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# Design Thinking for Education

## Conceptions and Applications in Teaching and Learning

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# Preface

In the fast-paced knowledge economies of today, workers are constantly confronted with complex problems that require them to engage in the design of innovative solutions. The ability to inquire into problems, create contextualized knowledge of problem situations and design plausible solutions are important competencies required of twenty-first century workers. Design thinking characterizes the mental processes that practitioners use as they frame, explore and re-frame ill-structured problems to derive design solutions. In recent years, professional fields such as engineering, architecture and business are recognizing that design thinking can be more effective for solving the complex and ill-defined problems than systematic problem-solving processes. Yet, in the field of education, design thinking has not yet seen widespread permeation into the pedagogical vocabularies of students and teachers. There is a need to better understand the potential applications of design thinking in educational settings.

This book therefore explores, through eight chapters, how design thinking vocabulary can be interpreted and employed in educational contexts. Chap. 1 examines the role that design thinking can play in today's educational contexts. This is followed by Chap. 2 that provides a critical examination of three perspectives of design and design thinking from the works of Herbert Simon, Donald Schön and Nigel Cross. With the cultivation of twenty-first century competencies being advocated as an important educational goal for schools, Chap. 3 examines how design thinking can be used as a means for supporting such goals. Chaps. 4, 5 and 6 examine design thinking in action through empirical studies characterizing the design thinking of children, pre-service teachers and in-service teachers. These cases describe how each group approach design tasks and highlight their specific challenges with design thinking. Referencing to the unique challenges faced by these groups, Chap. 7 examines the methods for developing and evaluating design thinking. The final chapter of the book discusses the future directions for the incorporation of design thinking into educational settings.

Through these chapters, we hope that this book will be beneficial for teachers, teacher educators and university instructors who are using or considering how design thinking can be applied to their specific educational contexts. We also hope that this book will stimulate critical conversation among educational researchers to further develop the use of design thinking in educational contexts.

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# Chapter 1
# Design Thinking and Education

## 1.1 Introduction

Design and design thinking has been an inseparable part of many industrial and commercial activities. Today, the interest in design has not only intensified in these traditional spheres of activity, but the process of design thinking has taken hold in the public sector as well as in a variety of nonprofit organizations. Much of the interest in design is based on its perceived ability to address a host of complex social, economic, technological, and political issues in the new global age. Design thinking has been widely promoted in popular media such as the Harvard Business Review, in TED talks (see, e.g., James Patten, April 2014, *The best computer interface? Maybe…your hands*), as well as at influential venues such as the World Economic Forum meetings at Davos.

Governments in advanced economies are increasingly exploring the potential of design thinking in meeting national problems and challenges. The Danish government, for example, supports a cross-ministerial innovative organization that combines design thinking with social science approaches to create new solutions for society (Kimbell, 2011). In the Asia-Pacific region, China, South Korea, and India have promoted design thinking in university education through establishing programs that are focused on cultivating design thinking (Kurokawa, 2013). In Singapore, design thinking is seen as a useful link between education and industry. Indeed, one of the key recommendations of its 2010 Report of the Economic Strategies Committee (ESC) was to "instil design thinking into our workforce by accelerating the introduction of design thinking programmes and modules at local education institutions" and to "step up efforts in the education system to inculcate a mindset of innovation amongst young Singaporeans" (Report of the Economic Strategies Committee [ESC], 2010, p. 25).[1]

[1] Report of the Economic Strategies Committee, Singapore, 2010, p. 25. Retrieved 3 August 2014 from http://www.mti.gov.sg/ResearchRoom/Pages/Report-of-the-Economic-Strategies-Committee.aspx



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The objective of the ESC is to help develop strategies to grow Singapore as a leading global city. In keeping with this recommendation, one of the country's leading polytechnics has integrated design thinking into its organizational practices as well as its curriculum (Singapore Polytechnic, 2011).

Not surprisingly, the potential of design thinking in improving curriculum and pedagogy has been advanced by a growing number of scholars and educational researchers (Laurillard, 2012; Trebell, 2009; Tsai, Chai, Wong, Hong, & Tan, 2013; Wong, 2011). In this book, we seek to contribute to this new initiative by examining and reviewing design thinking and its relation to education. Design thinking here is treated as a broad concept to encompass the kinds of thinking that occur in taking the design approach to deal with real-world problems or challenges. We will showcase several case studies to foster design thinking in the context of Singapore and Taiwan classrooms. In the following sections, we will elaborate on the nature of design thinking and on the scope of its contribution to teaching and learning.

## 1.2 Design and Design Thinking

Design thinking is an activity that is implicit in the process of design. As a concept, however, design thinking emerged only in the later part of the twentieth century. According to Kimbell (2011), one of the earliest book-length treatments of the concept was in Peter Rowe's *Design Thinking*, published in 1987. The discourse on design and design thinking is no doubt grounded in traditional disciplines such as industrial and graphic design as well as engineering and architecture. In *The Sciences of the Artificial* published in 1969, Herbert Simon characterized design as the core of all professional training—"the principal mark that distinguishes the professions from the sciences" (Simon, 1996, p. 111). Design permeates, or at least it has the potential to permeate, all human professions. Design professions working on the human body include hair stylist, fashion designers, and plastic surgeons. Design professions working on the environment would range from landscapists and interior designers to town planners, architects, and civil engineers. Perhaps inspired by Simon's pioneering work, there has been a concerted attempt to elevate the theory and practice of design to an academically respectable discipline. Cross (2001), for example, has attempted to distinguish the epistemology of design or designerly ways of knowing from the sciences on the one hand, and the arts and humanities on the other. And in light of the growing prominence of design, Buchanan has argued that it should be regarded as "a new liberal art of technological culture" (Buchanan, 1992, p. 5).

In tandem with efforts to elevate the status of design, much speculation has gone into understanding the process of design and design thinking. Several scholars and researchers take the perspective that design thinking is particularly suited to dealing with ill-defined or wicked problems (Buchanan, 1992). Wicked or ill-defined problems are problems that cannot be fully resolved in part because they cannot be fully comprehended. Wicked problems cannot be easily described or defined, and they can be changeable, shifting in nature over time. For this reason, designers are compelled to engage first in the process of setting or framing the problem. And how the problem is framed or formulated determines the range of possible solutions. The problems and associated solutions then coevolve in a symbiotic manner with new task goals, constraints, and insights being generated as the creative problem-solving processes emerge.

The qualities of design are affected by variables such as fixation, creativity, process strategy, and the generation of alternatives. A significant part of the problem-solving process in design thinking involves the ability to synthesize knowledge from a variety of sources (Cross, 2007; Pink, 2006; Simon, 1996). For this reason, design thinking has a multi-/interdisciplinary character. The problem-solving process frequently involves drawings or sketches but also the making and use of models, simulations, and prototypes. These tools are useful as external representations of thinking to reduce cognitive load. In addition, they provide alternative paths to experiential learning and often serve as the basis for the accumulation of tacit knowledge. In this way, they can help to bring about the discovery of new knowledge or modes of thought (Brown, 2009; Simon, 1996). Attempts have been made to distinguish design thinking as a form of abductive thought in light of its capacity to generate novel ideas (Cross, 2001; Dorst, 2011).

Design and therefore design thinking is integral to the production of things or artifacts. Indeed, design thinking is implicated in all aspects of the man-made world from physical artifacts to symbolic and conceptual objects like languages and mathematical theorems. On the basis of Bloom's revised taxonomy of educational objectives (Anderson & Krathwohl, 2001), design thinking could be said to involve all forms of cognitive activities including remembering, understanding, applying, analyzing, evaluating, and creating. The latter three forms—usually classified as higher-order cognition (Lewis & Smith, 1993)—are especially important for design. Collectively, both lower- and higher-order cognitive activities are necessary to engender design thinking. Broadly defined, design thinking encompasses the cognitive activities that are focused on changing natural resources or existing human artifacts in response to emerging human needs or desires (Brown, 2009; Heskett, 2005). In this regard, design thinking does not ignore relevant cognitive and affective dimensions of human experience.

As Herbert Simon has noted, the "world we live in today is much more a man-made, or artificial, world than it is a natural world" (Simon, 1996, p. 2). It is therefore important for us to understand the role that design plays in every aspect of our lives. Design thinking is an intentional act (Rowland, 2004). It is a conscious and mindful seeking of something new. We engage in design in order to make things that would help to improve our living environment and our social relations. Designing well is therefore a key to living well.

That design plays a distinctive role in the evolution of human civilization is beyond doubt. Design is the defining activity in the cultural development of societies. Civilization attests to the man's ability to shape and reshape his environment. And in changing his environment, man also changes his way of life. Design can be said to be an essential part of human evolution. But because design is such a ubiquitous human activity, it is not easy to capture all its aspects. This would require comprehensive knowledge of all human creativity and productivity, an impossible feat. Also history attests to the frequent abuses of human ingenuity and creativity. It would seem that design in itself is a morally neutral activity. Hence, it is important to pay due attention to current efforts to focus on the human-centered features and the ethics of design (Brown, 2009; Felton, Zelenko, & Vaughan, 2012; Steen, 2013). Steen, for example, has argued that ethics is an integral part of the human-centered approach to design. This is because human-centered design involves interaction with others, especially the intended beneficiaries of the product or service; hence, their moral experiences have to be considered in the design of the product or service intended for their benefit (Steen, 2013).

## 1.3 Situating Design Thinking in a Provisional Conceptual Framework

Karl Popper's three-world ontology provides a useful starting point for situating design thinking in a broader conceptual and epistemological framework. According to Popper, we ought to see the universe in terms of three interacting worlds. The physical world of things and events constitute World 1. Our subjective experiences or the world of mental or psychological states constitute World 2. World 3 comprise the products of the human mind in their abstract or conceptual form; these products may be characterized as conceptual or cognitive artifacts (Bereiter, 1994).

The three worlds are intertwined and they interact in various ways. For example, Shakespeare's *Hamlet* is a World 3 artifact that is realized or embodied in various texts and performances as well as recordings of those performances. As text, performance, or recording, the play exists in World 1. The experience and appreciation of the play through reading or watching it are events that occur in World 2. The play is therefore experienced differently by different listeners who can then engage in informed or critical discussion of the merits of the performance. Popper's understanding of the importance of World 3 is that it allows people to make objective claims about a particular performance: to say "It was a marvelous performance, but few people appreciated it" (Popper, 1978). In order to do so, they must be relating their understanding and experiences to the play *Hamlet* as it exists in World 3. The discussion of a particular performance of *Hamlet* in this context may not only enrich the understanding of the play but may even lead to its modification as well.

The three-world ontology was introduced to ground an account of objective knowledge that would address shortcomings in a (materialist) monistic or dualistic view of the universe. Monists reduce all things including thoughts and experiences to some physical property in the world. Dualists, on the other hand, take the commonsensical view that the world can be divided into the physical world and the mental world of experiences. According to Popper, neither view of the world allows us to make certain types of judgments or explain how we are able to engage in certain types of conceptual activities.

But the more pertinent point of Popper's ontology was to pave the way for a dynamic account of how our knowledge and understanding works to transform both the natural and artificial world around us. To Popper, many significant World 3 objects can serve as "instruments of change" (Popper, 1978, p. 154). Ideas can have profound effects on how we see the world or how we interact with one another. And according to Popper, a basic characteristic of World 3 objects is that they can improve and contribute to advancing the quality of human life. While Popper places great emphasis on the utility of criticism as a way of improving World 3 objects, design thinking offers a complementary means of transforming World 3 objects through a more integrative and pragmatic approach. Without denying the importance of criticism and analysis, design thinking incorporates not only other modes of thinking but modes of doing and making that further the process of change and innovation that Popper envisages.

Bereiter (2002) has argued that the conception of World 3 as consisting of improvable objects or artifacts triggers the design mode of thinking that seeks to understand the potential utility of ideas in their embodiment as World 1 objects or events. According to Bereiter and Scardamalia (2006), to employ the design mode of thinking is to engage in asking questions such as the following: (1) what is this idea good for, (2) what does it do and fail to do, and (3) how can it be improved (p. 701)? The design mode of thinking is akin to design thinking in that both are oriented towards the notions of utility (Pink, 2006).[2] While Berieter and Scardamalia are focused on the design mode of thinking as a means to foster knowledge-building communities, their approach is compatible with approaches pioneered by design thinkers to foster social innovation. Tim Brown of IDEO, for example, appeals to the criteria of feasibility, viability, and desirability to assess the value of ideas. The feasibility criterion ensures that ideas considered are functionally possible, while the viability criterion ensures that what is functionally possible can be made a part of a sustainable enterprise. The desirability criterion is intended to ensure that the enterprise meets the interests and needs of the people affected by it.

The difference between the two design approaches is that one is focused on improving ideas in the form of theories, explanations, and algorithms, whereas the other is directed towards improving a broad range of material artifacts, including social-cultural practices. Design thinking, moreover, complements Bereiter and

[2] The central concern of both approaches to design is in understanding the usefulness of ideas rather than focusing exclusive on the pursuit of its truth. That is not to say that truth is unimportant, especially in the context of education. Pedagogically speaking, the design approach can be seen as a matter of foregrounding the emphasis towards useful rather than devaluing truth. At any rate, the design of useful objects or the construction of conceptual artifacts cannot "ignore or violate the laws of nature" (Simon, 1996, p. 3).

Scardamalia's approach with its emphasis on the human-centered nature of idea generation and knowledge construction. Accordingly, design thinking highlights the normative and ethical aspects of knowledge creation and innovation that are particularly relevant to the sphere of education. The human-centeredness of design thinking develops the capacity for judgment and self-reflection. Because it seeks to improve the human environment in an inclusive way by incorporating the views and insights of users, this approach also helps to contribute to the development of practical wisdom. In light of the complex nature of challenges and problems of the twenty-first century, the development of such practical wisdom complements efforts to educate for responsible local as well as global citizenship.

Because of its practical and multidimensional approach to problem solving, design thinking contributes to the educational task of preparing the young to meet the complex global challenges brought about by uneven economic growth and rapid technological developments. Bereiter and Scardamalia (2006) propose that today's schools need to be radically redesigned as knowledge creation organizations. The overarching aim of their proposal is to foster the design mode of thinking among today's learners. Broadly speaking, their proposal is shared and endorsed by many other education researchers who have criticized current education systems and advocated greater emphasis on designing and creating as a means of knowing (e.g., see Collins & Halverson, 2010; Thomas & Brown, 2011). Others have incorporated design thinking as a practical and experiential extension of their more discursive and conceptual approach towards design (Tsai et al., 2013; Zhao, 2012). The complexity of current problems has led to serious debates about the purposes of education, what children are to learn, and how they should be taught. Increasingly, existing practices and principles of education are subjected to searching criticism and attack. In the next sections, we shall survey the main problems with existing educational practices and discuss how design thinking fits in with proposals to help overcome these problems.

## 1.4 Education: The Old Design and Its Problems

As with any artifact, education policies and practices are products of design, though not always of deliberate design. Education is a massive and collectively designed human system. Schools are designed and built with functionality in mind. Education policies are devices of learning design that envision forms of desirable practices, provide the supports to be provided to teachers, and set out the rationale behind learning goals (Cobb & Jackson, 2012). Public laws and school regulations are designed to ensure the proper running of schools throughout the system. Curriculum, assessment, and educational technologies are designed to facilitate classroom teaching. Today, the design of contemporary school systems has been challenged on many fronts. Parents who are dissatisfied with the design of the public school have opted for home schooling. Alternative models of schooling have also been experimented with. For example, the National University of Singapore

High School of Mathematics and Science is different from the mainstream secondary schools in Singapore. The school does not subject her students to external Cambridge examinations and the students must complete an advance research project (see http://en.wikipedia.org/wiki/NUS_High_School_of_Math_and_Science). Also in Singapore, Chai, Lim, and Tan (in press) documented multiple cases of how a primary school redesigned its curriculum through extensive and sustained professional development activities structured as part of the teachers' time table. All subject matters (English, Chinese, mathematics, science, and social studies) were redesigned with ICT integrated into the curriculum to align with the demands of twenty-first-century learning.

Many educators point to the historical premises on which the current design of the school system is built as the principal basis of the problems affecting education (e.g., see Collins & Halverson, 2010; Macdonald & Hursh, 2006). Founded on the premise of industrialization, the existing school system emphasizes the universal provision of education for all and standardized curricular and tests. Teachers are seen as experts, and learning as absorbing and reproducing verified knowledge (Macdonald & Hursh, 2006). The subjects that are deemed important are languages, mathematics, science, and humanities, which are somewhat akin to what Plato had proposed 2,000 years ago (see Noddings, 1998). Subjects are taught as isolated disciplines and the technologies employed consist mainly of textbooks and the use of the chalk/white board. Schools that operate on such modes are referred to as traditional schools. The main purpose of the traditional school is to prepare the young to become responsible employees for the workplace, understood along lines of the Industrial Age.

That the mission of school as a sociopolitical entity is to prepare the young for the future has been widely accepted since antiquity, and this understanding of the school's mission is unlikely to change (Facer, 2011; Noddings, 1998). What is contested today has to do with the conception of the workplace that children will enter when they leave schools. Up to the middle of the last century, the growth of knowledge and consequently the associated sociopolitical transformations that accompanied these changes occurred at a slow pace. Schools regarded as a sociopolitical establishment were generally able to train the young for work in industry. However, changes brought about by technological advancements especially in the fields of computing, information processing, and communications have challenged the old design of schools. Hargreaves and Shirley (2012) described these changes in technology as "rampant and relentless" (p. 1.), and they are increasingly making their presence felt in almost all aspects of daily life in contemporary society.

One striking example of the power of information and communications technology or ICT is the Arab Spring, in which social media such as Twitter and YouTube played a significant role in the overthrow of governments. More importantly, ICT changes the skill set needed for one to be successful in the contemporary world. ICT has enabled industries to automate many production jobs that are formerly handled manually. High-volume manual work has been replaced with high-value knowledge works (Reich, 1992; Thomke & Feinberg, 2009). Advances in artificial intelligence are posing threats to many traditional white-collar jobs

(Brynjolfsson & McAfee, 2014). While ICT causes many jobs to become obsolete and will continue to do so, it also creates new jobs that require different skill sets. Dufour (2010) points out that workers today need to produce “high value-added goods and services driven by . . . strong innovation performance” aided by the “intensive use of generic technologies” (p. 984).

ICT has not only changed the types of work needed in developed economies but also how people learn. The means and resources for learning have also changed qualitatively. New cultures of learning are emerging informally outside school through temporal participation in online communities. There have been documented cases of powerful learning experiences among teenagers without the formal structure imposed by school (e.g., see Thomas & Brown, 2011). Adventurous teenagers have been able to exploit the educational affordances of technologies. In one case, a teenager published a novel online which incorporated feedback from readers (Tan, 2010). In another case, a student who joined an online community to learn about programming was subsequently able to contribute workable programs online and even became a mentor to other novices (Resnick, 2013). Perhaps the most noteworthy example is the young entrepreneur Suhas Gopinath, who taught himself to build business websites in Internet cafes and was recognized as an outstanding entrepreneur by the World Economic Forum (Salkowitz, 2010). While these stories are anecdotal in nature, they highlight the potential new ways of learning that the current technology affords. Burdick and Willis (2011) maintain that design thinking is well suited for this new culture of learning and experimenting.

The design of the traditional school system is predicated on the assumption that knowledge is relatively stable and there is a core set of knowledge that should be understood by all. This core set of knowledge will enable people to be productive members of society. Furthermore, knowledge transmission had to be planned hierarchically to cater to the various developmental profile of students. For the most part, knowledge was acquired through the instruction of teachers. But these assumptions are increasingly being challenged. Today’s society faces problems and issues that are multifaceted, complex, and dynamic in nature. Prespecifying the knowledge needed for learners would not be adequate to the task of addressing these problems. Knowledge learned just-in-time is likely to be more powerful and relevant than knowledge acquired just-in-case (Kirschner, 2001). The tools and affordances of ICT may provide more varied and responsive resources to cater for the diverse learning needs and interests of students. Peer learning may be as important as teacher facilitation in this context. The active engagement with digital artifacts may prove to be a more powerful way to learn than passive absorption of teachers’ delivered lectures. In any case, these new ways of learning may be more compatible with the technology-enhanced ways of living that learners are experiencing nowadays. More importantly, the new ways of learning are more likely to foster designerly ways of thinking and knowing that are more adequate to resolving the complex challenges that confront society. From an educational perspective, design thinking has the potential to contribute to the development of the creative and adaptive capacities of students, thus enabling them to acquire the knowledge, skills, and attributes needed for collaborative problem solving of complex problems. The cases in this book provide some evidences in support of the influences of students' engagement in design thinking.

## 1.5 Education: The New Design

The limitations of the traditional school system have inspired serious efforts to reenvision how education should be used to address challenges today and those that may emerge in the future. To a considerable extent, the current emphasis on twenty-first-century learning reflects this desire to change educational practices. The movement towards change has also been precipitated by the spontaneous exploitation of technological affordances by highly motivated and self-directed learners, who have widened the horizon for new practices in learning. As many of these projects are just emerging and works in progress, it is not possible to provide a definite description of its many facets and trajectories. Collectively, however, several important dimensions of these new learning initiatives seem to be more or less gaining prominence in current discourse on education reform.

First, with regard to the epistemic dimension, there has been a noticeable shift towards greater emphasis on design as opposed to traditional epistemology (Cross, 2007; Rowland, 2004; Tsai et al., 2013). Traditional epistemology takes the view of knowledge as verified truth. The epistemic criterion for knowledge in classroom discourse is based on the establishment of its "truth" value as well as the evaluation of the authors of curricula about its future usefulness in preparing and qualifying a learner for certain professions. Design epistemology, on the other hand, is concerned with generating useful, practical ideas to resolve existing real-world problems. In the design context, ideas are constructed and proposed freely by learners and evaluated within the sociohistorical context of the community of discourse. Rowland depicts design thinking as constituted by processes that:

> do not confront decisions that are clearly correct or incorrect, right or wrong. Instead they (designers) make judgments and learn how wise those judgments are through their consequences. Judgment is neither rational decision making nor intuition. It is the ability to gain insight, through experience and reflection, and project this insight onto situations that are complex, indeterminate, and paradoxical. (p. 40)

The inclusion of the design epistemology (Rowland, 2004; Tsai et al., 2013) or designerly ways of knowing (Cross, 2007) enlarges and enriches the learning horizon for the new educational landscape. Design epistemology does not exclude the more traditional epistemology associated with the sciences. Resnick (2010) maintains that twenty-first-century competencies require knowledge-based reasoning that builds on the foundations of strong literacy and numeracy. Anderman, Sinatra, and Gray (2012) point out that fast-paced knowledge generation demands adaptive thinking among students with deep understanding of science content. To be sure, traditional education is not adverse to innovation or creative endeavor in principle. But it tends to be overly cautious in emphasizing that students should acquire sufficient knowledge and build strong foundations before embarking on knowledge creation enterprises. In the current context, this “learn first and create later” approach is unlikely to be the only or most productive way to go. Moreover, the overemphasis on learning may hinder the development of creativity.

Creativity is important when dealing with real-world problems that are often complex or indeterminate in nature. So-called wicked problems require designers to engage in problem setting or problem framing, and this often requires a high degree of creativity (Schön, 1983). Dorst offers an example that is highly instructive (Dorst, 2011). A particular nightspot popular with young people has problems with drunkenness, drugs, theft, and sporadic violence. Local authorities have treated these problems as law and order issues and have focused solutions on increasing security. This solution characterized young people as trouble makers who needed constant policing. These tough security measures, however, served only to darken the mood of young people and were thus counterproductive. Having observed the behavior of the young people more closely, a group of designers proposed that the situation can be seen as a problem akin to organizing a good-sized music festival requiring specific logistical provisions to deal with large energetic crowds. These proposed measures were based on the assumption that the young were fun loving people, whose needs could be easily accommodated through the creation of chill out spaces and areas with continuous attractions to entertain them. By reframing the problem, these designers proposed a nonthreatening and more effective solution to the challenge of dealing with the restlessness and exuberance of the young.

Second, from the perspective of Popper’s (1978) three worlds’ ontology, the new design of education should engage students on all three worlds of reality. For learners to thrive in the fast-changing knowledge age, it is important to develop the ability to traverse the three worlds in a seamless way (Chai & Lim, 2011). The design-thinking approach offers a practical perspective on how the three worlds interact. For example, the design-thinking approach proposed by Brown (2009) involves the following process: understanding, observation, perspective taking (points of view), ideation, prototyping, and testing. The first step in the process requires a person to be familiar with the nature of the problem and to conduct research as well as to consult with experts. A great deal of this part of the process is focused on World 3 objects or the thought content characteristic of World 3. The observation stage is clearly directed at World 1 objects or events. The point of view stage relates to the intersubjective of the world of personal experiences that constitute World 2. The remaining parts of the process brings into play critical, creative, and practical aspects of design thinking, with the prototyping and testing stages much in keeping with the Popperian spirit of experimentation in the service of piecemeal social development and progress.

In dealing with complex problems, designers are prepared to explore different tools and thinking protocols in order to create practical and/or ingenious solutions to resolve these problems and to fulfill human needs and wants. Exposure to design challenges helps to prepare the young to deal with uncertainty and ambiguity. In the course of exploring possibilities, designers need to synthesize disparate knowledge and information across disciplines (Brown, 2009; Harfield, 2007; Simon, 1996). This multidisciplinary approach often requires collaboration and teamwork. Furthermore, the human-centered element in design thinking serves to nurture qualities necessary for social interaction and the cultivation of empathy. In all, design thinking not only helps in the creation of new ideas and knowledge, but it also serves to foster skills in making and doing, including skills required to deal with ambiguous situations as well as those related to working with other people and empathizing with them. In this way, the teaching of design thinking contributes to the holistic development of children.

