challenges that can empower the knowledge construction process. Consequently, pedagogical solutions ought to be devised to afford the manipulation and use of plentiful resources, such as tools, materials or construction kits—whether physical or, in the new digital reality, virtual.
- The socio-cultural perspective: the view of knowledge as a social construct, grants peer interaction and collaboration a substantial role in supporting the collective creation of knowledge assets (Rogoff and Chavajay 1995). When the construction of knowledge is conceived as resulting from the interaction among peers holding different levels of expertise within a specific context (e.g., given social, cultural, economic or political realities, and even the quality of knowledge and resources available), pedagogical solutions are devised to support such collaborative work in continuous dialogue with the environmental context.
- An additional angle relating to the social aspects of learning is supplied by the constructionist approach (Papert and Harel 1991). From this standpoint, the creation of a 'public entity' (e.g., an artefact, a computer programme, a theory) means the externalisation and objectification of inner (to the mind) thinking processes and knowledge. In this process, the learner's externalised thoughts are open to peer discussion, critical evaluation, and insightful comments and suggestions, thus promoting both individual and group learning.

If the integrative approach is of value for understanding learning as a complex system, it is equally important for the development of pedagogies that address in holistic fashion all its different aspects—what is defined in this chapter as "pedagogical ecology". Such an ecology encompasses the range of human and physical resources and methods aiming to support learning in all of its individual and social dimensions.

Moving from this more general elaboration about learning and pedagogy to its instantiation in technology education, the following sections briefly introduce and explore some of the key issues that are relevant to the pedagogical ecology of TE.

To Learn Technology Is to *Learn to Think* Technology

A long-standing conceptual stance has dominated—and still does—the rationale for TE: the socio-technological approach (see, for example, Dakers 2006; Petrina 2000). This rationale embraces TE in its various forms, including what has been defined as "technological literacy" or "technology for all" programmes as well as expertise-oriented programmes (e.g., high school and higher education specialisation studies). The main drivers of this rationale call on social and economic considerations: Technology (and often science and technology) is an essential asset in evolving twenty-first century economies; technologically knowledgeable and skilled citizens contribute to a country's economic competitiveness; technology-related knowledge and skills are important resources for individuals' successful integration in contemporary workplaces and for ensuring their social mobility; and technology itself drives technological development and progress.

Following the above rationale, a range of pedagogical solutions has been developed. In one model, oriented towards what is conceived as needs of the economy and the workplace, technology teaching emphasises the development of craft-type skills and the acquisition of procedural knowledge rather than conceptual knowledge and the thinking behind the technological processes. Typical examples are lesson plans fostering the reproduction of teacher- or expert-made construction plans and design solutions, or tasks involving the manipulation of pre-set collections of materials or building-pieces. On occasion, background and contextual information relevant to the tasks are supplied as informative texts (rather than challenging the student with the need to gather, analyse and synthesise information), often in the form of "about technology" boxes in science textbooks. The 'pedagogical spirit' behind this view of TE as a means for educating future workers or actors in technology-based economies emphasises products over processes and measurable (assessable) end results over knowledge-construction processes (Brophy et al. 2008; Fritz 1996).

A contrasting pedagogical perspective moves away from the socio/technological approach towards a cognitive/epistemological approach (Mioduser 2009). The philosophical stance behind this approach relies on the view of technology as a defining characteristic of human beings' thinking and intellectual development (Nye 2006; Preiss and Sternberg 2005). Technology, here, refers not only to the sets of skills and knowledge as defined in the technological disciplines—the formal body of technological knowledge. It also refers to humankinds' stance (intellectual as well as affective) towards the creation of the made world out of the natural world in response to needs and opportunities, and to the thinking processes and capabilities involved in these acts of creation. From this perspective, therefore, learning technology involves learning about thinking, learning, the (outer) invented world vis-à-vis the (inner) inventor's world, and the results of the co-evolution—both phylogenetic and ontogenetic—of the designed and the designer's worlds. As Cole and Derry (2005) conclusively claimed: "We have met technology and it is us" (pp. 209).

Consequently, pedagogical solutions underpinned by a cognitive/epistemological approach emphasise processes over products. Lesson plans and tasks are devised as challenging situations demanding consecutive cycles of action and reflection. Materials supplied take the form of problem-solving playgrounds rather than pre-set building plans. Inquiry, exploration, analysis and synthesis cycles, and personal involvement in the very planning of the path leading from the existing situation to the desired situation (reaching the solution) are key components of this pedagogical form. Often, the process involves collaborative work, peer critical/reflective discussions, peer and teacher formative feedback, and whole-process assessment. In such a pedagogical programme, the body of target skills and knowledge exceeds the strict boundaries of formal disciplinary knowledge to encompass higher-order and metacognitive sets of skills such as these involved in system thinking, problem solving, and holistic perceptions of technological problems and solutions (Walmsley 2003; see also Chap. 8, this volume, by David Barlex and Chap. 9 by David Spendlove).

It is obvious from the above that a significant pedagogical challenge for technology education is to develop a balanced approach in which learning of relevant skills and information (i.e., formal technological knowledge and skills) is supported, while at the same time emphasising knowledge-construction processes by the learners themselves. I return to the discussion of these pedagogical questions in a later section of this chapter.

To Learn Technology Is *to Do* Technology

As obvious as this claim—To learn technology is to do technology—may seem, there is a significant gap between it and the pedagogical reality in many TE classrooms worldwide (Sherman et al. 2010).

The obstacles for implementing pedagogical solutions centred in *doing* technology are diverse in nature. In some cases there are logistical constraints that discourage teachers from planning classes centred in doing and making, for example, lack of time in the teaching schedule, lack of appropriate infrastructure for carrying out construction tasks, or—even more worrying—lack of appropriate background and training, particularly among teachers at the elementary and intermediate levels.

In other cases, where technological topics appear within integrative units (e.g., science and technology or social sciences), teachers often adopt a pedagogical approach in which technology-related content is delivered mainly in expository mode. In this approach, the dominant pedagogical resources are texts and visuals (e.g., from textbooks or the Internet), stories of and about technological developments and salient characters (e.g., inventors, entrepreneurs), and demonstrations (e.g., by the teacher in class, in museums, or using video clips retrieved from the Internet). Technology, in such contexts, is perceived as an 'informative' curricular subject and most activities rely on the manipulation of texts and visual materials, class discussions and, consequently, assessment of declarative knowledge gains.

In spite of these realities, there is ample consensus among practitioners and researchers in the TE community that students' active engagement in doing technology is an essential requirement for meaningful learning. This consensus is rooted in the theoretical standpoints briefly surveyed above, which emphasise the integration of constructivist as well as sociocultural theoretical perspectives about teaching and learning processes as complex systems (John-Steiner and Mahn 1996; Prawat 1996).

In addition, strong support for 'doing' technology stems from another theoretical standpoint focusing on the essence of technological development processes. Technology is essentially a thinking-and-making process in which action and reflection are intertwined and the resulting knowledge takes the form of both conceptual knowledge and its instantiation in an artefact, whether concrete or abstract, physical or symbolic. It is natural, therefore, to claim that the most logical way to be engaged in learning technology is to be engaged in *doing* technology—in experiencing the authentic process of creating a technological solution in response to a need or opportunity. Here, the pedagogical challenge lies in creating authentic learning contexts that can be holistically experienced by learners as credible and immersive and during which they create their own conceptual as well as artefact-embedded technological knowledge. In such pedagogical approaches the key idea of 'the creation of the made world' is conveyed through situations that allow learners to themselves be involved in manipulating and creating aspects of the made world.

Many "Technology Educations"

An elaboration on pedagogical issues and challenges in TE should take cognisance of the varying goals pursued for different ages, populations and target levels of expertise. For students in the school cycle (i.e., kindergarten to high school, and in some countries beyond this into tertiary pre-college institutions), roughly four emphases can be found: technological literacy, vocational preparation, expert specialisation and professional studies. Although some pedagogical principles are relevant to all these emphases (e.g., a learner-centred approach, affording student involvement in doing and making processes), others are unique to a specific curriculum emphasis.

For example, regarding technological literacy, pedagogical solutions are designed considering age and developmental aspects (literacy is usually targeted to the younger population), addressing the development of conceptual understanding and a technological worldview rather than formal expertise in a technological field. Usually these programmes focus on aspects of the made world at the conceptual and phenomenological levels (rather than at formal-disciplinary levels); on the conduction of simplified design processes (in the form of simple didactic versions of complex engineering-design processes); and on the elaboration of ethical, moral or social issues stemming from technological developments. Correspondingly, pedagogical practices include activities that aim to direct learners' awareness to technological phenomena and the multiple issues related to these, and design tasks that conceptually resemble processes in the technological world but are conducted within the constraints of the classroom (e.g., concerning available—and safe—infrastructure, materials, tools). 'Doing' tasks, even if highly active and fostering authentic immersion in hands-on processes, are to a large degree open-ended and provide learners with opportunities to explore diverse paths in developing their conceptual understanding of processes.

In contrast, pedagogies implemented in specialisation or trade-acquisition programmes (e.g., in vocational and practical-engineering programmes) are far more formally structured and explicitly oriented towards defined sets of skills and bodies of expert knowledge. This is not to imply that, in contrast to literacy-oriented pedagogy, expertise-oriented pedagogy should necessarily fall in the realm of 'traditional' and product-only oriented practices (as appears to be the reality in most expert-formation institutes worldwide, see Sjoberg 2001; Walmsley 2003). An illustrative, still challenging example is the almost century-old pedagogical approach implemented in the German Bauhaus school (Gropius 1919; Itten 1975).