Third, a review of current pedagogical practices for the new design in education is necessary. The "design and technology" subject in primary and secondary schools reflect contemporary efforts to evolve new pedagogies appropriate for the age of rapid technological advancement (Kimbell & Perry, 2001). However, this subject is often offered as a stand-alone subject for students who are not academically inclined (Foo, 2012). Nonetheless, having a stable subject matter where design thinking is directly relevant provides an anchor point for design thinking to enter classrooms legitimately.

In the 1970s, constructionism was introduced by Papert through the programming language Logo. Constructionism advocates design as a main pedagogical activity (Kafai, 2006). By encouraging students to design and build physical models or artifacts with or without the help of computers, constructionism seeks to engage and deepen students' experiential learning (Papert & Harel, 1991). In one instructive case, Papert recounted his idea of constructionist learning as inspired by what he observed at an art session devoted to soap carving. Students were actively engaged for many weeks talking, thinking, imagining, and changing the designs of their soap carvings. The invention of Logo programming language enables students to engage in more cross-disciplinary ways of knowing and also to deepen their understanding of various school-based subjects (e.g., mathematics, arts, and the sciences). More detailed discussion about Logo programming is provided in Chap. 4.

Bereiter and Scardamalia (2006) also advocate constructionism as a foundation of the knowledge-building approach where students are engaged in the design mode of thinking that draws on their collective efforts in improving ideas. Over the past two decades, Bereiter and Scardamalia have documented a range of interesting studies of the collaborative efforts of students in improving their knowledge of science through online posts (see Scardamalia & Bereiter, 2010). Based on these works, Scardamalia (2002) has articulated 12 design principles through which the knowledge-building approach could be enacted in the classroom. These principles include dealing with authentic problems that students care about, articulating theories and ideas (cognitive artifacts) in the form of publicly accessible network database, and working on improving the ideas collectively through knowledge-building discourse. This approach of structuring classroom progression with design principles is in keeping with the spirit of design which embraces open and elegant responses to emerging ideas. The knowledge-building approach, which has the potential to foster a dynamic and design-thinking mindset among the students, has been gaining attention among educators in both the west and the east. Chapter 5 provides a case study of knowledge building among preservice teachers.

Lastly, design thinking is not only useful as a pedagogical tool for students. It has the potential to be a useful learning and developmental tool for teacher professionalism. If teachers are to foster the design-oriented epistemic outlook among students, they first have to be well versed with the ideas of design and they have to engage in the practice of design (Chai, Koh, & Tsai, 2013). Mishra and Koehler (2006) proposed the technological pedagogical content knowledge (TPACK) framework as a means of fostering design thinking among educators. Laurillard (2012) goes even further in advocating teaching as a design science. In addition, an emerging research methodology named design-based research or design research points to a shift towards design as a means to create useful knowledge in the educational context (Anderson & Shattuck, 2012). This form of research is undergirded by pragmatism and seeks to enact and study practical design-based principles in the classroom. The key goal is to design rich learning environments that would have real impact on students' learning. The shift towards this form of research lies partly in researchers' dissatisfaction with scientific knowledge about learning that does not fully take into account of what goes on in the classroom. In other words, education researchers are also turning towards design thinking to produce useful knowledge for teaching practices.

## 1.6 Conclusion

This chapter has outlined the main characteristics of design and design thinking and its implication for education. We propose that education should pay greater attention to the design dimension that is characteristics of human and civilizational culture and accordingly embed design thinking as an integral part of education. Fostering design thinking among today's learners is essential for the knowledge age, much of which is driven by technological advances. Design thinking seeks to utilize knowledge and practices to find viable solutions that would meet the needs and interests of people in the context of the challenges of contemporary society. The human-centered approach to design thinking also promotes empathy and contributes to the character development of students (Rowland, 2004). Unlike scientific thinking that regards uncertainty and ambiguity as threats on knowledge development (Duschl, 1990), design thinking thrives on ambiguity and uncertainty; thus, it broadens students' educational experience by encouraging innovative and reflexive thinking, self-awareness, and social consciousness. In short, the design-thinking approach fosters many of the desirable traits identified as twenty-first-century competencies (Voogt & Roblin, 2012).

In the chapters to follow, we explore critical perspectives to design thinking (Chap. 2) and its relationships with twenty-first-century competencies (Chap. 3). We also provide examples of how design thinking is being applied by children

(Chap. 4), preservice teachers (Chap. 5), and in-service teachers (Chap. 6). The methods and challenges for developing and assessing design thinking are discussed in Chap. 7, and this is followed by a consideration of the future directions for design thinking in education (Chap. 8).

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# Chapter 2
# Critical Perspectives on Design and Design Thinking

## 2.1 Introduction

The interest in the uses of design thinking as a pedagogical tool in education is new and promising in terms of the scope of its application in the school curriculum and beyond. This interest reflects the growing popularity of design thinking as a professional tool in the production of innovative products and services in both the private and the public sector. The contemporary world governed by the imperatives of the knowledge or ideas economy is obsessed with creativity in order to satisfy the global demand for new products and services. As design is so fundamental to this intensification of the creative process, there has been a growing interest in the nature of design and design thinking. In keeping with this interest, there have been recent efforts to elevate the status of design and to extend its relevance into all domains of life. Since humans are surrounded by man-made things, most of which are products of deliberate design, should design not be taken more seriously? Should it not have the same credibility and respectability as a science (Simon, 1996)? As a practical activity engaged in by professionals, should it not be grounded in an appropriate epistemology of practice (Schön, 1983)? And would it not be more fitting for the field of design to have its own disciplinary domain (Cross, 2001)? And as design is implicated in the dramatic impact that technology has on the world, should it not also be more self-conscious of its global responsibilities by reflecting on its ethical bases (Felton, Zelenko, & Vaughan, 2012; Flusser, 2013; Nelson & Stolterman, 2003)?

This chapter will offer a brief critical perspective on some of the leading theorists and their conceptions of design. As noted by Kimbell, design continues to be "a fragmented discipline" (Kimbell, 2011, p. 290). Nonetheless, most attempts to articulate the nature and scope of design thinking have appealed to these theorists either individually or in combination. For this reason, it is important to be familiar with the strengths and limitations of the principal works of these seminal thinkers. The chapter will focus mainly on the major works of Herbert Simon, Donald Schön,



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and Nigel Cross. The aim of this chapter is to explore the power and limits of these works and to invite further scrutiny of the nature and implications of their arguments. These writers and their works reflect the growing confidence among serious design thinkers and design practitioners about the global importance of their field of expertise. As the study of design grows in importance and influence, it is appropriate also to set out an account of the historical role and importance that design has played in the evolution of human culture and the ethical considerations that arise from the exploitation of nature along with the relentless and unceasing transformation of the human environment.

## 2.2 Three Major Theorists of Design

Design and design thinking as an emerging field of inquiry and research is new, and for this reason, there is no dominant theory or practice that governs it (Kimbell, 2011). This has to do partly with the domain of design which spans the universe of man-made things throughout the course of human history. Just as there are various subdivisions in the sciences and humanities, there needs to be a clearly defined and articulated subdivision in the domain of design. Such a task has yet to be attempted. Currently there have been piecemeal efforts to mark out some area of design that demands more focused attention. The established professions, for a variety of reasons, have often been the major beneficiaries of these efforts. One invariably comes across the names of Herbert Simon, Donald Schön, and Nigel Cross in researching the literature on design and design thinking. Each of these writers has staked out positions that are quite distinct and perhaps even conflicting. The one thing they have in common is a determination to highlight the importance of design in the major professions and to place design on a rigorous intellectual footing.

### *2.2.1 Herbert Simon*

*The Sciences of the Artificial* first published in 1969 by Herbert Simon has often been cited as a pioneering work in the theory of design. The text was written in part to address a serious gap in the education of the major professions. Design, for Simon, was "the principal mark that distinguishes the professions from the sciences" (Simon, 1996, p. 111). But as he observed, "it is ironic that in this century the natural sciences almost drove the sciences of the artificial from the professional school curricula. . .Engineering schools gradually became schools of physics; medical schools became schools of biological science; business schools became schools of finite mathematics" (Simon, p. 111). Simon therefore intended the book to restore the element of design to the curricula of the professional schools by raising its academic respectability. To be regarded as a science, the element of design would have to be “intellectually tough, analytical, formalizable, and teachable” (Simon, p. 112).

In general, Simon’s work was focused on complex artificial systems. These include aspects of human behavior as illustrated in the case of “economic man,” which Simon characterizes as “a rationally designed system” (Simon, 1996, p. 12). Just as natural science sought to make “the wonderful commonplace, to show that complexity, correctly viewed, is only a mask of simplicity,” Simon’s work attempted to articulate the underlying simplicity in the construction of complex artificial systems. An indication of the simplicity of the structure underlying these artificial systems can be discerned from his perspective of an artifact as a “meeting place” or “interface” between an “inner” environment and “outer” environment. The “inner” environment refers to the substance and organization of the artifact, and the “outer” environment refers to the surroundings in which the artifact operates. If the inner environment “is appropriate to the outer environment, or vice versa” then the artifact will have served its intended purpose (Simon, p. 7). According to Simon, the description of an artifice in terms of its organization and function “is a major objective of invention and design activity” (Simon, p. 9). As an example, Simon draws on the structure and behavior of a business organization: “if we know of a business organization only that it is a profit-maximizing system, we can often predict how its behavior will change if we change its environment—how it will alter its prices if a sales tax is levied on its products. We can sometimes make this prediction…without detailed assumptions about the adaptive mechanism, the decision-making apparatus that constitutes the inner environment of the business firm” (Simon, p. 8).

The above characterization of the artifact has potentially serious implications for the relation between sciences of nature and the sciences of the artificial. As Simon observes, his notion of an artifact as an adaptive system applies “equally well to many things that are not man-made” (Simon, 1996, p. 6). Things in nature, especially living organisms, can be described as complex adaptive systems. But would this imply that nature as a whole could be conceived as a kind of sophisticated machine? In view of the current knowledge of the problems of science, in particular its inability to reconcile the general theory of relativity and quantum mechanics, can Simon maintain his view that complexity in science is merely a mask for simplicity? Is it not possible that some things in nature are just too complex to simplify and that they might remain mysterious (Pangle, 2014)? Consider his account of human beings. Viewed as “behaving systems,” they are fundamentally quite simple: “the inner environment, the hardware, is simple” (Simon, p. 110). Yet at the same time, he says that the “adaptiveness of the human organism …makes it an elusive and fascinating target of our scientific enquiries and the very prototype of the artificial” (Simon, p. 110). But what if the target persists in being elusive? What would become of the prototype of the artificial?

Simon’s understanding of what it means to develop the sciences of the artificial also has serious implications for the social sciences as well as the academic disciplines of the arts and humanities. After all, the subject matter in Simon’s book includes both economics and psychology, and he makes the claim that painting, acting, as well as music belong in the realm of design (Simon, 1996, pp. xii & 2). According to Simon, music is "one of the most ancient of the sciences of the artificial" (Simon, p. 136). Because music involves formal patterns like mathematics "we can even apply to music some of the same techniques of automatic design by computer that have been used in other fields of design" (Simon, p. 136). In exploring such musical possibilities, Simon envisaged the possibility of productive conversations between engineers and composers in the future. Indeed, advances in computing have brought this possibility into being. Diana Dabby is a case in point (Edwards, 2008). A professor of engineering and music, she utilizes chaos theory to generate musical variations of original compositions. This combination of mathematics and music might open up a new genre in music. But it is one thing to say that the sciences of the artificial contributes to the domain of music, quite another to say that it informs the domain itself. Furthermore, one wonders if musicians and composers understand themselves as practitioners in the sciences of the artificial.

Simon was confident at least that his work was influential in changing the attitudes of engineering schools towards the study of design and the advancement of design theory (Simon, 1996, pp. 113 & 114). But it is not clear if his theory has been as successful in the transformations of medical schools and business schools. This is not to deny that aspects of his theories and concepts are used in various academic disciplines. In other words, it is not clear if the practitioners of the disciplines, specifically those explored in the book, self-consciously characterize their disciplines as sciences of the artificial. At any rate, Simon held the view that his theory was applicable to all intellectual pursuits. There are certainly good reasons for Simon to propose a science of design when it relates to the practical aspects of the professional disciplines. But in doing so, he seems indifferent if not dismissive of other forms and understanding of design. As he says, "everyone designs who devises courses of action aimed at changing existing situations into preferred ones" (Simon, p. 111). This broad understanding of design would suggest that design goes beyond professional practice as well as other serious intellectual pursuits. According to Simon, one of the reasons why design was ignored as a serious pursuit in the professional schools was that it was seen to be "intellectually soft, intuitive, informal, and cookbooky" (Simon, p. 112). But if mathematics can contribute to music, why can't cookbooky approaches to design do the same for engineering? Design approaches that are intellectually soft, intuitive, or informal surely have their place in the design process understood as changing existing situations into preferred ones. Besides, one major role of design is simply to improve the look or appearances of artifacts, and this activity may be quite distinct from the process of adapting an artifact to meet human purposes. A watch is designed to tell time, but watches come in different shapes, sizes, materials, and colors. Simon is clearly aware of the esthetics in design, but do these elements have to be subjected to a framework that is intellectually tough, analytical, and formalizable? Furthermore, it is not clear how analytical ability is necessarily superior to intuition in the major professions and other serious intellectual pursuits. As Donald

Schön has argued, the practical knowledge that professions display in their work cannot readily be reduced to logic and mathematics or technical forms of rationality. The knowledge professionals enact in practice is much more intuitive and artistic in character (Schön, 1983). Others have found on the basis of careful observations of innovative designers at work that their methods or approaches to design are seldom, if ever, systematic (Cross, 2011).

Artifacts are judged in terms of how well they are adapted to human goals and purposes. If a particular artifact fulfills the purpose for which it was designed, would it matter whether the design and construction of the artifact followed a rigorous and formal method? One wonders if the design process could be too formalized and thus counterproductive in terms of constraining the scope for creativity so necessary to the process of design. As Simon remarks, the process of design could be a valued activity in itself: "the act of envisioning possibilities and elaborating them is itself a pleasurable and valuable experience. Just as realized plans may be a source of new experiences, so new prospects are opened up at each step in the process of design. Designing is a kind of mental window shopping. Purchases do not have to be made to get pleasure from it" (Simon, 1996, p. 164). So what is ultimately important about designing is the pleasure derived from imagining new possibilities. The question that arises from this is whether the sciences of the artificial would limit or enhance the pursuit of this activity.

### 2.2.2 Donald Schön

Trained as a philosopher, Schön pursued a career in product design and technical innovation that culminated in his appointment as Ford Professor of Urban Planning and Education at MIT. He is perhaps best known for his book *The Reflective Practitioner* in which he sets out his thesis regarding the role that tacit knowledge plays in the work and training of professionals. He is often contrasted with Simon. In contrast to the model of technical rationality attributed to Simon, Schön proposes "an epistemology of practice implicit in the artistic, intuitive processes which some practitioners do bring to situations of uncertainty, instability, uniqueness, and value conflict" (Schön, 1983, p. 49). Like Simon, Schön's work was written to address concerns that affected the professions. Social and political events in the USA during the 1960s and 1970s have been undermining "belief in the competence of expertise and brought the legitimacy of the professions into serious question" (Schön, p. 9). A major source of this problem was that professional knowledge was apparently "mismatched to the changing character of the situations of practice—the complexity, uncertainty, instability, uniqueness, and value conflicts which are increasingly perceived as central to the world of professional practice" (Schön, p. 14). Schön's work therefore sought to engage this gap between knowledge and practice. And one of his major contributions to the field of design is the notion of reflection-in-action.

In the course of their practice, professionals are often confronted with complex situations. Each situation presents unique challenges, and the practitioner has to design an approach to deal with the situation at hand. Knowledge acquired from textbooks and formal instruction is necessary but not sufficient to deal with the situation at hand. Schön introduced the notion of reflection-in-action to capture the strategic moves undertaken by a competent professional in dealing with such complex situations. According to Schön, the skillful action of professionals always reveals a "knowing more than we can say" (Schön, 1983, p. 51). He characterizes this as knowing-in-action, which is the characteristic mode of ordinary practical knowledge. When they confront a complex situation with no clearly defined problem, practitioners often do not have the time to step back and reflect. They have to make sense of the situation by imposing a tentative framework of understanding that has to be adjusted or abandoned as they engage with the situation at hand. The dynamic nature of the engagement with the situation means that the practitioners have to be constantly improvising along the way. The notion of reflection-in-action is meant to capture the artistic and creative ways in which competent professionals negotiate the twists and turns of complex situations. Reflection-in-action is a design activity that Schön characterizes as a reflective conversation with the situation. Although the notion of reflection-in-action was used to illuminate the design-like features of professional practice, Schön's characterization of design as a form of reflective conversation with the situation could conceivably apply to all occupations (Waks, 2001).

In the *The Reflective Practitioner*, Schön analyzes case studies of professionals at work in order to demonstrate various features of reflective practice. The paradigmatic example of reflective practice is the one that is reported in *The Reflective Practitioner* as well as in his follow-up book *Educating the Reflective Practitioner*. The case study is based on a recording of a dialogue between an architectural student and her teacher. The dialogue revolves around a problem the student has with designing an elementary school on a challenging sloping site. The analysis of the dialogue is very detailed and sensitive to the nuances of the exchange between the teacher and student. The analysis is intended to be an illustration and not meant to be comprehensive or exhaustive. Nonetheless there are questions that can be raised about the methodological aspects of the analysis (Finlay, 2008). In the first place, it is not clear how involved Schön was in the observation of the interaction between the teacher and student.[1] The analysis is based on a recording and some of the nonverbal aspects of the exchange relating to the sketches and drawings of the plan had to be artificially reconstructed. Given the importance of the nonverbal dimensions of the exchange in this case, one wonders why Schön did not subsequently engage the teacher in further reflection on the teacher's reflection-in-action. As Schön has indicated elsewhere in the text, there is scope for two parties in an interaction to engage in "mutual reflection" (Schön, 1983, p. 126). Would this not have added a deeper and more comprehensive account of reflective practice?

[1] Schön says that the case study was based on a review of architectural education in which he participated. He does not say if he was actually present when that particular observation of the teacher-student interaction took place (Schön, 1983, p. 360).

And even though the conversation between the teacher and student was focused on rationalizing the design of the school, there is very little in the exchange that is focused on whether the design is appropriate for students in an elementary school. Should a school even be built on such a site? Such considerations do not appear in Schön's analysis of the interaction between teacher and student. While there is passing reference to structural factors that had to take into consideration the height of school children, there is virtually no mention of how the design features meet school children's needs (Schön, 1983, pp. 88, 96 & 97). In other words, the ethical aspects related to children's learning environment did not seem to feature strongly in the interaction as well as Schön's analysis of the interaction. That Schön is concerned about the ethical aspects of professional action is evident from his later analysis of the town planning. Consequently, this apparent oversight in the case of the architecture example leads us to wonder about Schön's own reflection on his analyses of reflective practices. To what extent does his works reflect the evolution in his professional self-understanding as a reflective practitioner? Also to what extent is the practice of reflection an ethical activity that helps the practitioner improve himself or herself as a morally responsible professional? To be sure, there is much evidence that the text as a whole is governed by some moral imperative. Schön is, after all, very much concerned with the integrity of professional practice. And there is clearly a moral distinction implicit in his competitive (Model 1) and collaborative (Model 2) theories of action (Schön, pp. 226–235). But Schön is not very explicit about his moral commitments, an articulation of which would have enriched his study of professionals as reflective practitioners.

### *2.2.3 Nigel Cross*

Nigel Cross is another frequently cited scholar in the field of design and design thinking. With a background in architecture and industrial design, he has been writing and researching on design since the 1960s. He is perhaps best known for his work *Designerly Ways of Knowing*, which outlines the case for treating design as a part of a general education occupying a role as important as those taken up by the sciences and the humanities. Design education in this context should not be confused with what is taught in vocational schools: it is "*not* primarily a preparation for a career, nor is it primarily a training in useful productive skills for 'doing and making' in industry. It must be defined in terms of the intrinsic values of education" (emphases in the original; Cross, 2007, p. 21). Design education contributes to education by developing abilities to solve ill-defined problems and to broaden the horizon of cognitive development to include areas of nonverbal thought and communication, among others.

To help develop design as a discipline in its own right, Cross outlines the way towards a science of design, not unlike Simon's approach in *The Sciences of the Artificial*. To that end, he proposes a design methodology that "includes the study of how designers work and think, the establishment of appropriate structures for the design process, the development and application of new design methods, techniques and procedures, and reflection on the nature and extent of design knowledge and its application to design problems" (Cross, 2007, p. 123). In taking this disciplined and structured approach to design, Cross exhibits reservations similar to those Simon had towards the role that intuition plays in the design process. In the section on the development of design ability, he writes:

> In contrast to the artistic, intuitive procedures encouraged by the Bauhaus, design education has more recently concentrated on teaching more rational, systematic approaches. Some aspects of design ability have been codified into design methods. . .Designing is a form of skilled behavior. Developing any skill usually relies on controlled practice and the development of technique. The performance of a skilled practitioner appears to flow seamlessly. . .But learning is not the same as performing, and underneath skilled performance lies mastery of technique and procedure. The design student needs to develop a strategic approach to the overall process, based on some simple but effective techniques or methods. (Cross, 2007, pp. 46–47)

There is no doubt that the teaching of design can be facilitated by a methodological approach and that the skills of design students and designers alike can be improved by controlled practice and the mastery of technique. But nothing in this account of the education in design explains why intuition should not figure in the design process. After all, Cross's own reference to the Bauhaus school shows that at least one tradition of design practice takes intuition seriously.

Cross's inexplicable discomfort with intuition is not entirely innocent as it colors his understanding of design. In a later work, *Design Thinking*, Cross refers to interviews with professionals regarding their understanding of the practice of design. One recurring theme that emerged from these interviews is the designers' reliance on what they regarded as "intuition" and on the importance of an "'intuitive' approach" (Cross, 2011, p. 9). The thing to note is that by putting the term intuition in scare quotes, Cross seems to indicate that the designers may not understand their own thinking processes or that he has a better grasps of what the designers think they are doing. Indeed he then goes on to say:

> [Designers] are perhaps right to call their thinking 'intuitive' in a more profound sense, meaning that it is not based upon conventional forms of logical inferences. The concept of 'intuition' is a convenient, shorthand word for what really happens in design thinking. The more useful concept that has been used by design researchers in explaining the reasoning process of designers is that design thinking is abductive: a type of reasoning different from the more familiar concepts of inductive and deductive reasoning, but which is the necessary logic of design. (Cross, 2011, p. 10)

The amazing thing about this claim is that it is not backed by the research evidence. Moreover, he implies that the designers are engaged in a form of logical reasoning and that they have mischaracterized their thinking as a form of intuition. It is difficult not to see Cross in this context as attempting to impose an alien concept on professionals with respect to their self-understanding of the process of design.

The notion of abduction that Cross refers to is drawn from Lionel March who attributes it to the philosopher C.S. Peirce (Cross, 2007, p. 37). But it should be recalled that Peirce introduced the notion of abduction to explain the process of scientific discovery. For Peirce, abduction is the process "of forming explanatory hypothesis. It is the only logical operation which introduces any new idea" (Douven, 2011). But there is controversy about what it means to say that the discovery of a new idea or an explanatory hypothesis is a logical operation. What is more significant, however, is that in the chapter recounting how outstanding designers think, Cross never once mentions the process of abduction, which is supposed to be necessary to the process of designing. On the contrary, he points to the significance of nonlogical processes like flashes of insight and sudden illumination: "Not all the innovators reported examples of sudden illumination, and for some, solutions only come from continuous hard work, but it is clear that sudden illumination (within a prepared mind) is a frequent element in creative design thinking" (Cross, 2011, p. 72). Later he would add the observation that the working methods of innovators are "for the most part, not systematic; there is little or no evidence of the use of systematic methods of creative thinking, for example" (Cross, 2011, p. 74). In other words, there is clearly more to design thinking than abductive reasoning.

There is no doubt that the works surveyed here have had considerable impact on the development of theories of design as well as the practice of design in various professional as well as nonprofessional fields of activity. Even so these theories were mainly articulated with the view to raise the academic status of design and design thinking among the established professional disciplines. Nigel Cross in particular tries to make a case for design thinking as an academic discipline in its own right. The survey here is intended to show that even in the case of the professional disciplines, there is still more work to be done to clarify the nature and role that design and design thinking plays. Apart from the apparent incompatibility between Simon and Schön's approach to design, there are also legitimate questions about the similarities and differences in the way design is understood and practiced among the various professional and academic disciplines. This consideration does not even take into account the vast domain of design activities that take place in the nonprofessional and nonacademic realms.

Clearly it is not possible for one theory or school of thought to encompass the universe of design activities. In this connection, too, it should be noted that not all man-made things are necessarily the products of design, even though they may seem to be so. Some practices, norms, or institutions may have risen spontaneously or may have been the unintended consequences of disparate but intentional human activities. We need to be able to separate the world of artifacts into those that are the products of purposeful, intentional human design and those that are not. In addition more thought and effort needs to be put into the way the various domains of design activities are demarcated or classified and to make clear what may be significant differences in the nature, understanding, and practice of design and design thinking in these various domains. This would show how rich and diverse the field of design and design thinking is, without having one theory or set of theories unnecessarily dominating the discourse on design and thereby limiting an aspect of human creativity that may not be fully comprehensible.

Both Simon and Schön are clearly well aware that the contexts in which professionals currently practice have become increasingly complex, and this has come about partly because of the advances in technology and the growing marketization of professional work. In terms of the design of social systems, Simon acknowledged that members of society have to play their part as codesigners in systems that affect their well-being. But the reality is that the human environment is characterized by competing and conflicting desires, goals, and purposes that can confuse and even corrupt the practice of design. Moreover, among these contending parties are large and powerful institutional and organizational interests that influence the conduct and practice of the professions. Though evidently concerned with the question of ethics, none of the works surveyed here adequately addresses the ethical aspects of design and design thinking. The world that humans have created to meet their needs and desires also threatens to destroy humanity. None of the works in question have taken serious notice of the morally ambivalent role that design and human making plays in the history of human thought.

## 2.3 Design: History, Culture, and Ethics

To make or produce something, one often needs a plan or a design. The notion of design applies to things made by man as a consequence of deliberate or intentional human activity. The history of design is therefore tied up with the history of man as a maker of things—*Homo Faber* (Arendt, 1998; Flusser, 2013). The history of *Homo Faber* is a long and complex one with myriad cultural variations. Nevertheless, man's ability to make things has transformed the world we live in. Humans make use of what nature gives them to change and transform natural objects according to their designs. They make traps to capture animals and devise ways to domesticate them and even to produce new hybrids through breeding methods. The unique design of humans allows them to take advantage of nature in ways that other animals cannot do. In this regard, the human hand with its fully opposable thumb is of special significance as it can grip things securely in order to work over them (Sennett, 2008).

The human hand is the first tool man uses to change nature. Stones can be thrown as missiles and sticks wielded as weapons through the use of our hands. At that moment, sticks are no longer simply sticks and stones are no longer simply stones. They become artifacts because of the ways humans have used them. They become extensions or appendages of the human body, and over time they would take on cultural meaning and significance. What distinguishes humans from animals is not that human can use objects of nature as tools, animals do that too. Humans have the intellectual ability to transform these basic tools into more sophisticated ones; and in the course of interacting with nature and other human beings through these tools, humans also transform themselves. "A shoe maker not only makes leather shoes; he also makes a shoe maker out of himself. . .As soon as a tool—e.g. a hand-axe—is introduced, one can speak of a new form of human existence. A human being surrounded by tools, such as hand-axes, arrow-heads, needles, knives—in short, culture—is no longer at home in the environment in the way that primitive man using his hand is: he is alienated from the environment, and he is both protected and imprisoned by culture" (Flusser, 2013, pp. 44 & 45). As human culture advance, nature retreats into the background. Trees in the park are parts of human culture rather than nature. Human civilization attests to the importance of culture as a fundamental characteristic of human existence. Human needs go beyond the needs for mere survival.

Insofar as the history of design is tied up with the history of human making, it shares with that history an ambivalent place in the classical traditions of thought. Classical thinkers have always expressed concerns about human ambitions as reflected in the growth of arts, the development of technology, and the production of things. In the Socratic tradition, for example, there has been deliberate attempts to play down human reliance on the art of medicine and law, as the proliferation of these arts are held as an indication of the unhealthy growth of luxury and vice. In *The Education of Cyrus*, a fictionalized account of the founder of the ancient Persian Empire, the philosopher Xenophon notes how the acquisition of wealth sets the condition for the development of the division of labor:

> In great cities, because many people are in need of each kind of artisan, even one whole art suffices for supporting each—and frequently not even one whole art, but one person makes men's shoes, another women's. There are places also where one is supported merely by sewing shoes, and another cutting them out, and another by cutting only the uppers, and another who does none of these things but puts them together. It is by necessity, then, that he who passes his time engaged in a narrower work certainly be compelled to do it best. (Xenophon, 2001, pp. 241 & 242)

And it is in this context that Xenophon makes the observation that the food served in the court of the Cyrus the King is "labored over to a very exceptional degree." And just as the food of the king gets more and more refined and sophisticated, there is a corresponding development in the need for more and better doctors to deal with new illnesses and diseases.

The Judeo-Christian tradition also conveys similar reservations about the development of the arts. The Book of Genesis relates how Cain, who murdered his brother and was punished by God to become a fugitive and wanderer, ended up being the founder of cities and the arts. His descendants created musical instruments and "forged all kinds of tools out of bronze and iron" (*Gen*.4:22). Similarly, the descendants of Ham, who dishonored the patriarch Noah and was cursed by him, also went on to become founders of great cities. The Biblical concern with the human capacity and ingenuity to make things culminates in the story of the Tower of Babel. The story opens with the observation that human beings at that time had "one language and a common speech" (*Gen*.11:1). One day the men got together to build a tower to reach the heavens: "so that we may make a name for ourselves and not be scattered over the face of the whole earth." God on observing the building of this tower remarked: "If as one people speaking the same language they have begun to do this, then nothing they plan to do will be impossible for them." This concern about the man's unbridled ambition leads God to confuse the language of men "so that they will not understand each other" and to scatter them all over the earth.

The ambition to rival God recurs in the modern age, when men have found a new common language through science. The ambition to master nature through technology is reflected in the thought of the Enlightenment philosopher Rene Descartes:

> As soon as I had acquired some general notions concerning Physics. . .I believed that I could not keep them secret without sinning gravely against the law that obliges us to procure, as much as it is within us, the common good of man. For these notions have shown me that it is possible to arrive at knowledge that can be very useful for life, and that. . .one can find a practical philosophy, by means of which, knowing the force and the actions of fire, of water, of air, of the stars, of the heaven and of all the other bodies in our environment just as distinctly as we know the various crafts of our artisans, we might be able, in the same fashion, to employ them for all the purposes to which they are appropriate, and thus to render ourselves, as it were, the masters and possessors of nature. (Descartes, 1994, p. 87)

Concerns about this modern ambition are reflected in Heidegger's unease with the specifically modern character of science and technology. Heidegger, perhaps the most important philosopher of the twentieth century, correctly points out that in the modern age, technology takes priority over science—it employs the sciences in its service. But this is already implicit in Descartes view of the practical relevance of physics. Technology is understood as the sophisticated manipulation of things or "the mechanical ordering of beings" (Rojcewicz, 2006, p. 10). Technology takes on a life of its own that manifests itself as a form of imperiousness or the unbridled imposition of ends: "Human beings therefore become subjects, *the* sovereign, imperious subjects. The theory of beings as orderable through calculation is a correlate of this imperiousness: to be imperious is precisely to take beings as submissive to an ordering imposed by humans" (Rojcewicz, p. 10). This imperiousness is reflected in the "excessive, hubristic, unnatural demand on nature" which Heidegger regards as a violation of nature that is "equivalent to rape" (Rojcewicz, pp. 71–72). Nature is forced to yield to human desires and demands; and the dangers posed to nature would eventually redound on humans as well.

There is, to be sure, a dark side to design (Flusser, 2013; Nelson & Stolterman, 2003). The word design has a wide range of meanings including plot or scheme and is related to notions like cunning and deception. A designer "is a cunning plotter laying his traps" (Flusser, p. 17). The Latin word *artifex* means artist as well as schemer or trickster (Flusser, p. 18). Simon also notes that the English word for *artificial* includes synonyms like pretended, sham, spurious, and trumped up and concludes that these words reflect "man's deep distrust of his own products" (Simon, 1996, p. 4). Interestingly these aspects of design and the artificial are clearly brought out in a case study of an outstanding design practitioner in Cross' book *Design Thinking*. The case is about Gordon Murray the technical director for the McLaren Formula One Team and later the technical director of McLaren Cars Limited that produced the commercially successful road-going McLaren F1. The case, however, dealt with the early part of his career when he was the chief designer for the Brabham Formula One team.

Formula One racing is a highly competitive sport that thrives on innovative, technological developments. It is in the context of this competition that Murray developed the hydro-pneumatic suspension that gave Brabham cars that vital edge over its competitors in the 1980s. The gap between the body work of the car and the ground has a significant impact on the car's performance, especially when it is taking a corner at high speeds. The car performs more efficiently when the gap is smaller. Formula One rules at that time specified that there must be a 6 cm gap between the bodywork of the car and the ground and that there must be no driver-operated device to change the gap. This rule took into account that at various points in the race, the ground clearance for any race car will fall below 6 cm because of the effects of braking and rolls on cornering.

Murray was thinking how he could circumvent this limitation without explicitly violating the rules. His solution came in the development of the hydro-pneumatic suspension. This innovation drew on basic knowledge of physics to let the natural forces exerted on the car to push it down as it sped forward and to keep it down when it slowed for corners and then allowed the car to return to the 6 cm clearance when it was at standstill. No driver-operated device was needed to create these effects. The success of the innovation allowed Brabham cars to overcome its rivals who protested that the car must have been fitted with a driver-operated device. When the race authorities pointed out that the Brabham cars were clearly lower than 6 cm when on the circuit, Murray argued that every car on the track also fell below that limit at various points during the race. This, of course, was a clever piece of sophistry that nevertheless succeeded in silencing the protests. Murray also had a dummy feature attached to the car to mislead his competitors about the nature and location of the innovation.

Murray is reported to have compared the intensity of the competition in Formula One racing to a war in terms of the human, financial, and technical resources that are needed to maintain a vital edge over rivals that he characterized as "enemies" (Cross, 2011, p. 34). In this context, the account of Murray's development and deployment of the hydro-pneumatic suspension system has interesting parallels with an account of the qualities of a general in *The Education of Cyrus*. As Cyrus prepares his army for war, he asks his father how best to take advantage of one's enemies. To this query, his father replies: "By Zeus, my son, this is no ordinary simple task you are asking about. But be assured that the one who is going to do this must be a plotter, a dissembler, wily, a cheat, a thief, rapacious and the sort who takes advantage of his enemies in everything" (Xenophon, 2001, p. 54). Towards the end of the conversation, the father tells Cyrus: "you must yourself also be a poet of stratagems against the enemy, just as musicians not only use the tunes they learn but also try to compose other new ones. Even in music, fresh tunes are extremely well regarded; but in things military, new stratagems win still higher regard by far, for they are even more able to deceive opponents" (Xenophon, p. 57). This account reveals how intense competition could bring about modes of innovative thinking that are morally questionable, if it were not somehow excused by the exigencies of war. And in an age where economic competition is intensifying, the danger is that there will be a growing propensity among professionals and design practitioners to test the boundaries of ethics. Take, for example, the case of behavioral economics, which is growing in popularity.

Research in behavioral economics has led to a growth of a potential new discipline, choice architecture. Choice architecture can be described as a design activity that frames choices in a way that influences the way people make decisions. It may be regarded as a form of decision engineering. Choice architecture is premised on the belief that, contrary to the assumptions of classical economics, human beings are fundamentally irrational. And this irrationality is often exhibited in the bad choices they make with regard to important life issues. Choice architecture therefore aims to help people make better choices by designing options or choice sets that lead them to a particular decision. Furthermore, it seeks to influence decisions in a way that is subtle and nonintrusive. People would not be aware that they are being nudged in certain directions. One of the pioneers of this field refers to it as a form of libertarian paternalism (Thaler & Sunstein, 2008). As a form of paternalism, choice architecture presupposes that the people framing choices are not only experts but wise in knowing people better than they know themselves.

To be sure, choice architecture means to help and benefit people, but it is a form of manipulation as it seeks to intentionally influence choice. For this reason, it can be abused. With the growth of big data, ubiquitous computing, and the emerging Internet of Things, more and more power will be placed in the hands of choice architects. Governments and businesses are keen to exploit these technologies for their purposes, and there's no telling what negative effects may arise from the unregulated use of choice architecture. Choice architecture appears to be a powerful, postindustrial manifestation of the art of persuasion, and choice architects could perhaps be seen as the postmodern version of the classical sophists, who promoted their ability to teach others how to sway the opinion of the masses. Can we therefore be certain that the manipulation of choices and options will altogether be a benign affair? Perhaps the worst thing about this is not that choices are being shaped and manipulated, but that in time people may come to believe that this is being done in their best interest, and as a consequence, they become neither able nor willing to question these practices (Wolfe, 2009). Or as one critic says about the book *Nudge*, the seminal work on choice architecture: "The book is subtly condescending to its readers, who are gently and affectionately nudged to give up objections to the authors' proposals, and it adopts the tolerant, generous, and over-familiar tone of people who believe themselves very clever trying to explain things to the not so clever" (Mendelson, 2012, p. 96).

These considerations about the ethical dimension of design can serve as further justification for taking design as a subject worthy of serious study. It is in keeping with Nigel Cross' goal of making design thinking a part of the general education curriculum, but one which includes explicitly a moral dimension. On the one hand, designers, professionals, and nonprofessionals alike cannot evade the question of the ethical implication of their ideas and productions. On the other hand, the public should take responsibility for the kind of environment they choose to live in both for themselves and for future generations. The public especially needs to be educated and alerted to the potential for abuse that new technologies can bring about and be prepared to introduce appropriate safeguards or regulations governing their employment.

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# Chapter 3
# Design Thinking and 21st Century Skills

## 3.1 Introduction

In education, there are calls for teachers to be the designers who create specific conditions to support student learning outcomes (Sugar & Warren, 2003). Yet, there is still no widespread adoption of design thinking to support teachers' practice. By far, Schön's (1983) idea of design thinking as reflective practice has been appropriated as a pedagogy for teachers to reflect about their practices in teacher education and development programs (Loughran, 2002). There have also been some attempts to guide teachers' lesson design through models such as ASSURE (Heinich, Molenda, Russell, & Smaldino, 1999) and Understanding By Design (Wiggins & McTighe, 2005) that prescribe steps for analyzing instructional needs as well as designing and evaluating instructional outcomes. These attempts to systematize teachers' instructional design processes are close to the thinking behind Simon's (1996) conception of design. Nevertheless, there is a need to ask the critical question of "designing for what?"

The challenges facing the field of education are closely linked to the increasing complexities brought about by rapidly evolving knowledge economies. There is a constant cry against educational practices that remain at the level of content instruction and regurgitation. The educational models of the Industrial Age are no longer adequate (Macdonald & Hursh, 2006) as future industries need to be supported by workers who possess 21st century competencies or the abilities to solve complex and ill-structured problems through confident exploitation of technology, self-initiation, and the arbitration of diverse viewpoints. Correspondingly, schools need to equip students with these competencies. This implies that students need to have practiced how to exploit technology tools and online resources to build knowledge for productive problem solving in both individual and group settings within their educational experiences (Howland, Jonassen, & Marra, 2012). Nevertheless, such kinds of educational practices remain a challenge for schools because even when information and communication technology (ICT) tools are being used,



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classroom norms still tend to center on information acquisition and regurgitation (Gao, Choy, Wong, & Wu, 2009; Hayes, 2007; Lim & Chai, 2008; Ruthven, Hennessy, & Brindley, 2004; Smeets, 2005; Smeets & Mooij, 2001; Ward & Parr, 2010). These challenges suggest that in order to change educational practices, students' acquisition of 21st century competencies need to become a vision that is driving teachers' design of students' learning experiences. Yet, it appears that sound models of 21st century learning are generally lacking in schools.

In this chapter, we characterize the dimensions of 21st century learning and discuss the relevance of design thinking for supporting students' engagement in 21st century learning. We also explore the competencies needed by teachers to engage in the design of 21st century learning experiences.

## 3.2 The Dimensions of 21st Century Learning

To date, several frameworks such as the Partnership for 21st century skills (P21, 2007), the EnGauge Framework (Group & NCREL, 2003), the Organization for Economic Cooperation and Development's Key Competencies for Education (Organization for Economic Cooperation and Development [OECD], 2005), and the Assessment and Teaching of 21st century skills (Binkley et al., 2010) have been developed.

### *3.2.1 The Organization for Economic Cooperation and Development's Key Competencies for Education*

This framework describes three kinds of competencies that individual requires to function effectively in the society: Category 1 using tools interactively, Category 2 interacting in heterogeneous groups, and Category 3 acting autonomously. Category 1 competencies emphasize the individual's ability to harness various tools in order to interact effectively with the world. The definition of "tools" includes technological tools, language, symbols, texts, as well as knowledge and information. This competency emphasizes the creative exploitation of "tools" to create knowledge about the world and how one might relate to it. The second category emphasizes the social-cultural nature of work where an individual needs to have competencies for developing social capital. This requires the individual to have self-mastery of emotions and empathy to cooperate with others and to be able to strike a balance between personal and group goals through conflict management. The third category focuses on the individual mastery of one's life plans and the ability to assert one's rights, interests, and limitations. Even though several aspects of self are being emphasized, this does not mean that one does not understand the repercussions of one's actions on the larger context of one's environment. This framework emphasizes the reflective integration of the three kinds of competencies into concrete practice as an individual interacts with society.

### 3.2.2 The Assessment and Teaching of 21st Century Skills

This framework was designed as a model for assessing 21st century skills. Ten different skills were grouped into four categories: Category 1—ways of thinking, Category 2—ways of working, Category 3—tools for working, and Category 4—living in the world. Category 1 comprises of skills related to creativity, innovation, critical thinking, problem solving, decision making, learning to learn, and meta-cognition. These skills go beyond content acquisition and information reproduction. They emphasize essential thinking and learning skills such as divergent thinking, reasoned judgments, as well as reflective and reflexive learning. In comparison, the OECD framework does not emphasize such kinds of thinking skills. The skills in Category 2 emphasize communication and collaboration as the ways of working. It focuses on oral and written linguistic competencies, as well as the skills for interacting and managing groups in work contexts. By focusing on information literacy and ICT literacy, Category 3 emphasizes learners' ability to manage information and harness ICT for effective work which is similar to the OECD model. Category 4 comprises of the competencies for local and global citizenship, the management of life and career, as well as the management of personal and social responsibilities. These competencies prepare students with the cultural mobility to maneuver the increasingly global job markets.

### 3.2.3 EnGauge 21st Century Skills

This framework focuses on the kinds of literacies that students need in order to maneuver digitally enabled economies. It asserts that just as technology is changing the way people live and work, students need to be prepared for such future economies through technology-supported learning experiences. It defines four kinds of 21st century skills: digital-age literacy, inventive thinking, effective communication, and high productivity. Digital-age literacies comprise of basic language and numerical literacies as well as literacies in science, economics, technology, visual appreciation, information management, and multicultural and global awareness. The category of inventive thinking emphasizes curiosity and higher-order cognitive skills to support self-direction, risk taking, creativity, sound reasoning, as well as the management of complexity. Like the two previous frameworks, effective communication emphasizes abilities for interpersonal interaction and collaboration, as well as the maintenance of personal, social, and civic responsibility. The category of high productivity emphasizes effective and efficient work through competencies in planning, results management, as well as the effective use of tools to produce relevant and high-quality products. This kind of competency seems to be a combination and re-categorization of the areas related to tools use and self-management described in the other two frameworks.

### *3.2.4 The Partnership for 21st Century Learning*

Like the three frameworks reviewed thus far, this framework identifies four kinds of skills that educational systems need to develop in students: core subjects and 21st century themes; learning and innovation skills; information, media, and technology skills; and life and career skills. The framework asserts that schools need to provide core literacies in areas such as language, mathematics, science, and the arts that are anchored in the context of 21st century issues such as global awareness, civic literacy, environmental literacy, and financial, economic, business, and entrepreneurial literacies. Learning and innovation skills refer to higher-order thinking skills related to critical thinking, problem solving, creativity, and innovation, as well as the ability for social aspects such as communication and collaboration. Like the other frameworks, information, media, and technology skills emphasize literacies in information management, media interpretation, as well as ICT. Life and career skills relate to workplace skills such as flexibility and adaptability, initiative and self-direction, cross-cultural awareness, leadership, and productivity. Unlike the other frameworks, this framework also identifies four kinds of systems that are needed to support students' acquisition of the stated skills. These include teacher professional development, standards and assessment, appropriate curriculums, as well as appropriate learning environments.

Research studies that summarize 21st century competencies (e.g., Voogt & Roblin, 2012) tease out common facets among the frameworks that are useful for helping teachers pin down the features of 21st century learning. Generically, we would like to suggest that teachers need to design 21st century learning that engages students in five dimensions:

- Social-cultural dimension: 21st century learning is situated in collaborative contexts that at times may also be multicultural. These kinds of learning contexts provide students with opportunities to develop the social and cross-cultural/ discipline skills needed to interact, resolve conflicts, and collaborate effectively within the social-cultural norms of their environment.
- Cognitive dimension: 21st century learning requires students to apply their basic literacies and content knowledge to solve complex and ill-structured real-world problems. Through this process, students are challenged to engage in critical thinking, creative thinking, as well as risk taking as they attempt to engage in the innovation of problem solutions. Such kinds of problem contexts challenge students beyond receiving and regurgitating content information.
- Metacognitive dimension: 21st century learning emphasizes learning from the learning/problem-solving process. Opportunities for self-assessment, reflection,

as well as improvement of one's learning/problem-solving strategies engage students in the practice of metacognitive skills required to support life-long learning. It also allows students to develop the self-regulatory practices that are required to plan and adapt to their environmental challenges.

- Productivity dimension: 21st century learning embraces the notion of authentic learning. Not only are real-world problems used to anchor learning experiences, real-world productivity expectations of quality products and efficient work processes should also be incorporated within the assessment of student learning. This dimension enables students to develop appreciations of workplace realities that will strengthen the linkage between school and work.
- Technological dimension: 21st century learning invariably involves students exploiting ICT tools to support their learning. The technological dimension emphasizes students developing the information literacies to choose appropriate technology tools that can support them to gather and analyze information effectively. Students should also have opportunities to develop their media literacies through the use of technology tools to turn information into personal knowledge that is being externalized as multimodal expressions.

Confronting students with design problems is one valuable way of fostering 21st century learning as it involves complex problem solving and reflection (Lawson, 1997; Schön, 1983). In essence, design problems are ill-defined problems, sometimes referred to as wicked problem. Jonassen (2000) describes design problems as "among the most complex and ill-structured kinds of problems" and "they have ambiguous specification of goals, no determined solution path, and the need to integrate multiple knowledge domains" (p. 80). In order to solve such kinds of problems, students need to engage in creative and critical thinking; the collecting, editing, and prototyping of ideas; and the monitoring of progress and with the management of team dynamics. The educational value of design problems is therefore significant for the development of 21st century skills. It can also support students to develop positive character attributes such as perseverance and resilience.

## 3.3 21st Century Learning Through Student Engagement in Design Thinking

The earliest examples of students learning through design were those describing how constructionist notions of learning were being applied to students' design of software products with Logo (e.g., Harel & Papert, 1990; Papert, 1980). These studies largely focus on the effects of software design on school learning. Through working on design problems, students manipulate artifacts to represent their understanding of the problem in the form of design drafts (Kafai & Resnick, 1996). Learning emerges through the reflection and thinking that occurs as physical artifacts are being built (Papert & Harel, 1991). A number of studies have reported that student engagement in design activities enhanced their level of understanding, level of reflection, and self-regulation (Casey, Hastie, & Rovegno, 2011; Ching & Kafai, 2008; Liljeström, Enkenberg, & Pöllänen, 2013). This leads to the question of how design activities could be better structured as a conduit for 21st century learning. This is one aspect that has not been thoroughly explored in these early studies.

### 3.3.1 Episodes for Guiding Design Thinking

We propose that design activities can be thought of as involving a series of design episodes that occur from the initial conception of a design problem to the concretization of its solution. Thus, design thinking encapsulates how designers manage these episodes as they design the problem solution by manipulating artifacts. The various dimensions of 21st century learning can be externalized as episodes with customizable guide questions that scaffold students to maneuver the design process (see Fig. 3.1).

In the cognitive episode, students encounter the design problem and consider their content knowledge with respect to how it can be applied to the design problem. They also consider the opportunities and constraints presented to them by the problem as well as what they still need to know about the problem. This is because knowledge emerges throughout the design process as designers experiment and

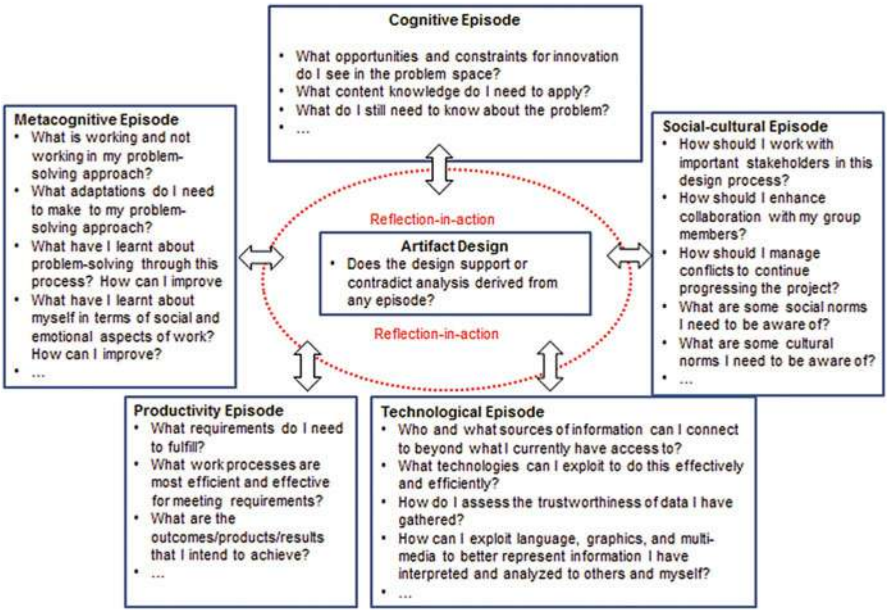


**Fig. 3.1** Guiding students' design thinking for 21st century learning

play with ideas (Lawson & Dorst, 2009). The guiding questions listed in the cognitive episode are designed to prompt students to consider the questions they should ask about the problem, information they should search for, as well as possible solutions they could try. As students are confronted with complex and ill-structured design problems, they are required to apply content knowledge critically and creatively to maximize opportunities and circumvent constraints.