Although the Bauhaus functioned for a relatively short period (1919–1933), its impact on design, architecture and various arts has been of crucial significance—not least because of the pedagogical philosophy and teaching practices developed by its teachers (themselves recognised artists, designers and architects). The school's curriculum, depicted as a series of concentric circles (an iconic entity representing the school's curricular philosophy), presents in the outer circle the basic or preliminary course, then the series of workshops focusing on diverse materials and technologies, in to the holistic integration of all components in the most inner circle: the artefact. The learning journey therefore integrated three main knowledge components: crafts, representational means (drawing, painting), and theoretical and scientific principles in the natural sciences and technology. Tasks and assignments aimed to develop the students' minds as well as hands, and their gradual mastery of concepts as well as skills. An additional important layer accompanying the formation process related to the social and historical context within which the work (a design, a building, a piece of art) is performed. The product of the formation process—the craftsperson, the designer or artist—should feel and be integrated in the community, and be aware of the social, economic, ethical and historical implications of their work. Correspondingly, the tasks faced were authentic in character and demanded attention to a whole spectrum of aspects—from the purely creative, through all facets of the design process, to industrial and commercial issues. In other words, the Bauhaus succeeded in fostering the development of professional designers and artists through a high quality and complex "constructivist" (in contemporary terms) pedagogical system, which has had significant subsequent impact on the way the holistic development of professional designers is conceived and planned.

Drawing on a completely different context, the “implicit pedagogies” that characterise the way novices gradually acquire mastery of professional skills in the workplace and informal settings are also of interest. These pedagogies have been linked to theoretical approaches emphasising “situated cognition” and “apprenticeship” processes (Collins 2006; Seely Brown et al. 1989). The main claim is that

> . . . for most of history . . . children learned how to speak, grow crops, construct furniture, and make clothes. But they didn’t go to school to learn these things; instead, adults in their family and their communities showed them how, and helped them to do it. (Collins 2006, p. 47)

Of course, apprenticeship as a way of acquiring skills and expertise is still relevant not only in many societies worldwide (concerning the traditional apprenticeship involved in learning a trade or a craft), but also in the context of the most advanced technologies. For instance, a great deal of knowledge and a large array of capabilities are acquired by children while interacting with and manipulating technologies in authentic real-world tasks and in informal settings, with the support of peers and adults. Similarly, many training and knowledge-upgrading processes are carried out in the workplace when facing real situations (i.e., the tools, methods, problems) and interacting with relevant experts. A challenging question for TE is how the features of these “real-world-pedagogies” can be harnessed to design classroom-based pedagogies with the aim of bridging between formal and informal learning processes.

Are There “Obvious” Pedagogical Models in Technology Education?

Without any doubt, much of the content included in any technology curriculum is taught using pedagogical methods commonplace across school subjects, and large segments of declarative and procedural knowledge are conveyed through tasks, exercises and text-based assignments similar in character to the majority of other learning activities in school. However, given the nature of technology education, there are several pedagogical models that appear to fit more naturally with the learning purposes.

These pedagogies stress aspects such as: engagement in doing; a systems perspective; emphasis on processes; non-linear paths (both for accomplishing tasks and for learning); collaborative work; and rich information-based decisions and actions. Well known examples of such pedagogical models extensively discussed in the educational research literature include ‘Learning-by-design’, ‘problem- and project-based learning’, and ‘case-based learning’ (Kolodner et al. 2003; Williams and Williams 1997).

Proven pedagogical models that have been implemented in large-scale programmes in different countries include the Nuffield project (see Barlex 2008) and the Israeli ‘New MABAT’ curricular project (Nachmias et al. 2007–2010). The

Nuffield approach follows a powerful motto: "Capable pupils can design what they are going to make and then make what they have designed" (Barlex 1998, pp. 143). The building blocks of the curriculum are tasks of two main types: resource tasks and capability tasks. Resource tasks ("small tasks") focus on knowledge and skills required in designing and making assignments; capability tasks ("big tasks") are the designing and making assignments. Effective learning demands learners' involvement in a sequence of making and designing tasks (rather than a single experience) characterised by a "mixed diet" of small and big tasks. Intertwined in the sequence are "case studies"—true stories about design and technology in the world outside the school—allowing learners to understand how products are designed, manufactured and marketed, and that they impact on the lives of individuals and societies.

Common to the vast majority of TE pedagogical models is a scenario in which the learner faces a problematic or challenging situation, or a need to be satisfied, and becomes engaged in a multifaceted process leading to the solution of the problem or the creation of a product—also known as the 'design process'. A key issue that has been a matter of debate among researchers concerns the structure and rigidity of the process to be followed by the learners. In many textbooks and proposals for lesson plans, the design process (or in some cases the project completion process) is depicted as a structured and almost linear sequence of stages leading from the initial step (usually "identification and definition of the problem") to the final step (usually "evaluation of the result") (Mawson 2003).

Contrasting views in the literature raise questions as to the appropriateness of the structured model, both as a valid representation of real-world processes and as a pedagogical method (e.g., Mawson 2003; Mioduser and Dagan 2007). The main claim is that neither real-world designers and engineers, nor learners, proceed in strictly structured and linear paths when solving a problem or designing a solution. On the contrary, they follow complex, iterative and cyclical paths, moving among stages, functions and methods as required by the evolving solution-creation process. For example, evaluation and critical analysis, rather than being a "stage" at the end of the cycle, are functions continuously activated at different stages along the working process.