The social-cultural episode speaks to the social-cultural contexts that teachers need to situate the design projects in. These can be created through group-based projects or projects with actual clients who are imposing real-world demands on students. Such kinds of contexts will prompt students to consider the key stakeholders of the design process, group collaborative processes, as well as the social-cultural norms that are pertinent. This allows students to appreciate some of the social-cultural concerns involved in work environments as described in 21st century frameworks.

The technological episode guides students to embrace the possibilities of a technologically connected world by going beyond currently available sources such as teachers and textbooks. These sources of information can be people connected to special interest groups as well as readily available information sources from the Internet. Throughout this process, students are self-directed as they need to consider which technologies to exploit as well as the trustworthiness of the information gathered. Students also need to consider how they could articulate and represent the knowledge they have generated throughout the design process by using the computer as a cognitive tool. Technology tools are used to support easy editing and for multiple versions of ideas to be represented in different forms (Chai & Lee, 2006), thereby facilitating students to tinker with ideas. In these episodes, students are prompted to consider multimodal expressions such as language, graphics, and multimedia. These kinds of knowledge expressions are used to benefit students' personal metacognition, as well as for information sharing with stakeholders and group members that are involved in the design process. Technology serves as a tool for supporting these kinds of expressions. Through this process, students learn to become astute exploiters of technology, as described in 21st century learning frameworks.

The efficiency and effectiveness of work processes, as well as the 21st century skills related to adaptability and flexibility, are being scaffolded through the guiding questions of the productivity episode. Here, students need to consider the deliverables set down by clients or the teachers' assignments as well as how these can be fulfilled productively through the way they structure work, plan, and manage the design project. These kinds of considerations enable students to experience workplace realities where quality standards often need to be balanced with work schedules and deadlines.

Learning to learn is the emphasis of the metacognitive episode. The guiding questions in this episode prompts for students to consider how they are approaching problem solving throughout the artifact design process, the adaptations they need to make, as well as their social and emotional reactions to these work processes throughout the design project. In this episode, students are prompted to reflect and consider how they might improve, which in turn fosters the visions of self-mastery as described in 21st century learning frameworks.

Where design activities are carefully orchestrated to engage students in the design episodes described, it has more potential to bring about the kinds of deep engagement with content that is envisioned in 21st century learning. In fact, by using a "learning-by-design" approach, Kolodner et al. (2003) found that students developed better science content knowledge as well as aspects of 21st century competencies such as collaborative skills and metacognitive skills when confronted with complex design tasks requiring iterative cycles of investigation, design, and redesign.

### *3.3.2 Artifact Design as the Nexus*

Studies in the field of design found that design thinking is best developed through the iterative refinement of artifacts that are being developed to represent design ideas throughout design episodes (Cross, 2011; Lawson, 1980). This process allows the designer to consider how the opportunities and constraints within their problem space can be optimized to create new products or experiences (Cross, 2004; Rowe, 1991). The representations of design ideas are examples of epistemic artifacts, as described in Popper's (1978) World 3 objects. According to Popper, these are cognitive objects created to explain theories, explanations, hypotheses, and problem solutions. Therefore, in our visualization, artifact design acts as the nexus where the contradictions among design episodes are being ironed out and design decisions are being made. The guide questions in each episode are scaffold towards design thinking which emerges through the iterative processes of artifact design.

It is needful to remember that the process of artifact design is messy and episodic rather than systematic. This is because designers go back and forth between these design episodes until they reach a desired understanding of the problem to pinpoint a solution (Lawson, 1997; Rowe, 1991). We assert that students' design thinking could comprise of many episodes. At times, it may lean more strongly towards one kind of episode for an extended period before another kind of episode is being considered. At other times, multiple episodes can be considered in quick succession. This encapsulates what Schön (1983) described as "reflection-in-action" whereby designers first develop appreciations of a problem situation to shape an initial solution. The consequences of these initial moves "talk back" to designers who respond with critical reflection to reframe and restructure their definition of the design problems and to work out new solutions. Such processes occur mentally, whereas its outcomes are externalized as modifications to the artifact that students are working with.

Chapter 4 provides examples of how students can engage in the design processes outlined in Fig. 3.1.

## 3.4 Teachers' TPACK for 21st Century Learning

In their experiences of "learning by design," Kolodner et al. (2003) found that teachers need to develop specific competencies for facilitating such kinds of learning activities. Shulman (1986) described teachers' pedagogical competency as pedagogical content knowledge (PCK). This is teachers' unique form of knowledge for implementing specific pedagogies related to a subject area. In the same respect, teachers require PCK to support 21st century learning (PCK-21CL), which can be defined as their knowledge for implementing the dimensions of 21st century learning within a content area. In recent years, the proliferation of ICT tools has brought forth the need to consider teachers' knowledge of designing ICT-integration lessons as an extension of PCK that is known as technological pedagogical content knowledge (TPACK) (Mishra & Koehler, 2006). Given that technology features as a common dimension in all 21st century learning frameworks, teachers' competency for designing 21st century learning should therefore be considered as TPACK for 21st century learning (TPACK-21CL). Cox and Graham (2009) clarify that TPACK is concerned with new and emergent kinds of technology. When such kinds of technology become a standard repertoire in teachers' practice, it is subsumed within teachers' PCK.

### *3.4.1 TPACK-21CL*

Teachers' design of ICT-integrated lessons is a complex process that involves various kinds of knowledge. The TPACK framework developed by Mishra and Koehler (2006) describes seven kinds of knowledge that support teachers as they design ICT-integrated lessons. Technological knowledge (TK), pedagogical knowledge (PK), and content knowledge (CK) are the three basic forms of teachers' knowledge needed for ICT integration. It is proposed that intermediary sources of knowledge can be derived from the connections that teachers make among TK, PK, and CK, which are forms of teachers' knowledge for ICT integration. For example, technological pedagogical knowledge (TPK) is derived from the connections between TK and PK. It describes teachers' knowledge of using technology to implement different teaching methods. The two other kinds of intermediary source of knowledge are technological content knowledge (TCK) and pedagogical content knowledge (PCK). TCK and TPK relate to the general uses of ICT with respect to particular content areas and pedagogical approaches, respectively (Cox & Graham, 2009), whereas PCK is derived from Shulman's conception and describes the implementation of particular pedagogies within a content area. TPACK embodies the connections teachers make among these intermediary sources of knowledge to formulate particular uses of ICT for particular lesson topics with respect to a pedagogical approach. It can also be understood as the specific ICT lesson strategies that teachers design.

Therefore, teachers' competency for designing 21st century learning can be considered as a kind of TPACK, that is, TPACK for 21st century learning (TPACK-21CL). It is teachers' knowledge of implementing 21st century learning dimensions with specific lesson content that is supported with ICT. We propose that the constructs of TPACK-21CL can be defined as:

1. Technological knowledge (TK)—teachers' knowledge of technology tools
2. Pedagogical knowledge for 21st century learning (PK-21CL)—teachers' knowledge of student learning issues and teaching methods for supporting the dimensions of 21st century learning
3. Content knowledge (CK)—teachers' knowledge of subject matter
4. Technological content knowledge (TCK)—teachers' knowledge of subject matter representation with technology
5. Technological pedagogical knowledge for 21st century learning (TPK-21CL)—teachers' knowledge of using technology to implement different teaching methods to support the dimensions of 21st century learning
6. Pedagogical content knowledge for 21st century learning (PCK-21CL)—teachers' knowledge of teaching methods to support the dimensions of 21st century learning with respect to subject matter content
7. Technological pedagogical content knowledge for 21st century learning (TPACK-21CL)—teachers' knowledge of using technology to implement teaching methods to support the dimensions of 21st century learning for different types of subject matter content

### *3.4.2 TPACK-21CL as Design Knowledge*

Studies of teachers' TPACK development found that TPACK emerges as teachers design plans of ICT lessons and its supporting artifacts (Jang & Chen, 2010; Koehler, Mishra, & Yahya, 2007; Koh & Divaharan, 2013). This is because these lesson design activities provide the context for teachers to make connections among their technological knowledge, pedagogical knowledge, and content knowledge (Koehler et al., 2007; Koh & Divaharan, 2011) as they consider how their instructional solutions can balance the needs of curriculum and students. These findings suggest many similarities between the practices of teachers and designers. Teachers' design of lesson artifacts enables them to consider and test out lesson ideas. As teachers design, they also develop one or more of the seven kinds of knowledge described in the TPACK framework. These describe their pedagogical reasoning (Shulman, 1999), which also encapsulate their teaching competencies. Therefore, like TPACK, TPACK-21CL is a kind of design knowledge. Yet, much still needs to be understood in terms of how teachers can foster TPACK through design because a criticism often made of the TPACK framework is the lack of guidance for *how* teachers should approach ICT lesson design (Cox & Graham, 2009). At the present moment, the seven TPACK constructs describe *what* teachers know about ICT integration but not *how* it can be fostered through teachers' engagement in lesson design.

### 3.4.3 Understanding Teachers' Design Thinking During Lesson Design

Teachers' lesson planning involves iterative cycles of design and redesign, as well as reflective practice (Laurillard, 2012). These aspects are not fully reflected in current ICT lesson design models. An example would be the ASSURE model (Heinich et al., 1999) that prescribes six sequential steps: (1) analyze learners; (2) state standards and objectives; (3) select strategies, technology, media, and materials; (4) utilize technology, media, and materials; (5) require learner participation; and (6) evaluate and revise. ASSURE is a typical example of an ADDIE-type model prescribed lesson design as a systematic and procedural process involving analysis, design, development, implementation, and evaluation (Molenda, 2003), whereas the iterative and episodic nature of design may not be comprehensively reflected.

In view of these limitations, the Summerville Integrated Model (Summerville & Reid-Griffin, 2008) considers lesson planning as one having multiple tiers. One tier comprises of considerations for learner analysis, task analysis, and instructional strategies. The other tiers deal with decisions related to areas such as the use of media, government mandates, and assessment. It is proposed that teachers may start from activities in one tier before moving on to another tier. They may also revisit a tier if needed. While the Summerville model provides for the iterative nature of design, the design decisions that teachers make as they move from tier to tier have not been articulated. Notably, the consideration of teachers' TPACK development throughout design and how this influences their design decisions are missing in these existing models.

What then might be some of the design episodes that are pertinent to teachers when designing for 21st century learning? In both Heinich et al. (1999) and Summerville and Reid-Griffin (2008), the requirements of national and state curriculums are important aspects for consideration during lesson planning as this determines the kinds of content to be covered. Government and school policies for 21st century learning as well as the demands of state examinations are some examples of cultural-institutional factors (Almas & Krumsvik, 2008; Levin & Wadmany, 2008) that teachers need to consider.

The second kind of design episode that could confront teachers might be the profile of learners and their competencies for engaging in 21st century learning dimensions. This requires teachers to draw upon their PCK, which encompasses what Shulman (1999) described as teachers' pedagogical reasoning, to identify particular learning opportunities as well as difficulties that students might face. It also requires teachers to draw upon their PCK-21CL to identify instructional strategies for circumventing particular problems that students might face with 21st century learning.

As 21st century learning invariably involves the use of technology, teachers may also be confronted with design episodes that are related to the selection of ICT tools. Mishra and Koehler (2006) purport teachers' competencies for ICT lesson design to be encapsulated in the intermediary forms of TPACK. Besides drawing upon their TK to select ICT tools, teachers may need to draw upon their TPK-21CL to consider how these tools can support the pedagogical implementation of 21st century learning dimensions. Teachers could also draw upon their TCK to select content-specialized ICT tools that may support their lessons.

These episodes encapsulate the kinds of considerations that teachers could need to make when designing lessons for 21CL, which embody teachers' design thinking. It is expected that by considering specific curriculum content and instructional problems, teachers derive enhanced understanding of the different aspects of their TPACK-21CL that was being applied during the process. The outcomes of these various considerations of teachers are then being represented as specific lesson plans, activities, and resources. These artifacts embody teachers' enacted TPACK-21CL. At the present moment, little is understood of how reflection-in-action occurs during teachers' ICT lesson design. Chapters 5 and 6 therefore seek to provide examples of how this process might take place.

## 3.5 21st Century Learning Through Design Thinking

This chapter suggests that design thinking can be a process that is used by students to engage in complex problem solving. Design activities that are being anchored in contexts supporting the social construction of knowledge, metacognition, the use of real-world assessment criteria, as well as the exploitation of technology can help students to apply the 21st century learning dimensions. Yet, at the present moment, models of such kinds of instruction are still developing. Thus, the challenge faced by teachers is one that needs to be resolved through design. However, insights into teachers' thinking during the design of educational innovations are largely missing. This is an important area of study because teachers' design thinking can support them to create the needed educational pathways towards 21st century learning through their day-to-day lesson planning. To do so, teachers need to develop appropriate considerations of TPACK-21CL as epistemic resources to support this process. The following chapters will explore the design thinking of students and teachers in these aspects.

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# Chapter 4
# Design Thinking and Children

## 4.1 Introduction

As highlighted in Chaps. 1 and 2, design is uniquely human and design thinking is a ubiquitous form of human cognition (Heskett, 2005; Razzouk & Shute, 2012; Simon, 1996). The focus of this chapter is that design thinking could start even from a young age. Even though it is difficult to determine the exact age for the emergence of design thinking and this is likely to vary from person to person, we can be sure that toddlers can also make stories and shape their living spaces to satisfy their needs for fun and fantasy. Children can build houses with wooden or LEGO blocks and transform their living spaces into adventurous story spaces. Children shape objects into make-believe tools by imposing meaning on them so that they can become props of fantasy. Design thinking is being evoked in these activities as children work on making meaning by transforming the objects around them.

While the connection between design thinking and children's activities can be easily established, how design thinking is being fostered through children's educational experiences in school is less clear, especially in primary or elementary education. To answer the question about what has been researched to date, a search through the electronic databases including the Web of Science, Education Research Complete, and ERIC was conducted in December 2013. The search terms used were "learning by design" AND "primary school" or "elementary school." The search terms also included "design thinking" in combination with AND "primary school" or AND "elementary school." These searches revealed that not much research has been conducted with respect to design thinking and younger children.

This chapter begins with a review of the literature we were able to identify about design thinking and children in the context of primary or elementary education. It then presents a case study of how a Singapore primary school formulated a design problem for two classes of primary four students to be engaged in designing a living quarter for migrant workers as part of a social studies topic on the history of



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Singapore. The effects of this learning experience were evaluated through surveys to examine the students' perception of their engagement in 21st century learning practices. This is then followed by the analyses of interviews conducted with 20 students to understand their experiences of learning social studies through the design project.

## 4.2 Literature Review

Design problems and design tasks are powerful for engendering complex learning (Kangas, Seitamaa-Hakkarainen, & Hakkarainen, 2013). Such kinds of learning experiences engage students to construct knowledge through artifact creation, which can in turn mediate several kinds of active learning processes. These learning processes involve students in identifying and framing problems, exploring problem and design spaces, generating and deciding on ideas to pursue, searching and synthesizing relevant knowledge resources, prototyping and evaluating ideas and/or artifacts, and engaging in metacognitive reflection of their design processes (Howland, Jonassen, & Marra, 2012). Design problems are usually solved through team effort. As such, communication and collaborative reasoning are essential parts of the design process. In general, learning through design provides rich opportunities for teachers to foster 21st century competencies (Lee & Kolodner, 2011; Yelland, Cope, & Kalantzis, 2008). It is sharply contrasted against the more conventional teaching practices where teachers transmit textbook knowledge for students' passive absorption. Design has the pedagogical affordances of facilitating students' learning of interdisciplinary knowledge as well as cultivating students' creative capacities for improving on their learned knowledge rather than accepting these as mere facts (du Plessis & Webb, 2011; Sawyer, 2012). Both learning and creative production are necessary as current research indicates that the passive learning of information results in inert knowledge; and cognitive skills learned without content are likely to be ineffective. In the following review, we organize research that leverages on design for learning into four subthemes: designing digital artifacts with child-friendly programming environment, learning by design, design and technology studies, and theory-building as human design.

### *4.2.1 Designing Digital Artifacts with Programming*

The first notable area of research on the use of design for children's learning is through the design of digital artifacts with child-friendly programming environments. Historically, learning through design or by design is undergirded by constructionism (Kafai, 2006). Papert and his colleagues' effort in creating the Logo programming language for students to learn through designing computer-based artifacts has initiated this line of constructionist-oriented research (Papert, 1980). Through Logo programming, students learn mathematics, especially geometry. Papert and Harel (1991) explicitly stated that constructionism shares the constructivist's tenet of viewing learning as a process of building understanding and knowledge structures. However, constructionism added the emphasis of using design to construct publicly accessible entities such as real objects, digital artifacts, or theories. Harel and Papert (1990) reported that getting students to design and create such mediating artifacts is a deeply engaging form of learning. Their research employed the Logo-based learning environment for a fourth-grade class to design and produce educational software for the teaching of fractions. The students were from an inner-city public school in Boston and they were engaged in the design task for a semester. When the Logo-based class' learning was compared to two control classes through pre- and posttests, they outperformed the control class, providing evidence that it is feasible and perhaps desirable for students to learn about fractions through design.

Logo was succeeded by the programmable modeling environment entitled StarLogo (Resnick, 1998). Resnick reported that elementary students were able to use StarLogo to build objects such as robotic creatures, build-it-yourself scientific instruments, and thinking tags. Resnick argued that through building these digital objects, students engaged in deeper learning than what traditional schooling may offer. For example, students had to research about the dinosaurs' behaviors in order to build robotic dinosaurs, whereas they would have focused on the names and categories of dinosaurs if they had undergone traditional lessons.

More recently, Resnick and his colleagues created *Scratch* (see http://*Scratch*.mit.edu), a visually oriented, blocked-based programming language that enables students to create and design interactive and multimedia-based artifacts (see Brennan & Resnick, 2013; Maloney, Resnick, Rusk, Silverman, & Eastmond, 2010). Resnick and his team claimed that programming with *Scratch* helps students to acquire mathematical and computational knowledge through systematic and creative thinking, as well as collaboration. The potential of promoting 21st century competencies through designing digital artifacts with *Scratch* is obvious. Since a website allowing students to upload their *Scratch* creations was launched in 2007, it has developed into an online community with more than half a million people worldwide. This website receives approximately one new project upload per minute (Brennan, Monroy-Hernández, & Resnick, 2010).

While their programming languages may be different, Logo, StarLogo, and *Scratch* exemplify how students can apply design thinking through the creation of digital artifacts. Papert, Resnick, and others in the MIT Media Lab have indeed created powerful environments to promote design thinking. Despite the abovementioned successes, Baytak and Land (2011) commented that learning through design has subsided somewhat since 2000, perhaps due to scalability issues. This form of learning is cognitively demanding, and its open nature may be contradictory to school-based learning that tends to be syllabi driven because there are no straightforward linkages between curriculum requirements and what students learn through design. Baytak and Land studied how ten fifth graders designed game environments for environmental science using *Scratch*. This multiple-participant case study conducted by Baytak and Land found that the students were able to create functional games and they were engaged in planning, researching, coding, sharing and collaborating, and iteratively developing their game environment over 21 days. These activities corresponded generally with the design-thinking episodes represented in Chap. 3, and these are the typical kinds of classroom activities advocated by educators to promote 21st century competencies. In another study, Ke (2014) used a mixed-method case study to examine the effects of middle school students ($N = 64$) who used *Scratch* to design computer games. The results indicated that such kinds of constructionist-oriented learning could help to improve the students' disposition towards mathematics.

We note that this line of research seems to be largely confined to the American classrooms. How such an approach can be taken up by Asian classrooms which tend to be more teacher-directed and examination-oriented is worth investigating. For example, Singapore secondary schools have incorporated *Scratch* as a programming environment for students to learn game design and media computing. In the USA, programming and computational thinking are increasingly being accepted as a core skill for students as more teachers and schools are incorporating these into their classrooms (Richtel, 2014). Based on the recent attention towards computational thinking (Guzdial, 2008), we predict that designing for learning with software programs such as *Scratch* would become more popular in the next few years. Generally, the pedagogy of learning through design in a programming environment is still underexplored (Baytak & Land, 2011) and it could benefit from more experimentally-oriented research.

### *4.2.2 Learning Science by Design*

Besides using programming languages, design thinking has also been actualized through "learning by design" (LBD) (Kolodner et al., 2003). LBD is a project-based learning approach that draws upon problem-based learning and case-based reasoning. This approach aims to develop middle school students' social and cognitive skills and to help them achieve deep and lasting learning about science. In LBD, students are generally involved in building physical artifacts for design challenges, e.g., building vehicles for an Antarctic exploration, and they have to justify their design by explaining the science behind it. Kolodner et al. reported that after several iterations of refinement, their LBD curriculum has enabled students to derive better understandings of science as compared to the traditional approach. Notably, the LBD students outperformed the non-LBD students in their collaboration and metacognitive skills.

LBD, however, has been reported to be very demanding on both students and teachers (Kolodner et al., 2003; Puntambekar & Kolodner, 2005). Kolodner et al. reported that teachers' modeling and scaffolding were essential for students' success and teachers generally took three cycles of LBD engagement before they could effectively facilitate students' design activities. Puntambekar and Kolodner

(2005) reported how they created more elaborated and targeted scaffolding by using students' design dairies to help them make connections between their design activities and the learning of science. This refinement resulted in significantly better learning outcomes. Doppelt, Mehalik, Schunn, Silk, and Krysinski (2008) reported that when engaging 8th grade school students to design and construct an electric fire alarm, they had to use structured scaffolds to facilitate students' thinking and reflection. By doing so, this design project was able to enhance students' engagement and learning outcomes.

Two other recent studies conducted on young children below 12 years of age provided further evidence of how design-based learning could facilitate the learning of science. Wendell and Rogers (2013) compared the pre- and posttest results of students' science content knowledge when they were taught using the existing curriculum in 1 year and the design-based curriculum supported by LEGO™ design challenges in the subsequent year. This study found that design-based learning for science had positive effects on young children's learning of science. Levy (2013) reported significant improvement in 5–6 year-olds' ideas about water when compared to a group of students who were taught the same concepts without design-based learning. These studies reflect emerging interest in incorporating engineering design challenges in science teaching, which is part of the science, technology, engineering, and mathematics movement. However, the positive results obtained from students who undertook LBD could be because the design tasks used by these studies were smaller and more well defined in scope and therefore more manageable. Apeddoe and Schunn (2013) pointed out that the purpose and practice of engaging in science and design are different. Science is focused on seeking explanations and building/verifying theories, whereas design seeks practical solutions with respect to contextual constraints. Their research among students in grades 9–12 indicates that scientific reasoning may not lead to success in resolving design challenges. In other words, the success or failure of LBD depends on how design challenges are being structured. When crafting design challenges, educators need to pay careful attention to the complexities of the design problem students are solving, its connection with disciplinary knowledge, the products they can possibly produce, and the types of problem-solving processes they could use (Apeddoe & Schunn, 2013; Dabbagh & Dass, 2013).

An interesting development in the studies of LBD is the particular attention they have paid to the design of the learning environments to facilitate students' learning. This is needed because of the aforementioned gap between science and design as well as the open and complex nature of design which could sometimes derail the predetermined learning objectives for the subject matter. For science content to be effectively learned through design, students need to activate multiple forms of thinking (e.g., critical and creative thinking, problem solving) and knowledge resources (science knowledge and knowledge about the contexts they are working in) and also manage social relationships if they are working in teams. Each of these aspects needs to be supported by learning scaffolds as well as teachers' modeling and guidance (Puntambekar & Kolodner, 2005). Some researchers who wish to embark on LBD have sought to recontextualize what Kolodner and her colleagues have designed with reference to their local curriculum (Lee & Kolodner, 2011). In an LBD project for secondary school students entitled the Science Created by You, de Jong et al. (2012) built a computer-based curriculum system by unpacking each design challenge into different learning activities. Each learning activity provides students with tools to support their creation of different learning objects. For example, in the Healthy Pizza mission, students are required to design a nutrition table and a food pyramid as learning objects while using modeling tools, concept mapping tools, and simulations to support the process. Nevertheless, LBD approaches still lack the explicit teaching of design process skills.

### *4.2.3 Design and Technology Studies*

The third way through which design thinking is being used for learning is through a school subject known as design and technology (D&T) which focuses on designing and product creation with specific users in mind (Benson & Lunt, 2011). The overall pedagogical aims are to promote students' creativity as well as their abilities to work with a variety of tools and materials as they evaluate and innovate upon existing products. This subject was introduced to replace the older version of technical education around the late 1980s. In some European and commonwealth countries (e.g., Finland, Australia, Canada, and England), D&T is being offered to primary students. In Singapore, this subject is offered only in secondary schools. Research carried out among children who learned D&T in primary schools is commonly reported in the *International Journal of Technology and Design Education*.

An early study of students' (ages 5–12) ways of designerly thinking indicates that it progresses with age (Hill & Anning, 2001). Students' approach towards design is also associated with their preferred ways of learning and communication and their abilities to draw or sketch. The students in these studies generally viewed design as a process whereby the ideas to make things are being formulated, during which they communicate their ideas with drawings, annotation, and measurement. The authors remarked that students' notion of design differs from that of the professional designers who consistently emphasized the importance of talking and working with other people. Benson and Lunt (2011) surveyed English children's views about D&T and reported that 85 % of the participants agreed that they learned to be creative in D&T and 78 % indicated a sense of ownership of the product because they could formulate their own ideas rather than follow their teachers' instructions. However, more research is needed to ascertain the creative quality of students' design as well as their design processes (ibid; Cross, 2006).

A recent study conducted by Kangas et al. (2013) among primary school students in Finland examined the collaborative design talk of three female students (aged 10–11) to understand their design thinking. These students were tasked to design a pendant lamp, guided by a professional designer and their teachers. This study seems to be the only one available that addresses the micro-genetic level analysis of design talk among elementary students, and the analyses revealed that despite the presence of some off-task talks and activities, the students were able to focus on the visual and technical aspects of design when they were on-task. Such kinds of on-task talk were interspersed within talks about design constraints. The authors concluded that the students' design thinking was mediated by physical artifacts (sketches and the lamp) and it is collaborative in nature. As the study aimed to describe students' design processes, it did not comprehensively address what the students learned and how it was related to the curriculum. This study demonstrates that there is still insufficient research in D&T to inform pedagogical practice (Cross, 2006).

### *4.2.4 Theory-Building as Human Design*

The fourth subtheme of research is also related to constructionism, and it is from the University of Toronto, led by Bereiter and Scardamalia (2006). Bereiter and Scardamalia put forward the pedagogical notion of "knowledge-building community" (KBC). A KBC can be defined as a community that is collectively responsible to advance theories that could resolve problems of understanding jointly identified by its members. In the classroom, a KBC is supported by Knowledge Forum™, a platform that serves as a multimedia database for students to write, critique, and revise online posts representing their understanding about the phenomenon they are investigating. In other words, the online posts that represent students' theories are the digital artifacts they work on through the "design mode" of thinking (for details, see Bereiter & Scardamalia). With its exclusive attention on theory-building, this form of constructionist-oriented learning therefore differs from studies reviewed so far. Bereiter and Scardamalia have made conscious and explicit efforts to distinguish KBC from project-based, problem-based, and inquiry-based learning. While students in a KBC could be involved in building physical or digital artifacts, such activities are directed towards and subsumed as part of the theory-building process. More than two decades of extensive research, mostly in primary science classrooms, has been conducted in this area (see Scardamalia & Bereiter, 2006, 2010). However, perhaps because of its distinctive focus on examining the refinement of conceptual artifacts (which are the theories built by students), literature discussing learning through or by design such as those reviewed earlier has seldom cited Bereiter and/or Scardamalia's work. Whether or not Bereiter and Scardamalia's work on KBC should be considered within design-based learning may be debatable. In addition, it is important to point out that KBC adopts a principle-based approach and appears to be more emergent and less structured in comparison with the three other forms of design-based learning we have reviewed. As Chap. 5 has provided a detailed review for the KBC, and two case studies are provided on how the KBC is being engineered to foster design thinking among preservice teachers, this chapter will not provide further review on it.

In summary, the general concerns of the research studies in design-based learning were to document the learning outcomes of content knowledge, process skills (subject-based thinking skills such as scientific reasoning, students' ability to collaborate, etc.), and, to a small extent, students' design thinking. The research outcomes indicate that with appropriate scaffolds provided and adequate teacher facilitation, students are able to develop multiple forms of skills and learn the required subject matter through various design challenges. However, our review thus far reveals several research gaps. Firstly, research on how design-based learning influence primary students have begun to emerge, but more is needed (Wendell & Rogers, 2013). Secondly, most studies are confined to the learning of mathematics and science. Design can also be situated in subjects such as social studies because societies and communities are the result of how human infrastructure and living environments have been designed. We argue that as the curriculum of social studies aims to promote good citizenship, engaging students in related design projects could instill in them a sense of designing for common good. This additional ethical dimension of design should not be ignored in the educational context (see Chap. 2). Thirdly, students' experiences of design-based learning are not well documented. While there are some studies, more vivid representation of students' voice is important for educators to understand the holistic effects and shortfalls of design-based learning (Benson & Lunt, 2011). Fourthly, the studies reviewed were conducted mostly in classrooms of the west, except for some studies in the area of KBC. How design-based learning is being perceived by Asian elementary school students is not clear. Research in a different cultural context could help unearth assumptions and enrich educators' understanding of the possible issues and affordances of design-based learning.

A notable trend of design-based learning is the apparent role of ICT in facilitating this approach. ICT serves as construction tools for students to create digital artifacts. Besides the use of programming environments as reviewed earlier, software programs such as *SketchUp* can assist especially elementary students in making 2D and 3D images to represent their ideas (Dolenc & Aberšek, 2012). The example of *Scratch* show that dedicated websites with communication tools to support collaboration can be set up to inspire more design work among children. ICT is commonly used by students as information tools for online research and as cognitive tools to organize and represent understanding (see de Jong et al., 2012). Simulations can also be used to scaffold students' active sense-making of the relationships between variables. Design-based learning is complex, open, and iterative, and students' use of ICT to resolve design challenges is closely associated to the conceptions of meaningful learning with ICT as proposed by Howland et al. (2012). Howland et al. argue that this can be treated as being equivalent to 21st century learning.

While design-based learning offers promising potential to cultivate students' 21st century competencies, explicit effort to study how students perceive design-based learning in promoting 21st century competencies is still lacking. This chapter therefore aims to contribute to current literature by investigating how Singaporean students have experienced design-based learning through a mixed-method research study.

## 4.3 Case Study

### *4.3.1 Participants and Background*

The participants for the study were four classes of primary four students from a Singapore primary school. The students' average age was 9.6 years (SD = 0.6) and there were 68 male students and 78 female students. Two classes participated in the intervention ($N = 81$), while the other two classes ($N = 66$) were the comparison classes. According to the ability streaming of the school, these classes were found to be equivalent in their general academic performance. The control classes had 66 students (30 males, 36 females), and the intervention classes had in total 81 students (38 males, 43 females). As the school is promoting the use of ICT for teaching and learning through mobile technologies with the aim of fostering 21st century learning, all students are equipped with a smartphone as their personal learning device, and the students access the Internet to research for information as and when needed. The students were also supported with laptop computers on mobile carts when their teachers made arrangement for it during classroom teaching; and they used the computer laboratories on a weekly basis for the learning of various subjects. For the learning of Chinese language and the learning of science, specially designed lessons were conducted regularly throughout the year, supported by a suite of tools such as computerized concept maps and graphic organizers. The students were therefore familiar with use of technology for learning. The differences between the intervention classes and the comparison classes for the learning of social studies will be described next.

### *4.3.2 Intervention*

The overall curriculum focus of the primary four students' social studies was about Singapore's history in the nineteenth century. The intervention designed for the experimental classes was to engage the students in designing a "coolies' house," which is a colloquial term for the living quarters of blue-collar migrant workers, situated in the historical backdrop of the beginning of nineteenth century in Singapore. The challenge was to build a house to accommodate 500 migrant workers within a piece of land measuring 600 square meters. The students worked in teams of four, playing the roles of civil engineer, health advisor, project manager, and interior designer. The project aims to activate students' prior knowledge of science (on building materials), health science education, mathematics (for computation of areas and budgeting), and their general knowledge. Students were briefed about the project and they clarified their roles and performed initial research in expert groups, that is, they were initially grouped according to their roles. After three sessions in the expert group, they returned to their home (project) groups to design proposals for health management, budget, building plan, and interior design.

All proposals need to be relevant to the historical time period, and the students were encouraged to use their textbooks as references for general understanding of the historical period. Outside of the classroom lessons, the students used the Knowledge Forum™ to engage in collaborative dialogue.

The comparison classes went through the lesson as they usually would. Their lessons were on the same theme of Singapore's history in the nineteenth century. Interviews with teachers and the social studies coordinator found that the teachers would usually share stories about the past and supplement the textbook materials with historical footages. Frontal teaching was the main approach and students were expected to complete relevant sections of the workbook after each lesson. The total instruction time for the intervention and comparison classes was 12 double-period classroom sessions, which amounted to 12 h for each class.

### 4.3.3 Data Collection

Multiple forms of data were collected as part of the effort of a larger research project. For this study, the two main forms of data collected were the 21st century competencies (21 CC) survey (see next section) and the qualitative one-to-one student's interview after the completion of the design project. The semi-structured interviews helped the researchers to gain access to the subjective understandings of the students (Drever, 1995) as these focused on gathering students' experience about their design-based learning. Examples of interview questions include the following: "Can you tell me about your experience in designing the coolie house?" "How did you work with your classmates?" Active listening was practiced by the research assistant whom the children were familiar with as she was present in most of their classes. The researchers who conducted the interview were present in most of the classroom sessions, and this helps greatly in grounding the students' recount on what had transpired in the classroom.

Other than these two forms of data, the researchers had access to the students' online posts and all the lesson observation field notes and video recordings of the lessons. These various forms of data were reviewed and used to triangulate the researchers' interpretation.

### 4.3.4 Instrument

This study used the 21 CC survey to measure students' perception of their engagement of six dimensions related to 21st century learning practices and their self-efficacy of knowledge creation. Based on the consensus that emerged in several discussions about 21st century learning (Dede, 2010; Howland et al., 2012; Voogt & Roblin, 2012), the 21 CC survey selected the dimensions of self-directed learning (SDL), meaningful learning with ICT (MLT), collaborative learning (CoL), critical thinking (CriT), creative thinking (CreT), authentic problem solving (APS), and knowledge creation efficacy (KCE) as the key dimensions of 21st century learning. Thirty-two items were constructed for the survey with each dimension having three to five items. The survey was reviewed by two education professors to establish face validity. In addition, two school teachers reviewed its language with respect to its appropriateness for primary schools students (primary three and above). The survey items were rated with a seven-point Likert scale (1, strongly disagree, to 7, strongly agree). The descriptions of the survey dimensions are as follows:

- Self-directed learning (SDL) dimension examines students' perceptions of the extent they are actively engaged in planning, executing, monitoring, and adapting their own learning processes. For example, "In this class, I adjust the ways I study based on my progression."
- Meaningful learning with ICT (MLT) dimension measures students' perceptions of using ICT tools and software to construct and communicate their emerging understanding. For example, "In this class, I construct ICT-based materials (e.g., PowerPoint slides, word documents, mind maps) to represent my understanding."
- Collaborative learning (CoL) dimension explores students' perceptions of working with their teammates, including interaction, discussion, and co-construction of ideas. For example, "In this class, my classmates and I actively discuss different views we have about things we are learning."
- Critical-thinking (CriT) dimension examines students' engagement in evaluating the value of the information they are getting and justifying their perspectives. For example, "In this class, I check which information is supported by evidence and which are not."
- Creative thinking (CreT) dimension investigates students' perceptions of their engagement in creating ideas or developing new ways of doing things. For example, "In this class, I produce ideas that are likely to be useful."
- Authentic problem-solving (APS) dimension studies students' perception about the authenticity of the design challenges they are working on. For example, "In this class, I learn about the real-life problems that people have."
- Knowledge creation efficacy (KCE) dimension measures students' sense of self-efficacy to produce new ideas or knowledge. For example, "I am able to create useful ideas that may help to address problems in our society."

To validate the survey, confirmatory factor analysis was conducted using another sample of primary five students ($N = 241$). The results show that the values of factor loadings for all items of the seven factors to be larger than 0.50. For all seven factors, the scores of composite reliabilities were higher than the cutoff value of 0.70, while the scores of average variance extracted were higher than the cutoff value of 0.50. Moreover, the values of chi-square per degree of freedom = 1.92, RMSEA = 0.06, and CFI = 0.91 showed reasonable model fit (Hair, Black, Babin, Anderson, & Tatham, 2006). For this study, the overall Cronbach alpha for the questionnaire was 0.98. The Cronbach alpha reliabilities for each factor are reported in Table 4.1.

**Table 4.1** Independent sample *t*-tests between the experimental and control classes

| Dimensions | Classes | Mean | SD | *T* | Cohen's D |
|---|---|---|---|---|---|
| SDL $\alpha = 0.93$ | Experimental ($n = 81$) | 5.64 | 1.13 | 1.68 | 0.28 |
| | Comparison ($n = 66$) | 5.31 | 1.21 | | |
| MLT $\alpha = 0.91$ | Experimental ($n = 81$) | 5.62 | 1.18 | 3.11** | 0.52 |
| | Comparison ($n = 66$) | 4.92 | 1.50 | | |
| CoL $\alpha = 0.93$ | Experimental ($n = 81$) | 5.94 | 0.97 | 5.86*** | 0.98 |
| | Comparison ($n = 66$) | 4.89 | 1.17 | | |
| CriT $\alpha = 0.94$ | Experimental ($n = 81$) | 5.68 | 1.03 | 2.36* | 0.39 |
| | Comparison ($n = 66$) | 5.25 | 1.19 | | |
| CreT $\alpha = 0.91$ | Experimental ($n = 81$) | 5.74 | 0.99 | 4.43*** | 0.75 |
| | Comparison ($n = 66$) | 4.87 | 1.32 | | |
| APS $\alpha = 0.92$ | Experimental ($n = 81$) | 5.53 | 1.18 | 0.33 | 0.05 |
| | Comparison ($n = 66$) | 5.46 | 1.47 | | |
| KCE $\alpha = 0.93$ | Experimental ($n = 81$) | 5.74 | 0.95 | 3.36** | 0.56 |
| | Comparison ($n = 66$) | 5.15 | 1.16 | | |

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

### *4.3.5 Data Analysis*

Independent sample t-tests were employed to determine if the students in the intervention classes possessed stronger perception of being engaged in 21st century learning than the comparison classes. Interview data was transcribed verbatim and analyzed through the constant comparative method adapted from the grounded theory approach (Strauss & Corbin, 1990). Open coding was first applied to the students' interview transcript. The codes were then grouped to form categories. The categories that emerged were generally about different aspects of the students' learning, which were first categorized using categories such as learning about history, design, Internet-based research, and collaboration. We then compared the emerged categories to the various dimensions of design episode articulated in Chap. 3 and found that it could fit quite naturally. For example, Internet-based research could be organized under the technological episode, and learning about history could either be classified as in the cognitive or the metacognitive dimensions, whereas collaboration was classified as a social-cultural episode. The productivity episode, however, was not clearly identifiable from the codes. Explication of the relationships between the codes and categories resulted in the themes reported next. To ensure the trustworthiness of the findings, we sent this chapter to the teachers teaching the class to review and critique its findings. The teachers agreed with the findings reported below.

## 4.4 Findings

Table 4.1 shows the *t*-test results of the 21 CC survey. The students in the experimental classes had significantly stronger perceptions in five out of the seven dimensions measured. They are MLT ($t = 3.11$, $p < 0.01$), CoL ($t = 5.86$,

$p < 0.001$), CreT ($t = 4.43$, $p < 0.001$), CriT ($t = 2.36$, $p < 0.05$), and KCE ($t = 3.36$, $p < 0.01$). The Cohen Ds indicated that these significant effect sizes were from medium to large. These results imply that design-based learning approaches are helpful in enhancing students' perceptions of their 21st century learning experiences. Notably, design-based learning experiences were perceived to foster strong collaborative learning among the students followed by engaging them in creative thinking. It was also perceived to promote critical thinking, meaningful use of ICT, and students' self-efficacy in knowledge creation. These outcomes are further strengthened with the qualitative themes that emerged from the interviews.

### *4.4.1 Emerging Themes of Students' Perception of Their Learning*

The overall emerging theme from the 20 students interviewed seemed to be that they were engaged in active learning that involved them in much research and collaboration. The students encountered multiple difficulties when coordinating their work and at times, difficulties with reaching consensus about which ideas were better (see later). Despite that, most students preferred this more challenging mode of learning. An overall comparison of their perceived experiences in "normal" social studies lessons and learning social studies through design is provided below. All initials used to reference the quotes are pseudonyms.

> For example, [during] Primary one, primary two, primary three it's just doing the activity book and not really much of researching. Just a little bit, only a fraction of Social Studies for primary three requires research. Ya, it's only a very brief but for Term 1, actually the whole year for primary 4 the Social Studies is very fun, we get to research, we get to write down what we learn, get to share, get to compete and yeah… stuff like that… Because we get to research [and] communicate with the computer… I believe everybody likes to use a computer, so it attracts a lot of people… attracts our class to use more effort for the Knowledge Forum™. (MA)

Students' recount of their learning experiences could be further categorized into the cognitive, metacognitive, technological, and social-cultural dimensions of design-based learning, largely corresponding to the design episodes we have articulated in Chap. 3. In terms of the cognitive dimensions, students researched about the content knowledge required to play their respective roles. In the following quotes, students reported how they learned about their roles and also about history.

> We see how many beds we need, the space and calculations. [Do calculations] level by level, how many beds [we need] and then we use the Microsoft [PowerPoint] programme to put in the shapes to represent the beds. (SK, civil engineer).
>
> Before that I didn't know what interior design is, so I searched [about] what an interior designer does. Then it gives me the answer. (IL)
>
> We learnt about what the coolies usually do and for very well-known [historical figures] like Sir Stamford Raffles, I will ask how and [what] made them famous. (J)

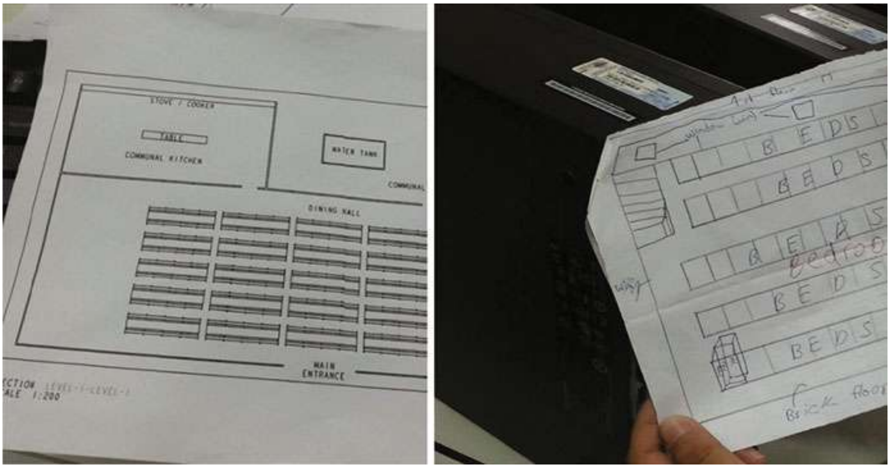


**Fig. 4.1** Students' designed floor plan for the coolie house

The cognitive dimension of design-based learning was found to be intertwined with the metacognitive dimension. Below are two quotes that indicate how students were engaged in iterative idea improvement and were consciously assessing their ideas.

> Actually I was thinking about doing it like big rectangular building, then I [thought of] something like a hospital but [with] no walls (*cognitive*, *working on ideas*). Then when I thought of it, there are better ideas than what I thought of (*metacognitive*, *thinking and evaluating about the ideas and changing them*). I put it on Knowledge Forum™ to Valencia our interior designer. Then she said "I'll try to put it on paper or computer." (MA)
>
> We have to search for cheap materials used for building beds… [for the] wall, we must also make sure that termites cannot bite [through], just in case…the whole house may collapse…and the beds, K suggested [what] I thought was a very ridiculous idea… triple decker beds but I don't think [it] is possible … if it's triple decker beds I'm afraid that the roof may be too short. (EH)

Designing involves solving ill-structured problems (Jonassen, 2000) and it usually requires some form of research. Throughout the 12 weeks of design-based learning, the teachers did reinforce some Internet-based research skills that the students were taught in the earlier part of the school year and the students were further developing their technological competencies in this aspect (see quote from WL below). In addition, Fig. 4.1 shows the students using different means to communicate. One student learned how to use an engineering software to develop his sketch (left picture in Fig. 4.1) from his father, while most of the other students used pencil and paper. There were also some students who used the Paint software in the Office environment.

> Tonnes of research. Research on the topic we have to do, [the] teacher instructed us. What teacher taught us [is] to be accurate in our answers. If you find answers from a website, try to find more answers from more websites. And if you merge them together, you should get correct answers. (WL)

> We need to do activities. We can also log-in and share about what we learn [and] what we are currently researching on… As in Knowledge Forum™, we will like [to] share our ideas. Erm, I will say that it is like chatting in Facebook.… more educational form of Facebook where we will share what we have learnt. (WY)

Engaging in group work for design naturally leads students to move from their individual forms of cognition into group cognition. CN, who was a project manager, started from his own idea and finished the project by building a group post, as shown in Table 4.2. This intersection of cognitive and social space naturally leads to students' struggle and growth in the social-cultural dimensions.

In the social-cultural dimensions, the collaborative design-based learning approach seemed to have provided important opportunities for students to develop social skills through working with others. In more collegial groups, student reported that "we always discuss relevant things. If we get wrong information, we will not scold each other but just ask each other to clarify on the [Knowledge Forum™]" (JH). However, more than half of the teams reported some problems such as off-task teammates and dominant members. To support students' collaboration, a set of rules were formulated for the students to foster collaborative talk based on Mercer and Littleton's (2007) recommendations. Some students seemed to apply the rules well and they tried to support each other. For example, they were concerned about their team mates' feelings and they were sensitive when providing feedback. "We cannot give bad comments because the person [could] feel that his idea is not good. We can add in something that we think is better [to improve] his idea." (V). Below is another quote illustrating how students explicitly referred to the rules of interaction which helped them to foster good working relations.

> We have a lot of rules and each and every rule is very important. So I try not to just push away anybody. Push away as in like I don't want you, don't want you to join, that feeling was to HK (a student's name), our health advisor. Actually it was a challenge when I need to work with everybody. (Mat)

**Table 4.2** The initial post and the final post by a project manager CN

| *What I think a coolie house should be designed like edit* by CN Last modified: 2013, Jul 30 (10:27:34) by CN | *Idea for finalized coolie house edit* by CN Last modified: 2013, Aug 27 (09:55:46) by CN |
|---|---|
| I think that a coolie house should be in an organized way. Since Ms H said that we are limited to only three stories, I have decided that the first floor of the coolie house should be housing 200 coolies with 50 rooms, each room having two double-decker beds with two toilets. On the second floor, I decided that there should be housing 150 coolies, with 50 rooms, with each room having a double-decker and single bed and two toilets. The top floor should house the remaining coolies with another 50 rooms, with one toilet and a double-decker and single-sized bed | We have decided to use all three floors. On the first floor, there will be four grasslands with plants and flowers so that the coolies can receive fresh air and five coolies tools room beside the grasslands so that the coolies do not have to walk a long distance to put their tool box. It will also house 200 coolies in 50 rooms, each room will have four coolies. There will also have ten toilets, each to be used by 20 coolies. On the second floor, there will be ten kitchens and 20 tables. There will still be ten toilets and 50 rooms. On the top floor, there will be ten toilets and 50 rooms |
| I have finished typing my design. SN, GL, and TN, can you all also contribute? | |

However, as expected, learning how to work together is challenging for young learners. Mercer and Littleton (2007) reported that disputes often occurred among primary students in group work when each insisted on their rights. Below is a quote from a team that had problems with cooperation.

> We can't really work as a group because we are always quarrelling. For example, we keep saying [that] this is the most suitable answer for the project [and] then someone else says that is more suitable and then we continue quarrelling all the way until the project is due... Me and my friends didn't do that well because we were all fighting over our ideas like we are quarrelling [that] my idea is better, your idea is better, whose idea is the best. And then we kept quarrelling so our floor plan was delayed by a few weeks. (Well)

In a dysfunctional group involving two boys (IL and DS) and two girls (ZY and Ar), ZY described her groups as "IL ok but DS always plays the fool. We had a very hard time to discuss." IL complained that DS kept "zapping" (using fingers to poke others) him and DS and one of the girls were often shouting at each other. Despite their fights, IL apparently enjoyed researching to "contribute to the group" and he reported that he was shy in face-to-face discussion. Ar also continued with the design activity "to build on our knowledge and to make our floor plan better... then we can put all our knowledge together to contribute a presentation." The students were conscious of the problem and they responded with various coping strategies. IL and Ar ignored the irritation from DS and continued to work for the group. There were other students who chose to shoulder the whole project themselves or to just leave the uncooperative ones out.

In summary, the learning experiences reported by the students were generally rich, and they provided further insights for the positive results obtained through the quantitative survey. They were provided with rich opportunities to work with each other to create a design for the coolie house and they exhibited critical and creative thinking.

## 4.5 Discussion and Conclusion

This chapter reviewed literature pertaining to design-based learning and categorized them into learning through designing digital artifacts in a programming environment, learning by design, design and technology, and theory-building as human design. These four strands of design-based learning are associated with constructionist learning theory which advocates learning through the production of artifacts. This form of learning engenders self-directed research, collaboration, authentic problem solving, and creative and critical thinking. To engage in design-based learning, it would make sense to use computers as cognitive tools (Howland et al., 2012). This form of learning is also closely related to 21st century learning that has attracted much attention in current education reforms (Voogt & Roblin, 2012). Our findings from the quantitative survey provide evidences that engaging primary four students in design-based learning for social studies created significantly stronger perceptions of being engaged in 21st century learning through the meaningful use of ICT, collaboration, and critical and creative thinking, and it also heightened the students' knowledge creation efficacy. This chapter therefore contributes to the literature of design-based learning by providing quantitative support to claims that design-based learning promotes 21st century learning (Lee & Kolodner, 2011; Yelland et al., 2008).