In contrast to the structured approach, a 'functional' approach has been proposed as more closely representing real-life design and technological problem solving (Mioduser and Dagan 2007). In this approach the different design and problem solving methods and resources comprise a 'toolkit' from which learners choose the appropriate 'tools' according to their needs. Research indicates that in the structural-linear approach, learners concentrate on a given stage at a time, often losing the view of the whole process or missing the contribution of the given stage to the solution. In contrast, the functional approach is more cognitively demanding, transferring the responsibility of constructing the solution path to the learners and requiring them to maintain a holistic mental picture of the various resources and stages.

No matter which approach is adopted, there is ample consensus about the pedagogical value of learners' active engagement in design and problem-solving processes. There is also increasing consensus as to the need to define the pedagogical goals of the tasks in pursuit of the mastery of cognitive as well as metacognitive skills, and fostering a systems view of the solution pathway. More often than not, design tasks are ill-defined and the complex process required for their successful completion cannot be reduced to a simple linear path nor to a simple set of skilled actions. Design-, project-, problem- and case-based assignments that make possible the acquisition and activation of a wide range of skills (e.g., planning, crafting, tools and materials manipulation, information gathering, adaptation and use) have therefore become powerful pedagogical resources in many technology education curricula.

Coping with Diversity vs. Celebrating Diversity

In our postmodern times, during which awareness of the multiple social, cultural and political currents coexisting and flowing within and among societies has intensified, it is important that educators address substantive questions related to diversity (Darling-Hammond 2007; Lubienski 2003). Roughly speaking, two contrasting approaches to addressing these questions can be identified: *coping with* versus *celebrating* diversity. The first approach typically leads to the search for methods and solutions to what is perceived as problematic, for example, the performance of low achievers in technology education. The second approach represents a need to support individual growth on the basis of each person's strengths (while also being aware of each person's constraints). Such approaches can also be identified when considering diversity among societies (and countries) of varied socio-economic, cultural and political realities. In this context, educational and pedagogical questions are related not only to the choice between approaches but also, even within the 'celebrating diversity' approach, to how to ensure a balanced perception of the interplay between strengths and limitations in order to design appropriate pedagogies to support individual students' learning.

Of course, 'diversity' when discussing pedagogical approaches (and an agenda for the future of these in TE) can take various forms. First, there is diversity among students. Second is diversity among groups in the same society or country. Third, and from an even broader view, is diversity among cultures and among societies and countries. Each of these dimensions pose serious questions to educators and policy makers in educational systems. TE will not escape the need to face these questions as well.

At the individual and group levels two main standpoints are briefly identified, each of which differently affects the design of pedagogical methods and resources. The first, of frequent use by educational policy-makers and researchers, is the *statistical* approach. Within this approach, large populations are assessed using standardised instruments deemed to be highly reliable. As a result, individuals are grouped and placed in scales of varied kinds (e.g., achievement in technology) and correlational analyses are conducted to identify covariance among substantial variables (e.g., achievement and socio-economic status). The immediate result, for our purpose, is the identification of diversity parameters characterising groups of students, and the development of pedagogical solutions based on this identification, for example, remedial programmes or 'basic level' curricula for the low-achievers and (perhaps less commonly) enrichment tracks for the high-achievers.

One critical observation of this approach is that when the individual becomes a 'statistical individual' placed in a scale, her or his prospects determined by correlational data, then we lose the real learner with her or his personal deviation from statistical means, and her or his complex grid of strengths and weaknesses. For the system, the actual learner is no longer the basis for pedagogical decision making (e.g., as happens in tracking procedures in many countries). A second critical observation is that what to measure as the basis for systemic decisions is an issue that is socially and politically fraught. It is no secret that strong emphasis is placed on subjects such as mathematics, science and language (and moreover, the English language) as the leading subjects to be supported in educational systems in response to the perceived demands of the world's economic reality. This trend is supported by the "race" in which many countries engage by participating in international comparative studies of achievements in these subjects. As a result, the scales within which learners are placed are unfairly unidimensional, focusing mainly on what is conceived as 'leading subjects'. In other words, a complex and multidimensional creature, the learner, is assessed, classed and assigned pedagogical solutions on the basis of a narrow assessment of her capabilities.

The contrasting approaches towards diversity among individuals can be depicted metaphorically using the image of sliders. In the statistical approach, there is one slider within which learners (or groups of learners) are placed according to their performance (achievement), most probably resulting in a normal distribution along the scales values. As an alternative, perhaps each learner could be conceived of as a collection of sliders, as in a sound equaliser console, each slider representing a specific capability or trait. Some will indicate high values, others lower values—each individual learner is the configuration of values for different capabilities, some stronger some weaker, but interacting as a whole and growing gradually at different paces. This is, in my opinion, the real educational and pedagogical challenge of our times—aiming to offer equal opportunities to all students according to their individual "sliders configuration".