The quantitative findings were subject specific and the students in the intervention classes exhibited stronger perceptions of 21st century learning than the control classes of students who had equal access to technology and who are equally well acquainted with technology-based learning. However, the intervention classes did not perform better in two factors of the 21 CC survey. These were self-directed learning and authentic problem solving. A possible reason for the lack of significant differences for the self-directed learning factor could be that the items were not context sensitive. Whether one learns in a traditional environment or in a design-based learning context, one could set goals, implement, and adjust learning strategies as needed. However, the qualitative data provided evidence that students in the design-based learning classes were engaged in self-directed research. As for authentic problem-solving factor, the social studies theme was about nineteenth-century Singapore. All items in the authentic problem-solving factor used the terms real world or real life to describe the problem-solving activities. History is about what happened in the real world. As such, both experimental and the control groups were dealing with authentic problems in a sense. In addition, to design a building for the historical past is in retrospect, not that authentic. The factor is thus scored the lowest among the intervention classes for the seven factors measured.

The qualitative findings of this study indicate that the students were engaged in the design activity which invoked multiple kinds of learning within the cognitive, metacognitive, social-cultural, and technological aspects of learning. This finding provides further support that design-based learning offers rich opportunities for complex learning (Kangas et al., 2013). The interweaving of such multidimensional learning provides an avenue to foster holistic development among the primary students. While there were conflicts among students, we did not detect any worrying issues from the interview. Benson and Lunt (2011) have pointed out that it is important to capture the students' voice. We believe we have provided some vivid representation of students' voice about their experiences in design-based learning.

Many aspects of the design-based learning unit which we have tested out could be improved. We wonder if there is a need to provide more scaffolds for the students to achieve better design outcomes. Currently, the students' final products are limited to the floor plan. Other products such as rules and guidelines of living together in healthy manner and the budget proposal were ignored. The teachers have also forgotten about this original requirement. The research and development team within the school is therefore re-crafting the project to adopt a more systematic approach as suggested by de Jong et al. (2012). This entails the need to analyze the "mission" that the students had to embark on and to perform finer task analysis to find out the possible supports that are needed. For example, *SketchUp* is being considered as a possible tool to scaffold students' 3D modeling. In addition, the evaluation rubrics are also being refined to make sure that all aspects of knowledge learned will be presented and documented. We will also be considering if there is a need to provide some explicit teaching of the design process which could change students' perceptions and discourse. Further analyses of students' design talk are also important.

Overall, the findings of this study indicate that embracing design-based learning offers many opportunities to facilitate students' development of 21st century competencies. It also engages teachers in the iterative design of curriculum and it demands teachers' active facilitation. Given the emergence of more computer-based tools that can help to support students' design-based learning, we argue that design-based learning should be made available in more primary schools.

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# Chapter 5
# Design Thinking and Preservice Teachers

## 5.1 Introduction

As the demand to help students develop 21st century competencies is increasing, the conventional methods for preparing prospective teachers also need to be reconsidered. Teacher education needs to transition from cultivating more knowledgeable and skillful future teachers to developing their potential to work creatively with ideas for sustained teaching improvement. In particular, prospective teachers need to be equipped with design-thinking skills so that they know how to better design instructional lessons to achieve the overall educational goal of fostering 21st century competencies among future students.

In the following sections, we first elaborate why it is necessary to help preservice teachers develop design-thinking skills. Next, we discuss a knowledge-building approach to fostering students' design-thinking capacity. Then, we present two case studies of preservice teachers learning to work with design ideas and artifacts (i.e., technological products and lesson plans) through knowledge-building activities. Finally, we discuss some potentials and challenges of knowledge building as a pedagogical approach to promoting design thinking among preservice teachers.

## 5.2 Literature Review

### *5.2.1 Design Thinking and Teacher Education*

The exploration and development of design thinking was originally associated with professional designers and engineers. Experts from other fields and professions, however, also recognize it as an important type of thinking skill in life (Scheer, Noweski, & Meinel, 2012). Specifically in education, there have been lines of empirical research dedicated to advancing the understanding and know-how for



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fostering students' design competencies, for example, design-based learning (e.g., Mehalik, Doppelt, & Schuun, 2008; Wang, Weber, Dyehouse, & Strobel, 2012), learning by design (e.g., Kolodner et al., 2003; Whyte & Cardellino, 2010), and constructionist-oriented learning (e.g., Kafai & Resnick, 1996; Papert, 1993). One important thing to note is that design-thinking studies are mostly carried out in the disciplines and fields related to design and engineering education. Nevertheless, the importance of cultivating design disposition and skills among students has been quickly gaining popularity among educational scholars in all discipline areas (Razzouk & Shute, 2012). For example, a global movement called "Design for Change" (DFC) (see http://www.dfcworld.com/) has been taken up quickly by educators in many different countries to promote design-based education on a large scale; the goal of DFC is to give students an opportunity to express their innovative ideas and implement them for the purpose of making our world a better place (Khushu, 2011).

Despite the growing recognition of the importance of cultivating design competencies among students, there is still a general lack of systematic studies in the area of teacher preparation. With the rapid development of ICT in education, demand for teachers to be able to design ICT-infused lessons is also on the rise (Collins & Halverson, 2010). Clearly, preservice teachers need to be equipped with design-thinking skills so that they can design effective lessons to meet individual differences, as well as to help cultivate design capacity among future students. In contrary, a more conventional approach to preservice teacher education tends to focus on preparing prospective teachers with core teaching knowledge and skills prescribed in teacher education curricula (Hirsch, 1996; Slavin & Madden, 2001; Tileston, 2000). In some earlier models, preservice teachers are largely trained to perform so-called direct instruction or scripted teaching based on word-for-word teaching procedures (Adams & Engelmann, 1996; Engelmann, 1980; Sawyer, 2004; Slavin & Madden, 2001). There is relatively less emphasis on preparation for the capacity to assume the role of designer or theory builder with the required design-thinking disposition to engage in sustained improvement for their own teaching practices (Bereiter 2002). Recent discussion, however, has started to focus more on cultivating adaptive expertise (e.g., see Hammerness et al., 2005; Hong, 2014), as well as design-thinking dispositions (e.g., Koh, Chai, Hong, & Tsai, 2014) among preservice teachers. The kind of design thinking required in teaching may be defined as cognitive processes that help teachers to produce innovative solutions that adaptively address teaching-related issues and problems in educational settings. Such kind of thinking is analogous to what Bereiter and Scardamalia (2003) called a "design mode" of thinking, which emphasizes the ability to go beyond the pursuit of justified claims about how and what to teach, and it argues for the necessity for teachers to work creatively with ideas. Indeed, all creative knowledge work in real life usually requires such a design mode of thinking (Cross 2007). With design thinking, it is more likely for teachers to see teaching as an enterprise from a more creative perspective. They would also be more likely to see teaching as an instrument to engage students in deep learning and understanding.

Even though the conceptual importance of design thinking is gaining recognition, the gap between theory and practice remains wide open, especially in the area of preservice teacher education. In particular, there has been little research dedicated to understanding how preservice teachers' pedagogical awareness and capacity can be developed from the perspective of design thinking. The practical question of how to foster preservice teachers' design thinking remains a pedagogical challenge. Chai, Ling Koh, Tsai, and Lee Wee Tan (2011) also pointed out that there is an urgent need to systematically investigate the relationships between design thinking and preservice teachers; in particular, they suggested that it is important to investigate how preservice and in-service teachers develop their technological pedagogical content knowledge (i.e., TPACK) from the perspective of design thinking.

One obvious way to cultivate design thinking among preservice teachers may be to directly teach the "design-thinking" concept and skills as a subject in a particular course. Alternatively, it may be possible to engage learners in design thinking in different courses while learning different subjects. Given the heavy curricular load in most teacher education programs, the latter approach seems to be more feasible. To be effective, however, this requires some integration among courses in curriculum, and more empirical studies on the effectiveness of related instructional approaches are needed. One thing worth noting is that in engineering and design education, there has already been plenty of discussion about instructional strategies for promoting design thinking (e.g., Carroll et al., 2010; Oxman, 2004). In the present study, however, we are more interested in searching for more generic pedagogical approaches that can be widely applied in most disciplines for promoting design thinking. For this reason, knowledge-building pedagogy has been chosen as a candidate.

### 5.2.2 A Knowledge-Building Approach to Facilitating Design-Thinking Capacity

Among many research initiatives, one innovative pedagogical approach that may be used to foster preservice teachers' design capacity is called knowledge building. As a deeply constructivist approach, knowledge building is defined as a social process focused on continual generation and improvement of ideas valuable to a community (Scardamalia & Bereiter, 1994). Knowledge building adopts a principle-based pedagogical approach, rather than a procedure-based approach (Hong & Sullivan 2009; Zhang, Hong, Scardamalia, Teo, & Morley, 2011).

A proceduralized pedagogical approach tends to have all the learning tasks and activities, and the needed resources and tools, prescribed under a detailed instructional plan. Learners are guided to follow lockstep instructional processes, or clearly defined teaching scripts, in acquiring prespecified knowledge and/or practicing certain skills (see Sawyer, 2004, 2006). Such a pedagogical approach, though useful for helping students to efficiently receive and accumulate large amounts of knowledge, has also been found to be ineffective for helping students to develop the important creative or design-thinking skills needed in 21st century learning (cf. Sawyer). In contrast, a principle-based pedagogical approach provides only heuristics or guiding principles. Learners are engaged in a more reflective and creative course of learning and are guided to invent solutions, interpret situations, adapt to contexts, deal with multiple variables, and learn to frame and solve pertinent problems. As no predetermined procedures are being specified in principle-based practices, learners need to invent their own procedures and continuously refine them in order to make them work effectively. Previous studies have suggested that such a pedagogical approach can be very effective in cultivating more creative and adaptive learners (Hong, 2014; Martin & Schwartz, 2009; Zhang et al., 2011). For example, in Hong's (2014) study, adventurous teaching was highlighted as a key learning principle. The participating preservice teachers were guided to tinker with various teaching ideas in their teaching practice, rather than to continuously practice the same instructional procedures for mastery. As a result, it was found that the participants were more willing to adapt or to innovate their teaching practice, as well as to try new ideas in their lesson design.

To implement principle-based practice, a set of knowledge-building principles has been proposed as pedagogical scaffolds (see Scardamalia 2002). Analogous to design thinking that highlights a process of forming, relating, and synthesizing ideas, knowledge-building principles also highlight sustained idea improvement by engaging learners in activities such as idea diversification, elaboration, and reconceptualization. As suggested from the knowledge-building principles, working innovatively with ideas is essential to knowledge advancement. For example, the principle of "real ideas, authentic problems" highlights the need to engage learners to produce real ideas for addressing real-life problems (rather than textbook problems); "idea diversity" highlights the importance of helping participants to understand that idea interaction and diversification are essential for continual knowledge advancement; and "improvable ideas" stress the importance of viewing all ideas (i.e., their quality, coherence, and utility) as improvable and therefore the need to create a psychologically safe environment for idea development. Previous studies indicated that a knowledge-building approach enhances student learning in natural science (Gan, Scardamalia, Hong, & Zhang, 2010; van Aalst & Truong, 2011; Zhang, Scardamalia, Reeve, & Messina, 2009), in mathematics (Moss & Beatty, 2006, 2010; Nason & Woodruff, 2004), and in reading (Sun, Zhang, & Scardamalia, 2010; Zhang & Sun, 2011). Knowledge building has also been proved effective in enhancing preservice teachers' learning to teach and transforming their epistemological beliefs (Chai, Teo, & Lee, 2009, 2010; Erkunt, 2010; Hong, Chen, Chai, & Chan, 2011; Hong & Lin, 2010; Laferrière, Lamon, & Chan, 2006).

However, it has not been examined whether knowledge building has any bearing on design capacity. It is, however, conceptually plausible to posit that there are relationships between knowledge building and design thinking. First, this is because both knowledge building and design thinking highlight the importance of addressing real-world problems, especially ill-structured ones. Second, it is because they both focus on working creatively with ideas as an essential step to address problems. Just as a typical design process usually begins with a search for solutions/ideas, knowledge building also emphasizes improving the coherence, clarity, and utility of ideas. In particular, a knowledge-building principle called "rise above" highlights sustained idea improvement by achieving new syntheses out of conceptual diversity, complexity, and messiness. This synthesizing effort is similar to the process of design thinking when designers encounter various ideas for consideration because a key challenge in this process is how to navigate through a sea of ideas in order to synthesize the most promising ones into higher levels of reconceptualization. As argued by Meinel and Leifer (2012), good design thinking is usually constituted by a synthesis challenge more than an ideation (idea diversification) challenge. Nonetheless, differences also exist between knowledge building and design thinking. Perhaps the most noticeable difference between knowledge building and design thinking is that the former is more concerned with knowledge advancement as a learning outcome, whereas the outcome of the latter usually requires the production of a product or artifact. This difference, however, may be quite insignificant if the development of some final products is integrated into a knowledge-building process.

### *5.2.3 Two Case Studies*

In this chapter, we report two case studies of Taiwanese preservice teachers learning to design epistemic artifacts through knowledge-building efforts. The shared instructional goal of the two case studies is to foster preservice teachers' design-thinking capacity. In Study 1, participants were planning to become elementary teachers for teaching subjects related to natural sciences and living technologies. They were guided to design technological artifacts for improving the quality of everyday living. In Study 2, participants were planning to become middle school mathematics teachers. The epistemic artifacts that they were to design were mathematics teaching plans. The main research question for both case studies focused on whether engaging the prospective teachers in knowledge-building activities would help to enhance their design-thinking capacity as reflected by their ability to work creatively with design ideas for improving their target epistemic artifacts (i.e., technological products in Study 1 and lesson plans in Study 2).

## 5.3 Method

### *5.3.1 Study 1: Preservice Teachers Designing Technological Products Through Knowledge Building*

#### 5.3.1.1 Participants and Context

This study was conducted in a teacher education course at a university in Taiwan. The participants ($n = 30$) in this course were prospective teachers who had never taken any design course before. They planned to teach living technologies/natural

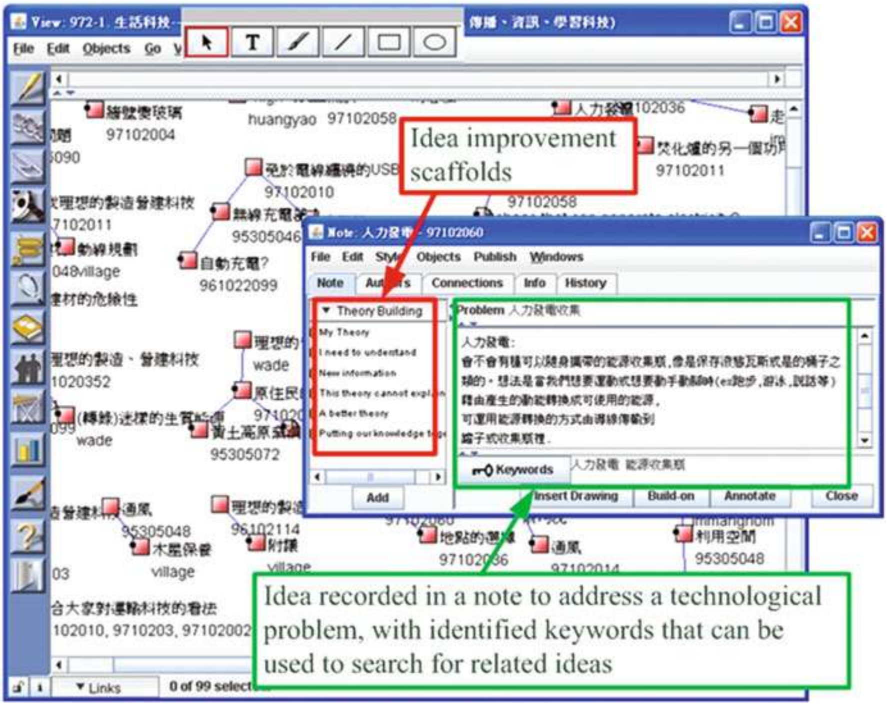


**Fig. 5.1** An example of a KF "view" (i.e., the window in the background) where participants can contribute and reflect on their own ideas in the form of a note (i.e., the pop-out window in the foreground) and/or give feedback to improve others' ideas

sciences at elementary school level after graduation. The ages of the participants ranged from 18 to 20. The duration of the course was 18 weeks. One main instructional goal of this course was to help the participants develop design-thinking capacity. To this end, students were engaged in knowledge building; they were guided to generate their design ideas, work innovatively with these ideas, and accordingly design technology artifacts that can be used to address some real-world problems (e.g., to make a technology device more energy saving). A computer-assisted online learning environment called "Knowledge Forum™" was set up for the participants to develop their design ideas into some technological products/artifacts. A tutorial lesson was given at the beginning of the semester (e.g., teaching students how to create notes and build on others' notes), in the form of PowerPoint slides, helping the participants to be familiar with the use of Knowledge Forum. The instructor who served as a facilitator in this course had more than 6 years of experience using Knowledge Forum in college teaching and did not intervene in any way in students' online learning. Figure 5.1 shows an example of the preservice teachers' work on Knowledge Forum. In it, each square box represents a note posted by a user, and a link between square boxes indicates efforts to elaborate, question, exchange, or improve ideas. As a university convention, the

**Table 5.1** Types of idea development

| Type | Description | Example |
|---|---|---|
| Diversification | Presenting divergent ideas for solving a technological issue or problem | My ideas of a well-constructed building include (1) having excellent safety measures, (2) using high-quality materials, (3) having practical value, and (4) being environmentally friendly |
| Clarification | Adding details or more explanations to a focal idea for addressing a problem | I wonder if it is possible to change some electric equipment by using wireless power transmitters and receivers so that we no longer need electric wires or cables. But will this change cause other issues or problems? Let's think about it |
| Integration | Synthesizing two or more ideas into an even more persuasive idea | After reading all your ideas about generating electricity through daily human activities (e.g., during walking, swimming, talking, or cycling), I think we can integrate all the ideas by designing a power collector that can gather together all the tiny amounts of electricity generated from our bodily movement |

semester was divided by a midterm examination into two equivalent instructional phases (phases 1 and 2). As knowledge building is a continual process, this division allows us to perform an overall comparison between the two phases and provide some information regarding the students' progress in their online learning and knowledge building.

#### 5.3.1.2 Data Source and Analysis

A mixed approach to collecting and analyzing data was employed in this case study. The main data sources included (1) students' online interaction logs and discourse recorded in a KF database and (2) the technology products designed by students.

##### Analysis of Online Interactions and Idea Development

First, in terms of students' online interactions, three key indicators recorded in the KF database (including number of notes posted, read, and built on) were quantitatively analyzed to illustrate the overall online interaction pattern. T-tests were performed to compare the two knowledge-building phases to examine major change over time. Furthermore, we content-analyzed the development of ideas by looking into how ideas were improved, using the following three criteria: diversification, clarification, and integration. Table 5.1 shows the description of each code and examples. Two researchers coded all ideas and the Cohen's kappa (κ) coefficient was computed as .894. As argued by Meinel and Leifer (2012), deep design thinking is usually represented by idea synthesis activity. It was therefore expected that progressively more idea-synthesizing activities (rather than just focusing on idea diversification and clarification) could be found towards the end of the course. T-tests were employed to compare between the two phases and see if there were any changes in terms of how ideas evolved over time.

Analysis of Technological Products

Second, the quality of the technology products designed by the participants was peer-assessed using Besemer's (1998) "Creative Product Analysis Matrix (CPAM)." The original scale has an internal consistency reliability level of Cronbach's $\alpha = .83$. One thing to note is that due to time constraints, students were only required to design technology products in concept form during the course. No actual products were made. The instructional goal was to engage students in design thinking by means of a collaborative process of working with ideas, rather than producing real products. So, of the three dimensions of CPAM, only the first dimension (i.e., novelty) was employed in the final assessment. In this dimension, there are two assessment criteria, including originality and surprisingness. The assessment adopted a seven-point Likert scale. Using a four-point average as a baseline rating for comparing another commonly seen product (e.g., a typical toilet), students were asked to judge the novelty of a designed product. As there were ten groups in this course, there were ten products/artifacts to be assessed. A one-sample *t*-test was conducted to see if there were any significant differences between the designed products and the baseline products.

### 5.3.2 *Study 2: Preservice Teachers Designing a Lesson Plan Through Knowledge Building*

#### 5.3.2.1 Participants and Context

The participants in this case study included 13 preservice teachers who had never taken any design course before; and they were studying to become mathematics teachers also in a teacher education program. The duration of this study was 18 weeks. Knowledge Forum™ was employed for the participants to generate their teaching ideas, develop their teaching artifacts (e.g., lesson plans, learning sheets, and teaching media), and provide feedback to one another for improving teaching. A conventional view of education in Taiwan tends to see learning as knowledge telling with a goal of teacher education being helping teachers to master core teaching knowledge and skills. In contrast, a knowledge-building approach in this teacher education program highlights sustained improvement in the participants' teaching ideas and teaching artifacts (e.g., lesson plans) by means of collaborative knowledge advancement. Similar to Study 1, at the beginning of the course, a tutorial lesson on how to use Knowledge Forum™ was provided. Students learned some of the basic features and functions such as how to create a note in a "view" (i.e., a collective problem-solving space in Knowledge™ Forum) or "build on" a previous note. The main course requirement was for each participant to practice their teaching twice, to design a complete lesson plan before each practice, and to provide peer feedback for teaching improvement in Knowledge Forum™ after each practice. Each participant took turns to practice teaching for the first time during the first half of the semester, and the same cycle was repeated during the second half of the semester (i.e., the second teaching practice). The main class activities were thus participants' teaching practices, and the main online activities were their idea generation activity (i.e., posting initial teaching ideas for their design of lesson plans) and their idea improvement activity in the form of peer feedback through sustained online collaboration.

#### 5.3.2.2 Data Source and Analysis

Data sources include ideas recorded in the database, students' lesson plans and their videotaped teaching practices. Details regarding data analysis are explained as follows.

##### Analysis of the Quality and Types of Ideas

To understand how collaborative knowledge building affected the quality and types of feedback for ideas contributed online, content analysis was conducted. The main feedback activity was focused on improving one another's teaching ideas and practices. This is important in this study as the capacity to give constructive and productive feedback to help one another design lessons and improve teaching practices represents a critical factor in developing one's critical-thinking and articulation skills (Shute 2008), which constitutes an important part of one's design thinking. To assess the quality of feedback ideas, a coding scheme based on the TPACK conceptual framework originally proposed by Mishra and Koehler (2006) was adopted. Table 5.2 shows the coding scheme, with a description of each form of teaching knowledge and coding example being provided. The seven forms of TPACK were further categorized into two levels: (1) basic, lower-level TPACK, which includes only one form of teaching knowledge (i.e., TK, PK, and CK), and (2) integrated, higher-level TPACK, which includes two or three forms of teaching knowledge (i.e., TCK, PCK, TPK, and TPACK). Using each specific idea as a unit of analysis, each suggested improvement idea was categorized into one of the two levels mentioned above. Furthermore, all online ideas were categorized into two additional types. One type focuses on ideas contributed to address teaching weaknesses, another on ideas contributed to reinforce teaching strengths. This was used as an indicator to tell how preservice teachers' teaching practices were improving over time. A paired-sample *t*-test was performed to see whether there were any

**Table 5.2** A coding scheme developed based on TPACK framework

| Knowledge | Description | Example |
|---|---|---|
| Content knowledge (CK) | Understanding of the subject matter taught | There is too much emphasis on test items in terms of teaching contents. (S3) |
| Pedagogical knowledge (PK) | Use of teaching approaches and strategies to promote learning, manage classroom, and create proper learning atmosphere | You lecture too much, but I like that you summarized what you taught at the end of the class. (S4) |
| Technology knowledge (TK) | Knowledge to utilize various instructional media, including books, blackboards, PowerPoint, video clips, internet information, etc. | It is exciting to use an interactive whiteboard to teach as it can be used both as a projector and a blackboard. (S6) |
| Pedagogical content knowledge (PCK) | Understand how to utilize various pedagogical approaches for different teaching content, and select appropriate ones for different classes/ teaching purposes | My teaching strategy is to let students solve the problem first by themselves, instead of feeding them the correct knowledge/ answers directly. (S2) |
| Technological content knowledge (TCK) | Effectively combine the use of instructional media and teaching content | Before, I seldom used (technology-based) teaching aids, but I just found out that with the help of them, I can make a huge difference in helping students understand the content that I want them to learn. (S8) |
| Technological pedagogical knowledge (TPK) | Understand how to use instructional media with various instructional approaches; select proper media for various instructional strategies | Using a learning sheet as a media to promote discussion among students can make class learning more joyful; also students can learn from one another that there is usually more than one way to solve a math problem. (S1) |

changes between the first and the second teaching practices in terms of the quality of ideas (as reflected in the use of TPACK) and types of ideas (as reflected in whether teaching strengths or weaknesses were addressed by the contributed ideas).

### Analysis of Design Focus

Rubrics for assessing participants' design focus were employed in this study. The rubrics were developed based on Collins' (1996) conceptualization about designing for different kinds of learning activities. He argues that depending on one's design focus, there are trade-offs in designing any learning environments. For example, if a teacher intends to design a more didactic-oriented learning environment, he or she might highlight memorization (i.e., memorizing things in order to do tasks fast and easily) rather than thoughtfulness. Table 5.3 shows eight design dimensions.

**Table 5.3** Rubrics for assessing two courses of design focus

| Rubrics | Description |
|---|---|
| Didactic-oriented design focus | |
| Memorization | Memorizing things in order to do tasks fast and easily (e.g., memorizing a multiplication table) |
| Component skills tasks | Having students perform simplified tasks that focus on specific subskills (e.g., having students practice sounding out different phonic patterns) |
| Breadth of knowledge | Having students learn a little about a lot of things |
| Uniform expertise | Having all students learn the same thing (perhaps at the same time) |
| Constructivist-oriented design focus | |
| Thoughtfulness | Learning to do things thoughtfully (e.g., solving complex problems) |
| Whole tasks | Having students perform whole tasks that involve integration of a variety of skills (e.g., having students read a whole book for enjoyment) |
| Depth of knowledge | Having students understand a few topics in a deep way |
| Diverse expertise | Allowing students to gain diverse expertise by learning different things at the same time |

In it, the first four dimensions indicate a didactic-oriented design focus, whereas the later four dimensions indicate a more constructivist-oriented design focus. Using a five-point Likert scale, students were instructed to peer-assess their two lesson plans designed for implementation of their first and second teaching practice. A paired-sample *t*-test was conducted to see if there was any change in terms of students' design focus as reflected in their lesson plans.

### Analysis of the Two Videotaped Teaching Practices

Accordingly, to understand how participants performed their teaching practices, analysis of the videotaping of students' two teaching practices was conducted. Using each instructional activity as unit of analysis, the two teaching practices were parsed from the video and categorized into various types of teaching activity (e.g., teacher lecture or student discussion). Then, the activities were content-analyzed following the same coding categories mentioned above, namely, the two main types of instructional activity: didactic-oriented and constructivist-oriented activities. The former mode highlighted conventional instructional activities such as lecture, demonstration, asking true-false questions, direct instruction, and the like. The latter mode highlighted self-initiated or self-directed student learning activities, such as problem solving, teamwork, open-ended questioning, group debate and discussion, and the like. The percentage of time actually allocated to each mode of teaching activity (as shown in the video) in the two teaching practices was compared, using a paired-sample *t*-test for analysis.

## 5.4 Results

### *5.4.1 Study 1*

In Study 1, participants were planning to become elementary school teachers for teaching subjects related to natural sciences and living technologies. The main research question for Study 1 focused on whether engaging the prospective teachers in knowledge-building activities would help enhance their design-thinking capacity, as reflected in their work with design ideas and designed objects (i.e., technological products).

#### 5.4.1.1 Online Interaction and Idea Development Activities

Table 5.4 shows students' online interactional behaviors from phase 1 to phase 2. First, in terms of note contribution, each student contributed a mean number of 5.1 notes in phase 1 and 11.10 notes in phase 2. A *t*-test showed a statistically significant difference between the two phases, indicating progressively more active online contribution. In terms of note reading, each student on average read 38.90 % of all notes in phase 1 and 33.70 % of all notes in phase 2. A *t*-test showed a significant decrease from phase 1 to phase 2. This may be due to a significant increase in the number of notes in phase 2, so even though the percentage dropped, the participants still read more notes in phase 2 ($M = 112.22$; $SD = 36.95$) than in phase 1 ($M = 59.52$; $SD = 24.06$), which suggests that the participants were able to maintain a high interest in others' ideas (i.e., a strong community awareness) over the whole semester. Next, in terms of note building on, it was found that there was a significant increase from phase 1 to phase 2, indicating a positive synergy in working collaboratively online. Figure 5.2 further shows the collaboration patterns in terms of building-on activities where there were more connections in phase 2 than in phase 1. This confirms that student collaboration was supported and

**Table 5.4** Online interaction and idea development patterns over time

| | Phase 1 | | Phase 2 | | |
|---|---|---|---|---|---|
| | *M* | SD | *M* | SD | t-value |
| Online interactions | | | | | |
| # of notes posted | 5.10 | 3.01 | 11.10 | 5.36 | 6.90*** |
| % of notes read | 38.90 | 26.65 | 33.70 | 22.98 | −2.13* |
| # of building-on notes | 2.30 | 1.83 | 6.80 | 4.72 | 3.66** |
| Idea development | | | | | |
| Diversification | 1.37 | 1.03 | 0.60 | 0.81 | −3.04** |
| Clarification | 0.53 | 1.01 | 0.70 | 1.01 | .63 |
| Integration | 0.00 | 0.00 | 0.43 | 0.73 | 3.26** |

*$p < .05$; **$p < .01$; ***$p < .001$

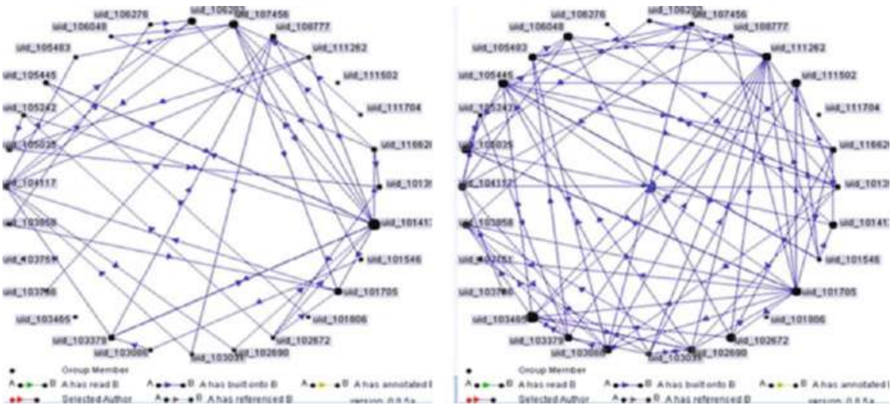

**Fig. 5.2** Online knowledge-building activities in terms of note building-on patterns, from phase 1 (on the *left side*) to phase 2 (on the *right side*). Each *black dot* represents a participant, with *bigger dots* indicating more influential participants (i.e., having more connections with others); and each link represents at least one building-on connection

they were more likely to exchange ideas by reading or linking to other peers' notes. All these online measures indicate that students were progressively able to collaboratively work with others. However, this does not tell us much about the quality of idea development.

Further analysis of idea quality was conducted using ideas as unit of analysis. As shown in the bottom part of Table 5.4, it was found that there was a decrease from phase 1 to phase 2 in terms of both idea diversification and idea clarification; in particular, the decrease for idea diversification is statistically significant ($t = -3.04$, $p < .01$). In contrast, it was found that there was a significant increase from phase 1 to phase 2 in terms of idea integration. The findings indicated that some convergent design thinking in this community was taking place towards the end of technological design. This was a sign of productive design thinking as too many divergent ideas would lead a design process nowhere. One notable thing in the statistics is that there were obviously fewer reintegration activities than the other two activities (idea diversification and clarification). Clearly, there is still room for students to further improve their design-thinking capacity, and this represents an area where future studies may be fruitful.

#### 5.4.1.2 Working Creatively with Design Ideas and Designed Artifacts

In terms of learning outcomes, students' designed artifacts (i.e., their technology products) were analyzed. As each of the 10 groups designed one specific technological product in this case study, there were 10 products in total. Peer review was conducted as a method for product assessment. Using Besemer's (1998) Creative


**Fig. 5.3** A prototype of an improved technological product designed based on a commonly seen product (i.e., a toilet on the *right*)

Product Analysis Matrix (CPAM), which is a seven-point Likert scale, students were asked to rate the quality of the other nine groups' technological products. Figure 5.3 shows an improved toilet (see left side of the figure) as an example of a group's designed product and another commonly seen product (right side of the figure) that is used as a baseline/comparison product in the study. A one-sample *t*-test was conducted to compare the peer assessment ratings on a group's designed product with the ratings they assigned to a baseline/comparison counterpart. The result showed a significant difference between the two sets of ratings ($M = 5.83$, $SD = 0.77$, $t = 19.05$, $df = 9$, $p < .001$), indicating enhanced design capacity among students.

To illustrate how students worked collaboratively to synthesize their design ideas and reconceptualize their designed products, the same product mentioned above (i.e., toilet) was used as an example for discussion. For this product, it was found that students initially worked with a diverse set of ideas. After discussing online over some time, some of these ideas were deemed as less useful and were discarded, whereas the others were further improved. Eventually, the following four trajectories of idea development were formed: (1) nano-materials, (2) a toilet in connection with a hand-washing sink, (3) an enhanced suction device, and (4) other ideas (i.e., storage space; see Fig. 5.3). Table 5.5 summarizes the number of ideas contributed in each of the four idea development trajectories, the duration of idea development, the number of collaborators, and a summary of the key ideas. Apparently, the development of the designed artifact was based on sustained work with relevant ideas over a period of time. It is worth noting that participants in the discussion of this product also included other peers from different groups. The results imply that students were moving towards a more designerly way of knowing through working creatively with design ideas and designed objects.

**Table 5.5** An example of the development and synthesis of diversified ideas to design a technological product (i.e., toilet technology)

| Idea trajectory | # of ideas | Duration (days) | # of collaborators | Summary of key ideas |
|---|---|---|---|---|
| Nano-material | 3 | 80 | 3 | To use new nano-materials to protect the toilet surface and get rid of the bad smell |
| Toilet combined with a sink | 4 | 35 | 7 | To combine with hand-washing sink to use recycled water (after hand washing) to flush toilet |
| Enhanced suction device | 3 | 41 | 4 | To design a more effective suction device that can prevent a toilet from getting dirty |
| All other ideas | 5 | 39 | 7 | Example: To propose a new multifunctional toilet that can do many things such as deodorizing |

## *5.4.2 Study 2*

In Study 2, participants were planning to become middle school mathematics teachers. The main research question for Study 2 focused on whether engaging the prospective teachers in knowledge-building activities would help to enhance their design-thinking capacity, as reflected in their work with design ideas (in the form of teaching feedback) and their designed epistemic artifacts (i.e., their teaching lessons).

### 5.4.2.1 Analysis of the Quality and Types of Teaching Ideas

A main online knowledge-building activity among the participants was to provide diversified and more explanatorily coherent ideas for improving their teaching practices; these ideas were analyzed. As Table 5.6 shows, there were on average 6.3 (SD = 3.33) and 5.6 (SD = 2.18) ideas, respectively, contributed by peers for improving teaching lessons and performance in the two (the first and the second) teaching practices; and it was found that there was no significant difference between the two teaching practices ($t = -.65$, $p = .52$).

Further analysis of the quality of teaching ideas contributed online was conducted by examining its relationships with the use of TPACK knowledge in giving teaching feedback. As mentioned above, the seven types of TPACK were categorized into basic (lower-level) TPACK (including TK, PK, and CK) and integrated (higher-level) TPACK (including TCK, PCK, TPK, and TPCK). First, it was found that there were significantly more ideas contributed to improve lower-level TPACK ($M = 5.54$, SD = 2.82, for the first teaching practice, and $M = 5.08$, SD = 1.89, for the second teaching practice) than higher-level TPACK ($M = 0.77$, SD = 1.01, for the first teaching practice, and $M = 0.54$, SD = 0.88, for the second teaching practice) for both of the teaching practices ($t = -6.57$, $p < .001$, for the

**Table 5.6** Analysis of the quality and types of teaching ideas

| | 1st practice | | 2nd practice | | |
|---|---|---|---|---|---|
| | *M* | SD | *M* | SD | *t*-value |
| Number of ideas | 6.31 | 3.33 | 5.62 | 2.18 | −0.65 |
| Quality of ideas | | | | | |
| Ideas contributed to improve basic TPACK | 5.54 | 2.82 | 5.08 | 1.89 | −0.52 |
| Ideas contributed to improve integrated TPACK | 0.77 | 1.01 | 0.54 | 0.88 | −0.82 |
| Types of ideas | | | | | |
| Ideas contributed to improve teaching weaknesses | 4.85 | 2.70 | 3.15 | 1.86 | −1.74 |
| Ideas contributed to enhance teaching strengths | 1.46 | 1.51 | 2.46 | 1.39 | 2.79* |

*$p < .05$

first practice, and $t = -4.54$, $p < .001$, for the second practice). Specifically looking into each of the two types of TPACK (basic and integrated), however, it was found that there was no significant change from the first practice to the second practice both in the use of basic TPACK ($t = 0.53$, $p > .05$) and integrated TPACK ($t = 0.82$, $p > .05$). This indicates that there is still room for students to develop their critical-thinking and articulation skills (which are part of their design thinking). Apparently, the quality of teaching ideas contributed online can still be further improved. Nevertheless, we believe this is normal as the participating preservice teachers were just starting their teacher preparation courses, and they had not had much experience of teaching practices yet.

In addition, all ideas contributed online were categorized into two additional types. The first type is ideas contributed to address weaknesses in someone's teaching practices; another is ideas contributed to reinforce one's strengths in teaching practices. For this particular analysis, it was found that there was a decrease in the number of the first type (weaknesses in teaching) of teaching ideas from the first practice ($M = 4.85$, SD = 2.70) to the second practice ($M = 3.15$, SD = 1.86), although this was not statistically significant. However, there was a significant increase in the number of the second type (teaching strengths) of ideas from the first practice ($M = 1.46$, SD = 1.51) to the second practice ($M = 2.46$, SD = 1.39). The results indicated that students were reasonably able to progressively improve their teaching practices by reflecting on and reducing their weaknesses while enhancing their strengths in their teaching practices. Overall, although their knowledge advancement was mainly focused on lower-level TPACK, there was still some progress in their teaching practices as reflected in their continual idea generation and improvement activities.

#### 5.4.2.2 Change in Students' Design Focus and Teaching Performance

It is posited that participants' design thinking is related to how they work with their designed artifacts. In this mathematics teaching preparation course, the designed

**Table 5.7** Change in participants' design and teaching orientation as learning outcomes

| Performance | 1st time | | 2nd time | | t-value |
|---|---|---|---|---|---|
| | *M* | SD | *M* | SD | |
| Design focus | | | | | |
| Didactic-oriented design | 2.95 | 0.52 | 2.82 | 0.74 | −0.72 |
| Constructivist-oriented design | 3.01 | 0.72 | 3.53 | 0.59 | 2.32* |
| Teaching practice | | | | | |
| Didactic-oriented practice | 0.68 | 0.18 | 0.52 | 0.19 | −2.51* |
| Constructivist-oriented practice | 0.32 | 0.18 | 0.48 | 0.18 | 2.50* |

*$p < .05$

artifacts are mathematics lesson plans. Our analysis focuses on two types of design foci that were predefined based on literature review, including didactic-oriented and constructivist-oriented design foci. It was expected that participants' initial design focus would be more didactic oriented as they had virtually no actual teaching experiences and their vicarious experiences of teaching were their prior observation as students in class through K–12. It was posited that participants' design-thinking focus would progressively move towards a constructivist-oriented direction after engaging in knowledge building over a semester. To examine this postulation, analysis was employed on the data gathered from participants' peer assessment using rubrics for assessing design focus (see above Table 5.3). As Table 5.7 shows, *t*-tests demonstrated that there was a decrease in ratings from the first lesson planning to the second lesson planning in terms of didactic-oriented design focus ($t = -.72$, $p > .05$), although this was not statistically significant. However, in terms of constructivist-oriented design focus, it was found that there was a statistically significant increase in the ratings from the first lesson planning to the second lesson planning ($t = 2.32$, $p < .05$). The results confirm the above postulation.

Accordingly, if participants' design thinking is moving away from a didactic-oriented direction, it is likely that participants' teaching practices will also move away from more didactic-oriented teaching practices to more constructivist-oriented teaching practices. To examine these claims, analyses of participants' videotaped teaching practices were conducted, using instructional activity as unit of analysis, and the time spent in two generic types of instructional activity (didactic-oriented vs. constructivist-oriented) was statistically computed. As a result, t-tests showed that there was a significant decrease in the percentage of time allocated to more didactic-oriented instructional activities from the first to the second teaching practice ($t = -2.51$, $p < .05$). In contrast, it was found that there was a significant increase in the percentage of time spent on more constructivist-oriented instructional activities from the first to the second teaching practice ($t = 2.50$, $p < .05$).

## 5.5 Discussion (Potentials and Challenges)

In summary, this chapter described the importance of design thinking for preservice teacher education, introduced knowledge building as one possible effective pedagogical approach to facilitating prospective teachers' design-thinking capacity, and presented two case studies as empirical evidence to demonstrate the possibility of using knowledge-building pedagogy to develop preservice teachers' design-thinking capacity. There are, however, limitations in the two case studies. First, as the measurement was mainly focused on assessing design ideas and designed artifacts, we have no direct evidence to confirm that there is a causal effect on participants' design-thinking skills. The indirect evidence provided by the two case studies can only suggest that knowledge-building activities are related to positive changes in participants' work with their design ideas and designed artifacts. Second, in the present two case studies, knowledge building with KF (as intervention) was implemented as a rather generic pedagogical measure to enhance students' design thinking (as outcome variable). For future research, it would be helpful to focus on investigating how more specific knowledge-building activities or strategies may contribute to the development of certain design-thinking components. This would help us better understand the particular relationships between knowledge-building practices and design-thinking skills. Perhaps more qualitative studies (e.g., in-depth interviews) would help in this regard.

Nevertheless, it is obvious that the two case studies have resulted in a positive learning experience among the participating preservice teachers. This indicates that knowledge building, as an innovative pedagogical approach, is conducive for fostering design activities. In particular, principle-based instruction seems to be able to give the preservice teachers enough flexibility to work more creatively and adaptively with their design ideas for continuously improving their design artifacts. In conclusion, we confirm that a knowledge-building approach has the potential to engage preservice teachers in a more designerly way of knowing and doing. The present studies only represent an initial step towards a better understanding of the relationships between knowledge building and design thinking. Further research may need to employ more carefully developed assessment approaches in order to replicate the current studies and to triangulate the derived findings.

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# Chapter 6
# Design Thinking and In-Service Teachers

## 6.1 Introduction

In-service teachers' expertise for teaching can be found in the instructional repertoires that they have established through daily engagement with curriculum, school, classroom activities, and different profiles of students (Shulman, 1986). As compared to preservice teachers, in-service teachers have richer sources of contextual knowledge to draw upon when designing lessons (Harris, 2008). It would seem that in-service teachers are well poised to integrate the pedagogical practices envisioned under 21st century learning, but in reality, such practices are not widespread in schools (Windschitl, 2002). One reason could be that in-service teachers have yet to establish the appropriate design frames for pedagogical change.

In design literature, frames are designers' conceptions of design problems which determine the kinds of solutions that they eventually adopt (Cross, 2004; Schön, 1983). Dorst and Cross (2001) propose that the kinds of framing adopted by designers typically determine the efficacy of their design outcomes. In-service teachers have developed extensive routine expertise or the ability to execute successful problem-solving strategies with high levels of automaticity within a prescribed environment (Hatano & Inagaki, 1986). As they design, the influence of their existing routines remains strong (Hoogveld, Paas, Jochems, & Van Merriënboer, 2002) because these tried and tested repertoires significantly reduce the cognitive effort expended during design. Nevertheless, pedagogical change often presents teachers with nonroutine problems, best resolved through the design of new pedagogical practices (Hammerness et al., 2005). When teachers fail to modify existing frames or create new ones appropriately, that which typically results from design is what Windschitl (2002) described as surface-level change where deep pedagogical integration is absent. Therefore, a critical aspect of in-service teachers' design thinking lies in how they navigate their pedagogical dissonances through the creation, development, and adoption of new frames.



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In this chapter, we focus on the processes that a team of six Singapore in-service teachers in an elementary school have used to design pedagogical change. Using a case example, this chapter aims to describe how teachers create, develop, and adopt frames as they design an educational innovation that is related to 21st century learning in group-based contexts. It examines the kinds of frames adopted by teachers as well as the factors that perturb and influence teachers to modify or recreate their frames. The implications for teacher professional development through codesign will be discussed.

## 6.2 Design Framing

Design is the creation of new products or experiences by optimizing the opportunities and constraints of a problem space (Cross, 2004; Rowe, 1991). Design problems have been described as having the characteristics of wicked problems where the outcomes desired as well as the means to achieve these outcomes may both be unknown (Rittel & Webber, 1973). As a result, designers need to coevolve both these aspects during design. To do so, designers create frames as temporary bridges between the "what" and "how" of a problem (Paton & Dorst, 2011). Paton and Dorst note that design framing could be "value laden" (p. 574) and the process has characteristics of what Peirce (1955) described as abduction where explanatory hypotheses are being set up to examine its relationships to particular outcomes. By adopting frames, designers are able to concretize some aspects of the design problem to develop some initial solutions (Dorst & Cross, 2001). Designers can then evaluate and improve upon these ideas. Design thinking or the reasoning processes used to design can also have an emergent, reflective, and intuitive aspect (Dorst, 2006; Schön, 1983), whereby designers engage in reflective conversations with the design situation. By developing frames to shape and evaluate possible solutions, designers create opportunities for "talk back" from design situations which helps them to reframe their definitions of design problems and to work out new solutions. According to Schön, such kinds of "reflection-in-action" typify how designers engage in design through the creation, development, or recreation of frames. Designers' ability to do so influences how they can create change when faced with novel and unfamiliar problems (Dorst, 2011). Design framing is therefore an important competency for teachers seeking to effect pedagogical innovation.

## 6.3 Teachers' Design Framing

Using extant literature of teachers' design practices, we suggest three perspectives that can be used as lenses to understand teachers' design framing.

### *6.3.1 Process-Based Perspective*

The first perspective focuses on the activities that teachers carry out during lesson design. It has been characterized as a process largely involving five basic activities: analysis, design, development, implementation, and evaluation of instruction or the ADDIE process (Molenda, 2003). Early instructional design models purport a linear process moving from one activity to the next in lockstep fashion (Andrews & Goodson, 1980). Recent models suggest that the process is dynamic and need not begin with analysis (e.g., Morrison, Ross, Kalman, & Kemp, 2013) because teachers may move back and forth between these five activities as they design (Laurillard, 2012; Summerville & Reid-Griffin, 2008). When these activities are used to analyze teachers' design practices, it was found that they mostly focused on development but least on the analysis of learner needs and learning problems (Hoogveld et al., 2002). Teachers' design behaviors appear to resemble the practice of novice designers who tend to pin down ideas quickly and devote a large part of their efforts on working out its details (Cross, 2011). Conversely, Lawson (1997) and Cross (2011) found that expert designers typically spent more time on analysis where they established frames to develop crude initial solutions that were used as a means to understand design problems. Rather than attempting to formalize solutions early during the design process, expert designers continually played with ideas and even allowed conflicting ideas to coexist until such time that is judged as appropriate for consolidation (Schön, 1983).

Hoogveld et al. (2002) concluded from their study that teachers' incomplete application of the design activities could point to some gaps in their design capacities. Yet, it is needful to consider the design context as well as the role played by teachers' routine expertise. If teachers were solving well-defined problems of high familiarity to them, they would have already possessed the appropriate routine expertise to resolve them. Their intimate knowledge of curriculum and the students could have curtailed the need for them to explore alternative frames through analysis. On the other hand, if teachers were working with ill-defined problems, the lack of analysis could suggest that teachers were adopting their established routines as problem-solving frames, whereas frame creation and modification may not have been extensive. Therefore, the kinds of problems could influence how teachers are maneuvering the different instructional design activities.

### 6.3.2 *Knowledge-Based Perspective*

The second perspective that can be used to understand teachers' design frames is to consider the different kinds of knowledge that are being created as they design. Teachers' expertise for teaching was first termed as pedagogical content knowledge (PCK) which is understood as more than a simple addition of teachers' pedagogical knowledge (PK) and content knowledge (CK) (Shulman, 1986). PCK has a transformative nature because it is the new knowledge that teachers create as they draw upon their pedagogical knowledge and content knowledge to develop specific instructional strategies for different profiles of students (Gess-Newsome, 1999). With technology as a key enabler for 21st century learning, PCK has been extended as technological pedagogical content knowledge (TPACK) (Mishra & Koehler, 2006). Like PCK, TPACK is considered to be a kind of transformative knowledge, and many studies have found that it is created when teachers engage in lesson design (Koehler, Mishra, & Yahya, 2007; Koh, Chai, & Lee, 2013; Koh & Divaharan, 2011, 2013). As teachers design, they draw upon their existing knowledge of technology, pedagogy, and content for problem solving.

When designers encounter a design problem, they rely on their prior experiences to evoke the appropriate frames for problem solving (Dorst, 2011). Similarly, the opportunities and constraints of instructional problems provide the impetus for teachers to evoke the various forms of knowledge that are needed for problem solving. As teachers design, they work upon these knowledge sources, using them as epistemic resources to create the appropriate instructional solutions. Teachers' design-thinking capacity is determined by their ability to create new forms of knowledge throughout the design process. Drawing reference to the TPACK framework, this can take the form of new kinds of lesson strategies without the use of ICT (PCK) or with the use of ICT (TPACK). Teachers may also deepen their understanding of new or existing technologies (technological knowledge, TK) and pedagogies (pedagogical knowledge, PK) and even enhance their understanding of the content they are teaching (content knowledge, CK). It is premised that the latitude for knowledge creation through design may be limited if teachers are entrenched within their routine expertise. The forms of teacher knowledge can also be used to articulate the content of teachers' design framing.