In TE processes, teachers are aware of the differential capabilities, strengths and limitations of learners—analytic and synthetic; number oriented, word oriented or image oriented; skilled in the crafts; planners and "doers"; convergent or divergent thinkers; and soloists or collaborators. Certain design projects might offer fertile ground for the expression of all these capabilities, and this offers a further—intriguing—pedagogical challenge.

When considering diversity at a more global level, social, cultural, economic and political (SCEP) differences among communities and countries also represent significant challenges for TE. Obviously, pedagogical solutions devised for particular contexts will not necessarily be relevant in different contexts. Pedagogical solutions are means toward ends, and they reflect choices of educational philosophies (e.g., an integrated constructivist/socio-cultural stance in the proposals above; see also Chap. 8 by David Barlex, this volume). However, they are expected to serve educational goals and convey educational content in close correlation with the characteristics of specific social realities. Aiming to define the questions to be addressed in an agenda for the pedagogical future of TE, it is clear that there is a need to develop theoretical as well as practical indicators for identifying the relevant variables in a country's SCEP reality that demand particular pedagogical solutions. In addition, there is need to develop theoretical as well as practical procedures to assess the appropriateness of the suggested pedagogical solutions for the given context.

Transformations and processes at all SCEP levels in educational jurisdictions worldwide deserve the attention of researchers, decision makers and politicians, in particular in light of the astonishing pace of scientific and technological transformation. The implications of these transformations in shaping our individual and social lives, our culture and economies, unveil with increasing force the emerging differences among countries, societies and communities—that is, diversity. Education in general, but TE in particular, stands in a strong position to help address and respond to this diversity thanks to the potential embedded in technological tasks to reach all members in a community and offer them multiple ways to acquire relevant knowledge and skills.

In summary, there is no doubt that the agenda for the future should include a great deal of research and development into addressing questions related to individual, group and social diversity. In particular, I argue that it is critical that diversity is viewed as enriching, the multiple facets of a social gem, and the raw material for the creation of adaptive pedagogical solutions.

Emerging Pedagogies with Emerging Technologies

These are times of rapid and continuous technological developments—the digital age. Since the sixth decade of the previous century, on-going innovations in information and communications technologies have affected education and challenged educational researchers and practitioners in search of effective as well as innovative ways to integrate digital technologies and pedagogy. The dialogue between such technology and pedagogy has, over the years, produced ideas and practices at many different levels. Salient issues include the way information is produced, stored and retrieved; the ever growing amount of information available for learning (far more than in any time in the textbook-based past), stored in varied representational formats (e.g., texts, images, pictures, video and sound clips, interactive scenarios); and the growing, rich repertoire of digital pedagogical objects (e.g., lesson plans, models and simulations, virtual environments for learning, assessment instruments, online courses). In addition, innovative pedagogical forms are being developed, studied and in cases implemented, for example, virtual gathering spaces for learning, ubiquitous-learning models, distance-learning courses (and even complete degrees), support for schooling in out-of-school settings (e.g., home, distant locations, hospitals), and developments in mobile and localised learning.

It is important to note that the new information technologies (either a physical artefact, a piece of software, or a communications-networked system) are not only a technical phenomenon. These technologies are imbued with ways of thinking about important aspects of our individual and social lives, including about the world of information, social processes and phenomena, economic processes, the workplace, and education. The implications of the impressive extent and pace of technological developments for discussion about future pedagogies are manifold. These range from supporting and upgrading current practices, to the development of new practices that were not possible before the new information technologies came to be. Examples of potential lines of research and development relevant to TE pedagogies are:

- Real-world tasks—using authentic tasks and design assignments, pedagogical formats may be developed based on in-situ data gathering and its online sharing and discussion. Mobile devices allow for data to be collected in diverse formats (e.g., pictures or video data, recorded interviews, quantitative data fed directly into appropriate software) and uploaded in real-time to public repositories for further elaboration.
- Collaborative work—public virtual spaces and shared design and analysis tools allow students to collaborate from distant locations and construct collaborative products.
- Informed design processes—information is an abundant commodity, easily accessible from any location. Herein lies significant advantages and opportunities for learning, but also some challenges. A key pedagogical question relates to the design of methods and procedures to support learners' acquisition of effective information manipulation skills. The aim is to reinforce learners' abilities to retrieve, evaluate, adapt and use information to appropriately inform the task at hand.
- Microprocessor-based tools supporting learning—many tools that are educational versions of real-world technological processing tools have reached mature status, and many more are under development (e.g., controlled manufacturing and assembly lines, robotic systems, 3D printers). The pedagogical challenge is to devise ways to integrate these (and future technologies) into constructivist pedagogies in order to transform these sophisticated tools into construction playgrounds for invention and creative learning.
- Perhaps at an even more complex and innovative level, a bigger question relates to the study of alternative formats of schooling and learning settings and configurations. For decades visions have been espoused about the possibility, enabled by the technology, to support learning beyond the constraints of space and time. Looking at the reality in most school-age systems worldwide, substantial changes have not yet taken place (Voogt and Plomp 2010). The integration of mobile devices with cloud technologies and ubiquitous wireless communication facilities are calling out to researchers and educators to explore innovative pedagogical models and conceptualisations of technology-supported teaching and learning.

Marc J. de Vries picks up many of these themes in Chap. 14, in which he argues strongly that research questions and research findings need to connect more closely with teachers. In addition, he highlights the need for research that targets how to better support students' technology learning.

An Agenda for R&D of Pedagogical Solutions

The previous sections considered a series of issues that I believe affect, and will continue to affect, the way the pedagogy of TE is researched and implemented. Below, I suggest a conceptual framework—an R&D pedagogical ecology framework—to frame the agenda for: (a) the identification and definition of relevant research questions, and (b) the formulation of guidelines for the development of pedagogical solutions.

The R&D pedagogical ecology framework is defined on the following premises:

- There is need to base the study and development of pedagogical methods and resources in existing—and future—theoretical and research work. Many theoretical proposals have been investigated over the years, and many lessons have been learned. However, most of these insights remain confined to discussions in conference gatherings and academic publications. An agenda for the future should include an exploration of the ways in which the knowledge produced can be harnessed to inform pedagogical practices and to enrich teaching decision-making. This point is also strongly put in Chap. 14, this volume, by Marc J. de Vries.
- Pedagogical solutions should be conceived as part of a systems view of technology education in which specific (and even disciplinary) knowledge and skills are contextualised within a holistic perspective of a twenty-first century person's cognitive, affective and moral being. Pedagogical opportunities should not only lead to the achievement of specific curricular goals, but also support learners' perceptions of the gained knowledge as substantial thinking tools for interacting with real-world situations.
- Researchers and developers should be aware of the broad diversity characterising the population of learners, and the increasing need to pay attention to diversity when making pedagogical decisions. The landscape of diversity includes individual differences and capabilities; gender; social, economic, cultural or political differences; and even differences among countries' economic, cultural, technological and political realities. While the design of pedagogical resources may rely on certain commonalities, no real solution can escape the need to accommodate diversity as a critical component of different countries' realities and educational policies.

The R&D framework comprises four dimensions: Conceptual, contextual, pedagogical resources, and planning and implementation.

Conceptual Dimension

The conceptual dimension refers to key conceptual components of the rationale guiding the design of pedagogical models for TE, and the planning of their systematic study. The following is but a partial account of these components, but is offered here as being indicative of the conceptual stance adopted in this chapter.

- *Foci of TE*: There is need to displace the focal point of the teaching/learning process from 'learning about' technology (still part of contemporary practice in many classrooms) to 'learning the very essence and substance' of technology. Pedagogical models should stress the importance of becoming involved in planning and implementing technological processes, coping with technology-related dilemmas, and developing awareness of the roles and implications of technology for our current and future lives.
- *Making and doing*: Consequently, pedagogies should foster both conceptual learning and praxis as necessary and complementary layers of the formation of a technologically literate person. As stated above, *to learn technology is to do technology*—in terms of conceptual and intellectual processes (e.g., analysis of and elaboration about technology-related social issues, or acquaintance with development paths of a given technology over time) *and* in terms of actual involvement in making (e.g., the design process).
- *Doing and reflecting*: Pedagogies should support and encourage students' reflection about their doing. Research observations indicate that often learners engaged in practical tasks are not requested to conceptualise and formalise the knowledge and ideas involved in, or resulting from it (e.g., McCormick et al. 1994; Rowell 2004). Thus, beyond the doing experience (valuable in itself), the distillation and abstraction of ideas and concepts is often not promoted as part of the learning process. In contrast, Stables and Kimbell (2006) have depicted students' design processes in terms of the

  > interaction between mind and hand (inside and outside the head) [...] and the activity as being best described as iterative as ideas are bounced back and forth; formulated, tested against the hard reality of the world and then reformulated. We coined the phrase 'thought in action' to summarise the idea. (pp. 315)

  Reflection, conceptualisation and explicit knowledge construction intertwined with actual making is a high priority pedagogical goal to be pursued.
- *Technological thinking toolkit*: TE should approach the teaching of concepts and skills in a way that emphasises their role as building blocks for the development of a technological worldview and technological thinking (e.g., the Nuffield 'resources' referred to in Barlex 2008, or 'primitives' in Mioduser 1998). Technological disciplines are continuously growing in scope as well as in the amount of information generated. It is critically important to equip students with a meaningful thinking-toolkit enabling them to approach, understand and consequently make decisions and act while coping with existing and future developments in the technological world. Candidate components for the toolkit might

pertain to different layers. An example at the 'rudimentary' level are schemas related to transmission configurations and parts that are found in many different artefacts, and their indexing by their advantages and constraints in different situations of use. Examples at the 'methods' layer are schemas for alternative ways to approach a technological problem and its solution.

- *Pedagogical stance*: This chapter advances the idea of a pedagogical ecology based on learning as a complex system. In this system, an intricate web of factors (related to, for example, individual capabilities, social and cultural contexts, curricular content) affect the design of specific pedagogical solutions. An essential feature in the system is the interaction between individual and cultural cognition, or more broadly between individual growth and socio-cultural processes. Thus, the pedagogical stance adopted favours constructivist, collaborative, process-oriented pedagogies over expository, "soloist", product-oriented pedagogies.
- *Values and ethical issues*: Pavlova and Middleton (2002) pointed out that "Like science, technology, and by implication, technology education, was once thought to be value-neutral. Such propositions are now discredited, however, the question concerning the values that technology educators hold is still an open one" (pp. 103). In congruity with the socio-cultural components of the rationale adopted in this chapter, pedagogical solutions should foster students' explicit confrontation with moral, ethical and value aspects of the technological processes and products under study (see also Chap. 3 by Marilyn Fleer). Authentic, situated, context-aware or prospective-evaluation activities, among others, are pedagogical resources that might contribute substantially to achieve the goal.

Contextual Dimension

The contextual dimension of the R&D framework relates to specific contextual characteristics affecting the design of pedagogical solutions in terms of the curricular goals pursued and the populations addressed.

- *Strategic goals*: TE programmes may pursue different goals and needs, for example, technological literacy, specialisation, vocational training or professional (e.g., engineering) expertise. In general, it is seen as desirable for the whole population to acquire the rudiments and skills required to understand and act mindfully in our technology-saturated reality—to be technologically literate. In contrast, only some of the population will choose specialisation tracks in technology, usually at secondary or tertiary levels. Obviously a narrower fraction will pursue careers as expert (professional) technologists. While common pedagogical solutions can be found across all these curricular emphases, the concern here is with pedagogies aimed to support the whole population's development of technological literacy.
- *Literacy*: In this sense, the targets for the development of appropriate pedagogies are the intellectual and affective resources required to perform as technologically

literate citizens in relation to historic, current and prospective technological realities. Among these resources are: language, sets of skills and methods, a knowledge base, and the ability to evaluate and morally judge the consequences of technology-related phenomena.

- *Diversity*: In line with the above elaboration about diversity, there is need to develop and study appropriate pedagogies addressing the needs stemming from different individual, group, cultural, socio-economic or geo-political realities. At each of these levels, pedagogies should be developed targeting a range of core issues, for example, dissimilar capabilities, learning styles or interests of different individuals, and distinctive goals and needs among different population groups and even regions and countries.

Pedagogical Resources Dimension

The pedagogical resources dimension of the proposed pedagogical ecology relates to characteristics of the actual resources, teaching models, and means that need to be developed and studied.

- *Knowledge and skills space*: The intense pace of technological development accentuates the need for a renewed definition of appropriate blends between different types of knowledge with regards to different age levels and targeted expertise levels. The continuously increasing body of knowledge comprises multiple layers, for example, factual, conceptual, procedural and meta-level knowledge. Pedagogical models aiming to teach the balanced blends required for acting mindfully in our changing technological world should address, besides traditional 'knowing' and 'making' skills, new sets of higher-order skills and knowledge types (DeMiranda 2004). Examples include knowledge pertaining to declarative, procedural and qualitative categories; mental modelling and running of technological systems; information manipulation skills and methods; capabilities involved in processes such as analytic, synthetic, anticipatory or goal-oriented thinking; and collaborative work skills.
- *Pedagogical repertoire*: This is the actual pedagogical toolkit comprising the building blocks out of which tasks, assignments, lesson plans, and even comprehensive curricular plans are constructed. Examples of these at the strategic level are project- or problem-based assignments, or instruction-embedded assessment tasks. Examples at the more practical level are contextual and focused methods and activities addressing specific skills or methods, in other words, candidates for modular implementation in different learning processes. As discussed above, many of these have already been developed, studied and even implemented in large curricular systems in many countries (e.g., see Barlex 2008; Compton and France 2007). A research and development agenda for the near future should consider the consolidation of previous work and further expansion and systematic study of this repertoire towards its implementation in teacher education programmes and curriculum development.

- *Classroom practices and 'the world'*: Pedagogical solutions should contribute to closing the gap between classroom practices—what is feasible within the possibilities and constraints of the classroom context—and real-world technological processes and artefacts. It is well established that many constraints (e.g., available resources, time limitations, teacher's knowledge) limit the classroom treatment of topics such as those related to complex technologies, high-tech developments, and even our sophisticated, artefact-saturated environment. Often these topics appear in 'about' boxes in textbooks or are presented in expository mode with materials from the Internet, while the actual experiences supposedly aimed to address them in class are conducted with 'low-tech' materials and processes, with students expected to make the cognitive linkages. There are cultures and societies in which there is natural flow between skills and knowledge stemming from social and economic needs, and school practices. New pedagogies should foster both classroom practices built on an essential and principled linkage with the technological processes under study, as well as situated (out-of-school and in-situ) activities in relevant technological contexts.
- *Assessment*: Existing models for assessing students' performance in technological processes (and research results of their implementation, see Kimbell et al. 2009) reinforce the need to deepen the *synergy* among the components of the teaching-learning-assessment cycle. Instead of focusing exclusively on summative accounts of learning, *process* and instruction-embedded assessment with relevance to key aspects along the learning journey should form an integral part of the pedagogies implemented. This approach stresses the importance of real-time feedback tailored to the identified needs and prospective learning paths of individuals and groups engaged in performing technological tasks (see also Chap. 7 by Kay Stables).
- *Assessment II*: Fostering the previous item's aims requires a substantial change of perspective in educational systems' perception of the interaction between teaching and assessment: from 'assessment-driven-teaching' (the prevalent policy in many educational systems) to 'learning-driven-assessment'. Pedagogies to be developed should address (and solve) the conflict between 'teaching what can be measured' versus 'measuring what can be taught' in diverse contexts and with diverse learners.
- *Learning technologies*: The rapid and on-going evolution of information technologies and the enormous effect of these on all technological fields poses serious challenges to education. Many of these new developments might function as powerful cognitive technologies when appropriately incorporated into teaching and learning processes. There is need for the design of innovative pedagogical approaches emerging from the educational use of advanced technologies, for example, ubiquitous learning, transcending the time/space boundaries of the school, collaborative and team-work supported by technology, community involvement and learning mediated by technological resources, and, at the systemic level, alternative (to school-based) learning configurations and modalities afforded by the use of technology.

Planning and Implementation Dimension

As part of the elaboration about the future of the pedagogical ecology of TE, serious questions concerning policy making and systemic issues need to be addressed.

- *Flexible curricular planning*: In technology education, curricular planners and developers face the need to create the most appropriate balance between the foundational building-blocks of the discipline's knowledge base, and continuously evolving knowledge areas and fields of innovative application. Pedagogical frameworks guiding curricular development based on the printed textbook culture (characterised, for example, by structured, linear, hierarchical, within-clear-boundaries knowledge packages) have lost their relevance. Instead, new pedagogical frameworks, advancing a systems perspective about the curriculum, comprise intricate webs of interconnected knowledge (the 'hyper-curriculum') and multiple layers for approaching a topic under study (e.g., in terms of multiple sources, representation forms, or kinds of tasks—from exclusively academic to intensely hands on). Moving to these new approaches will require a wide range of theoretical and research considerations.
- *Pedagogical infrastructure*: Some of the claims presented above—such as the centrality of making and doing in TE, or the need to close the gap between technologies that are physically feasible to bring to the classroom and technologies in the world outside the classroom—require the examination of key questions concerning the pedagogical infrastructure needed to conduct tasks and projects. For example, there is no such thing as a 'technology lab' or even an appropriate resources toolkit in many educational jurisdictions, particularly at primary school level. While in some countries—but not all of them—schools have become increasingly better equipped with information technologies, these resources offer only partial answers to the pedagogical needs of TE. For example, they supply tools to access information, design software, virtual models and simulations, or control software for devices or robotic systems. More comprehensive issues related to the IT infrastructure to be incorporated in the pedagogical ecology of TE still demand thorough research.
- *Teaching configurations*: As the discipline of technology becomes increasingly complex, so does its teaching. A key aspect here is teachers' mastery of the disciplinary content as well as their pedagogical content knowledge (PCK, see Shulman 1987)—teachers' integration of specific content and pedagogical resources into sound pedagogies for particular students. More often than not, a range of expertise (rather than one teacher's focal expertise) is required to support students' learning, leading to the need for relevant team configurations. Currently this is not a reality in most educational systems, with the extreme situation occurring at the primary level where 'generalist' teachers, often not specifically trained in TE, teach this curricular area. Future research efforts should deepen the inquiry into teachers' PCK with regards to the multiple facets of the discipline, as well as team-teaching configurations and models addressing the complex pedagogical needs of TE.

- *Teacher education and professional development*: Expanding the previous point, vis-à-vis the continuous technological developments and technology-related economic and social transformations, there is urgent need to revise teachers' pre- and in-service professional development (Jones et al. 2013). In particular, it seems critical that all of the pedagogical issues raised in this chapter are addressed in all programmes designed to support educators who have to address these issues in their everyday encounters with TE students.

Concluding Remarks

In this chapter I set out to define a future agenda for the R&D of pedagogical issues in TE from a systems perspective—TE's pedagogical ecology. Teaching and learning in TE, a complex system, comprises many interacting factors affecting both individual and social learning processes. Numerous factors, including learners, teachers, content, pedagogical means, socio-cultural realities, value systems, educational goals, labour-market expectations, organisational characteristics and institutions, and many others interact in intricate ways, affecting teaching and learning processes. I believe that this ecological/systems perspective opens a rich space of questions to be addressed in future research, as well as multiple avenues for the development and implementation of innovative TE pedagogies.

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