### 6.3.3 *Contextual Perspective*

Teachers' instructional decisions are influenced by the larger ecology of their school systems which includes factors such as school culture, education policies, school programs, as well as classroom practices (Zhao & Frank, 2003). In our own research of teachers undertaking educational innovation through technology integration, we found the presence of cultural/institutional, physical/technological, interpersonal, and intrapersonal factors that influence teachers' design decisions (Chai, Koh, & Tsai, 2013). Cultural/institutional factors refer to the demands from what Porras-Hernández and Salinas-Amescua (2013) termed as the macro and mezzo levels of school contexts. These are the sociopolitical environment and policies (macro) which can shape culture and policies at the school level (mezzo). Educational policies and curriculum at the macro level influence the vision, goals, and programs launched at schools as well as the kinds of pedagogies that teachers adopt. In high stakes educational systems, for example, teachers emphasized the use of ICT for information transmission rather than constructivist pedagogies (Gao, Choy, Wong, & Wu, 2009; Lim & Chai, 2008). At the mezzo level, when school leaders shape school culture and policies to support innovative practices, it influences teachers' willingness to change their instructional strategies (Tondeur, Valcke, & Van Braak, 2008). Another important factor influencing teachers' instructional decision making is the availability of resources such as equipment, budget, and technology tools, which we have termed as physical/technological factors (Guzey & Roehrig, 2009; Hew & Brush, 2007). The lack of resources may impede teachers' desired pedagogical actions, but schools may sometimes be tied to using available hardware and software, and these factors invariably influence the frames that teachers adopt during lesson design.

Teachers' beliefs of teaching, learning, pedagogy, and students can also influence the kinds of frames they adopt during lesson design. Ertmer (2005) commented that such kinds of intrapersonal factors may exert even stronger influences than external factors that are physical/technological in nature. For example, several studies have found direct correlation between teachers' perceptions of constructivist beliefs and their integration of technology (Hermans, Tondeur, van Braak, & Valcke, 2008; Sang, Valcke, van Braak, Tondeur, & Zhu, 2011). When considering pedagogical innovation, it is also proposed that peer support through collaborative design could be interpersonal factors that help teachers to successfully maneuver the changes required (Meirink, Imants, Meijer, & Verloop, 2010). Some current studies propose that teachers can work in collaborative teams to cocreate the new knowledge needed to design for pedagogical change (Meirink et al., 2010; Simmie, 2007; Voogt et al., 2011). It is believed that such kinds of design work can be more effective in interdisciplinary teams led by leaders with an aim on pedagogical change (Meirink et al., 2010; Putnam & Borko, 2000). Therefore, the various elements in teachers' context can potentially shape their adoption of design frames as well as their willingness to modify frames. The influence of group dynamics in codesign situations is another important factor for understanding teachers' design framing.

## 6.4 The Case

### *6.4.1 Context*

The case study we are describing involves our work with six teachers at a Singapore elementary school. The case study describes one of the projects undertaken as a research partnership between the school and a teacher education institution of a

Singapore university to infuse 21st century learning into the school curriculum. The teachers working on this project were responsible for designing innovation for the Grade 3 math curriculum. This design group was led by the head of department (HOD) of mathematics who is an experienced teacher with more than 10 years of teaching experience. The other teachers in the group had between 5 and 10 years of teaching experience. Researchers specializing in educational technology from the university were part of the design team, assisting the teachers with the pedagogical and technological integration as well as the research aspects of the project.

Based on the teachers' observations of Grade 3 students, they identified an instructional need of enhancing students' ability to communicate their mathematical reasoning. This aspect was chosen as it supports the development of critical and inventive thinking as well as communication, collaboration, and information skills—two of the 21st Century Competencies identified by Singapore's Ministry of Education (MOE, 2014). This vision involved learning experiences that equip children with the skills to explore, think critically, and communicate their ideas effectively. To support these educational goals, teachers chose to use a 5E inquiry-based approach whereby learning occurred through five phases—engagement, exploration, explanation, elaboration, and evaluation (Bybee et al., 2006). This was because the 5E process supported students to develop and deepen their explanation of phenomenon through exploration. Furthermore, clear articulation of mathematical reasoning processes is also an important skill to support math evaluation at the national examination that students take during their sixth grade. Therefore, the 5E pedagogy allowed teachers to emphasize this critical skill in the lessons.

Teachers implemented this new approach on one mathematical topic during each semester, focusing on topics that were more difficult for the students. These lessons were piloted with a class of mid-ability students that were taught by Teacher Ana. Teacher Jerry was responsible for the development of the lesson resources. The other teachers in the team would be implementing these lessons in their third grade classes during the following school year. The redesigned lessons appeared to have positive impact on student learning when conducted with a class of 43 grade three students. There were significant increases in students' pre- and posttest scores when assessed on the topic of area and perimeter. Details of the intervention as well as the implementation results can be found at Lim, Ang, and Koh (in-press).

### 6.4.2 Data Collection and Analysis

Weekly design meetings were held by the teachers from January to November 2013, but the researchers participated in the discussions only from July 2013. These meetings typically lasted between 1.5 and 2 h, and during this time, the teachers reviewed and improved upon the drafts of lesson plan and resources for the upcoming lessons. After these activities have been implemented, teachers reviewed video recordings of the lessons to identify areas for improvement. Data for this study was collected through audio recordings made during the meetings. These were transcribed into textual data and analyzed using content analysis (Weber, 1990). The data was broken down into utterances which were considered the unit of analysis. Utterances were used as the unit of analysis so that distinctions between units were established syntactically (Krippendorff, 2004).

Each utterance was analyzed by making reference to the three perspectives. In the activity-based perspective, the five stages of ADDIE (Molenda, 2003) were used as the starting point to understand how teachers engaged in the different stages of instructional design. Analysis of the data found the need for a second layer of codes that considered how members of the team shared, clarified, and justified ideas among each other as they mediate design tensions within each stage of ADDIE. These are processes reflective of what Smith (1994) described as group-mediated cognition where knowledge is created and extended. While the knowledge sources of the TPACK framework (Mishra & Koehler, 2006) were used to code the data from the knowledge-based perspective, the refinements and transformation of each kind of knowledge were further indicated to describe the process of knowledge creation. The four categories proposed by Chai et al. (2013) were used to code the presence of contextual influences. It was found that contextual knowledge was regarded as common knowledge among teachers that need not be discussed. Therefore, it rarely appeared overtly in teachers' discussion, but it nevertheless had a powerful background influence. Therefore, the presence of context was described more generally in the commentary and indicated in the transcript only if overtly mentioned by the teachers.

The transcript was first coded by one coder. The second coder reviewed the coding, and all inconsistencies were negotiated among coders until there was full agreement. Representative examples are highlighted in the following sections.

### *6.4.3 Teachers Designing Independently*

The following episode exemplifies teachers' design talk as they attempted to change a current practice. Apparently, as teachers sought to engage students in deeper explanation of their mathematical reasoning, they also needed to better differentiate between the different levels of reasoning that students furnished. Therefore, the teachers were confronted with the problem of whether they should alter their marking scheme.

For the topic of fractions, teachers debated about how they would be able to grade the depth of students' reasoning, especially to confirm that students have derived the correct answer through appropriate reasoning rather than an arbitrary statement of the answer. The teachers' discussion was based on the following question that students had to solve in a practice exercise (see Fig. 6.1).

The discussion in Table 6.1 shows the head of department (HOD) attempting to seed a new design frame, that is, the need to separate the grading of students' approach towards problem solving from their reasoning.

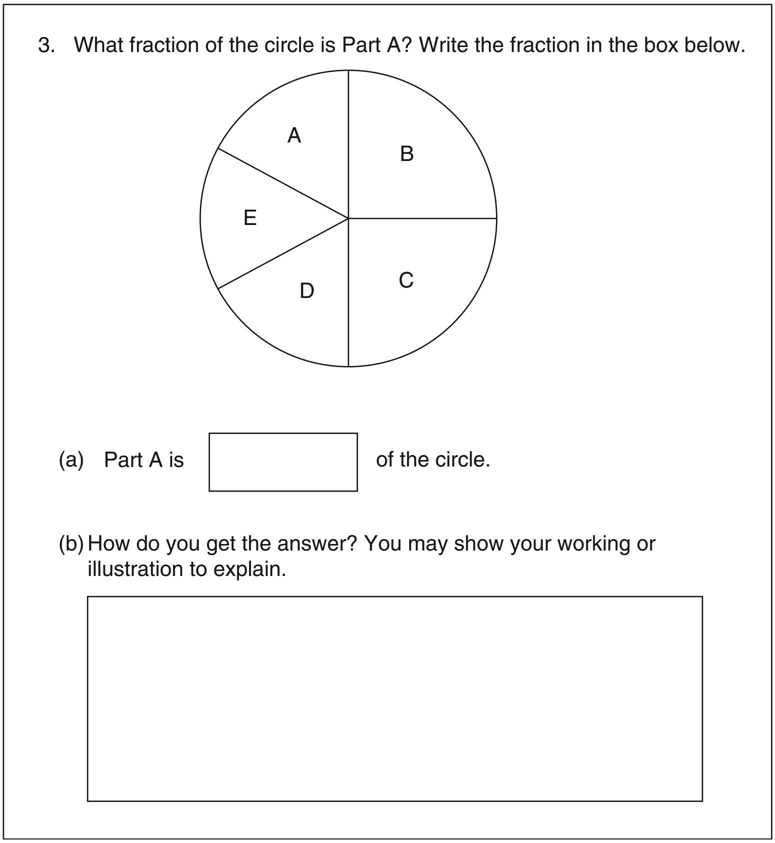


**Fig. 6.1** Question from practice exercise

From the process-based perspective, it can be seen that the seeding of a design frame began with an analysis of the current situation. In lines 1a to 1c, the HOD started her analysis by describing the current practice. This was the precursor to her identification of the problem with the current practice (line 1d) and, finally, her proposal of the new frame, that is, a different practice where the grading for approach and reasoning would be separated. The seeding of the new frame occurred as a design move (line 1e) which is further substantiated by an analysis move (line 1f). From line 2, it can be seen that the team's transition to the new frame was not immediate. It appeared that further rationalization from the HOD was needed as Teacher Jerry justified the current practice where "approach" and "reasoning" were considered as being integrated within the students' answer. In terms of the design process, this moved the team back to analysis. The HOD continued with the analysis by proposing an advantage of transitioning to the new practice which justified the new practice (line 3). Therefore, it can be seen that within a team-based design environment, the pickup of a new design frame was not immediate.

**Table 6.1** Seeding a new design frame

| Transcript | Process based | Knowledge based |
|---|---|---|
| 1. HOD | | |
| (a) We have three marks for the approach and reasoning | Analysis—describe current practice | PCK |
| (b) Two marks if they draw six equal parts without explanation | | |
| (c) If they shade on the diagram, that is one mark | | |
| (d) If they give the answer 1/6 and draw, we give one mark, but there is not much explanation, no reasoning | Analysis—identify problem with current practice | PCK (gap) |
| (e) How do we separate the approach and reasoning? | Design—propose new practice | New PCK |
| (f) Because they are two different things | Analysis—justify new practice | New PCK (refine) |
| 2. Teacher Jerry—the whole thing is approach and reasoning | Analysis—justify current practice | PCK |
| 3. HOD—if we separate them, we can target [the skills] clearly | Analysis—justify new practice | New PCK (refine) |

The pros and cons of the current and new frames need to be articulated and rationalized. From the knowledge perspective, it can be seen that the proposal of new design frames (line 1e) was the move that kick-started the creation of new PCK from teachers' design talk. This occurred as the HOD identified problems with their current practice. This kind of process move surfaced the gaps of teachers' current PCK (line 1d) which was refined through further rationalization in subsequent moves (lines 1f and 3).

Table 6.2 shows the rest of this design episode where teachers further developed and adopted this design frame. Following HOD's rationalization in line 3, Teacher Ana picked up the design frame and moved forward to design by first suggesting a "work backward" strategy and then asking a question about the end product that teachers envisioned from the students (line 4). Even though the teachers were discussing a new grading practice which involved PCK, the consideration of students' end product at this juncture shifted the team to consider a new form CK. This is because teachers needed to first develop a new understanding of what constituted good mathematical reasoning for the topic of fractions (CK) before they could translate it into a rubric for grading (PCK).

The interchange between the HOD and Teacher Ana (lines 5–9) shows that frame development could occur through a series of design-analysis turns. In each turn, problems of the new practice identified through analysis led to a movement forward to design where the new practice was further conceptualized to address the identified problem. Each problem that was surfaced indicated gaps in the new CK that teachers were creating, but the design moves continually refined the new CK. As a result, teachers' articulation of the new practice became clearer. This is an example of the reflection-in-action that occurred during design thinking.

**Table 6.2** Developing and adopting a new design frame

| Transcript | Process based | Knowledge based |
|---|---|---|
| 4. Teacher Ana | | |
| (a) We work backwards then | Design—propose design strategy | – |
| (b) What is the reasoning you want them to write? | Design—conceptualize new practice | New CK |
| 5. HOD—to be clear in reasoning is to cut [the diagram] into six equal parts and write down A is how much, B is how much | Design—conceptualize new practice | New CK (refine) |
| 6. Teacher Ana—if I draw and cut, it is the same to me as writing | Analysis—identify problem with new practice | New CK (gap) |
| 7. HOD | | |
| (a) They may show or illustrate their answer | Design—conceptualize new practice | New CK (refine) |
| (b) Must be clear in labeling | | |
| 8. Teacher Ana | | |
| (a) If they just draw, they know how to do it. . . but how to separate [approach and reasoning]? | Analysis—identify problem with new practice | New CK (gap) |
| (b) Because they write a word? | | |
| 9. HOD | | |
| (a) If they can draw, then they must label clearly | Design—conceptualize new practice | New CK (refine) |
| (b) If [they] just draw six [parts], it doesn't tell me anything | | |
| 10. Teacher Ana | | |
| (a) I think they will draw and cut | Analysis—predict outcome of new practice | PCK |
| (b) Some into 6 and some into 12 | | |
| 11. Teacher Ana—but after they draw, they won't explain unless you said to list down the steps. . . show your working or illustration [in your question] | Analysis—predict outcome of new practice | PCK |
| 12. HOD | | |
| (a) Then we add show "your working or your steps" | Design—conceptualize new practice | New PCK |
| (b) This is what our project is [about] | **contextual* | |
| 13. Teacher Ana—then we should split | Analysis—confirm new practice | – |
| 14. HOD—[it will be] easier for us if we need any data | **contextual* | |
| 15. Teacher Jerry—then how do we change [the marking scheme]? | Development—create new practice | New PCK |

Lines 10–12 showed that frame development can also occur when teachers apply their PCK, or their knowledge of students, to predict the potential outcomes of a new practice they were designing. In doing so, the teachers created new PCK to preempt students from misinterpreting the activity instructions (line 12a). Therefore, it can be seen that teachers need to create multiple sources of knowledge in

order to support a change of practice. Such kinds of knowledge can be created either through analyzing the problems of the proposed new practice or through predicting its outcomes.

Lines 12b to 15 showed how the teachers confirmed their adoption of the new design frame. The turning point occurred in line 12b when the focus of their project was reiterated. While the contextual factors related to the teachers' design project had not been overtly mentioned thus far, it nevertheless had substantial influence on teachers' frame adoption once it was mentioned (lines 12b and 14). In fact, it led Teacher Jerry, who was initially hesitant about frame modification (line 2), to move the team forward to the development phase where the new practice will be formally articulated as a marking scheme. This artifact would embody the new CK and new PCK that teachers have created throughout this design episode.

### *6.4.4 Teachers Codesigning with Researchers*

The patterns whereby design frames are being seeded, developed, and adopted differ slightly when teachers were codesigning with researchers. It appeared that new design frames suggested by researchers could challenge the routine practices of teachers. Frame adoption then depended on how both parties rationalize the dissonances between their pedagogical vocabularies.

In this design episode, the group was discussing a lesson in the topic of area that teachers have redesigned using the 5E inquiry approach. Teachers sought to arouse the students' curiosity for the topic through the construction of a K-W-L chart where students would articulate "what I know" (K), "what I wanted to know" (W), and "what I learned" (L) about area. During the first lesson, the students completed the K and W portions of the K-W-L chart. Using these responses, teachers got students to vote for four questions that they were most interested to know, and teachers would incorporate additional activities that allowed students to explore and explain their answers to these questions. At the end of the topic, students would review what they have listed under "what I wanted to know" and reflect about "what I have learned." The strategy of using a K-W-L chart to start off new math topics is a routine that teachers have been practicing with the Grade 3 students. Table 6.3 shows the design episode where this activity was being discussed among the teachers and a researcher.

As this was the first time the teachers were attempting to design according to the 5E model, Teacher Jerry started the discussion by seeking confirmation that the K-W-L strategy had addressed the engage phase of the 5E model (line 1). The HOD clarified that only K and W were involved during engage. Teachers' use of an unfamiliar pedagogy as well as the participation of the researcher led to several analysis moves to clarify the current pedagogy or PK (Lines 2–4).

The researcher seeded a new design frame by proposing a change of practice. Rather than doing the K-W-L chart, the researcher suggested that children could be engaged with another pedagogy—by having them to estimate the area of an object

**Table 6.3** Researcher seeding a new design frame

| Transcript | Process based | Knowledge based |
|---|---|---|
| 1. Teacher Jerry | | |
| (a) For the overview of the lesson, we start with K-W-L | Analysis—describe current practice | PK |
| (b) This is part of engage, right? | Analysis—clarify current practice | PK |
| 2. HOD—engaging is for K and W | Analysis—clarify current practice | PK |
| 3. Researcher—why is K-W-L engaging? | Analysis—clarify current practice | PK |
| 4. HOD | | |
| (a) When we ask them what they know and what they want to know... we give them opportunities to find out more | Analysis—justify current practice | PK |
| (b) So the activity is engaging them into thinking about what they want to know | Analysis—justify current practice | PK |
| 5. Researcher | | |
| (a) If we are talking about engaging, can it be even easier and more direct? | Design—propose new practice | New PK |
| (b) For example, if the child is sitting at the table, he can estimate the area of their desk | Design—propose new practice | New PCK |
| 6. Teacher Belinda—we give them a task | Analysis—clarify new practice | New PK (refine) |
| 7. HOD—so we give them a task | Analysis—clarify new practice | New PK (refine) |
| 8. Researcher | | |
| (a) Yes | Design – conceptualize new practice | New PCK (refine) |
| (b) Ask them right from the start if they know how big the area of the table is | Design – conceptualize new practice | New PCK (refine) |
| (c) That is faster and more concrete for the children | Analysis—justify new practice | New PCK (refine) |
| 9. HOD | | |
| (a) We are starting with K-W | Analysis—describe current practice | PCK |
| (b) You mean they are having that question in the K-W? | Analysis—clarify new practice | New PCK (refine) |
| 10. Teacher Jerry—that is in the later part | Analysis—justify current practice | PCK |
| 11. Researcher—in explore, engage, or elaborate? | Analysis—clarify current practice | PCK |
| 12. Teacher Jerry | | |
| (a) Explore | Analysis—describe current practice | PCK |
| (b) In the later part . . . lesson 4 | Analysis—describe current practice | PCK |
| 13. HOD—do you mean to do that during K-W? | Analysis—clarify new practice | New PCK (refine) |

that they were familiar with (lines 5a and 5b). This design move introduced new PK to the team and the researcher's example in line 5b provided teachers with an example of what the activity may look like, which is an instance of new PCK. Teachers appeared to be perturbed by this new design frame because they have planned for such kinds of hands-on tasks at a later phase when students explore the concepts (lines 9, 10, and 12). While the researcher suggested that teachers abandon the use of the K-W-L chart, the teachers had yet to arrive at the same understanding because the HOD clarified if this was part of the K-W-L activity (line 13).

Table 6.4 shows that frame development occurred as the teachers and the researcher sought to reconcile their interpretation of what engage in the 5E model meant. The researcher refined the design frame in lines 14a and 14d by mentioning the need to help students connect learning content to the real world. It was a more sophisticated expression of the new PK and new PCK he initiated in lines 5 and 8. This reframing by the researcher moved teachers to analyze if this aspect was being addressed in their current design (lines 15 and 16).

In line 17, it appeared that the HOD had picked up the suggestion for an alternative pedagogical approach to K-W-L. Her interpretation of the researcher's suggested activity had developed from that of a "task" (line 7) to that of a "scenario" (line 17). Whereas a "task" may have suggested hands-on activities for students' exploration, a "scenario" indicated a problem that students could work on which might have seemed closer to the original K-W-L activity. This interpretation refined the team's working vocabulary of PK (line 17) which also led the researcher to emphasize that engage could also be used to address students' motivation and interest for learning (line 18a). In so doing, the researcher pointed out a gap in teachers' current PCK (lines 18b–c). Having understood the researcher's pedagogical intent, the HOD was then ready to evaluate its viability. In lines 19 and 21, the HOD identified a gap in the researcher's suggested PCK where the children's lack of prior knowledge for area had to be considered. The researcher then refined the design frame by explaining that the scenario was a real-world context used to introduce the concept of area to students (line 22).

Table 6.5 shows that the design frame was fully adopted when teachers were able to establish linkages between their current pedagogical practices and the new practice proposed by the researcher. In line 23, the HOD sought a compromise of integrating the scenario with the K-W-L activity. The researcher refined this idea in line 24 by suggesting concrete examples of how the big ideas related to area could be elicited from the students' K-W-L to help them make real-world connections (lines 24b–d). This reframing closed the gap of understanding between the researcher and the HOD who further reiterated and elaborated the researcher's idea (lines 25 a–d). Yet, there appeared to be still some concern that it is demanding too much from the students as the HOD sought to test if her suggestions were acceptable (line 25e–f).

In a further refinement of the design frame, the researcher connected to the teachers' pedagogical vocabulary by suggesting concrete examples of how different aspects of the scenario exploration could be integrated within the KWL activity (lines 26c, 26i, and 26j). This refinement found congruence with the HOD who

**Table 6.4** Frame development

| Transcript | Process based | Knowledge based |
|---|---|---|
| 14. Researcher | | |
| (a) In any lesson, you need to connect it to reality | Analysis—justify new practice | New PK (refine) |
| (b) For example, how big is your table? | | |
| (c) How do you express it? | | |
| (d) One of the difficulties [for students] when learning about area and perimeter is to find the reference to real life | | New PCK (refine) |
| 15. HOD—is that in elaborate when they do deduction? | Analysis—clarify current practice | PCK |
| 16. Teacher Jerry | | |
| (a) That will come later | Analysis—justify current practice | PCK |
| (b) They will count a small area using square units | | |
| (c) We will start with K-W-L of what they know about area | | |
| 17. HOD—you mean we can actually start with a scenario? | Analysis—clarify new practice | New PK (refine) |
| 18. Researcher | | |
| (a) Engage is for motivation and interest | Analysis—justify new practice | New PK (refine) |
| (b) Imagine if you are a student and your teacher comes in today and says, "We are studying about area and perimeter" | | PCK (gap) |
| (c) How do the children know the connection of area and perimeter to themselves? | | |
| 19. HOD—there is no context for the children to understand the content | Analysis—identify problem with new practice | New PCK (gap) |
| 20. Researcher | | |
| (a) Everybody knows something about area—it is just whether you know it mathematically | Analysis—justify new practice | New PCK (refine) |
| (b) You can start by asking them how big their desk is | Design—conceptualize new practice | |
| (c) Ask them why does it matter? | | |
| (d) [For example,] if you buy a house, the total area is 90 square meters... is it big enough for you with five siblings? | | |
| (e) By doing something like this, the concept of area will come alive to them | Analysis—justify new practice | |

(continued)

**Table 6.4** (continued)

| Transcript | Process based | Knowledge based |
|---|---|---|
| 21. HOD | | |
| (a) The children have not touched on area before | Analysis—identify problem with new practice | PCK |
| (b) Is it a bit too deep for them? | | |
| 22. Researcher | | |
| (a) No. . . just the idea of, for example, how big the table is and how it affects the arrangement of the classroom | Analysis—justify new practice | New CK |
| (b) That's where we start on area—it has something to do with your everyday life | | New PCK (refine) |

**Table 6.5** Frame adoption

| Transcript | Process based | Knowledge based |
|---|---|---|
| 23. HOD—would we be able to do this scenario with the K-W? | Design—conceptualize new practice | New PCK (refine) |
| 24. Researcher | | |
| (a) Yes | Design—conceptualize new practice | New PCK (refine) |
| (b) Then you can elicit responses such as "area is the size of things" | | |
| (c) But this is not mathematical | | |
| (d) So, then how do we calculate the area? | | |
| (e) Once you make this connection to real life, then learning becomes meaningful to the children | Analysis—justify new practice | |
| 25. HOD | | |
| (a) We can engage with a scenario for the children to know about area, what it is and how to measure it | Design—conceptualize new practice | New PCK (refine) |
| (b) From there, we ask them to think about what they know and what they want to know about area | | |
| (c) Don't have to go further | | |
| (d) Then they can go in-depth and explore how to connect to real life, what is 1 $cm^2$ or 1 $m^2$ | | |
| (e) Is this more feasible? | Analysis—clarify new practice | |
| (f) Is it too much if we address everything in the scenario? | | |

(continued)

**Table 6.5** (continued)

| Transcript | Process based | Knowledge based |
|---|---|---|
| 26. Researcher | | |
| (a) What I am suggesting is an overall idea | Design—conceptualize new practice | New PCK (refine) |
| (b) We engage by asking where does area appear in your life | | |
| (c) Explore is what you want to know | | |
| (d) You set a context | | |
| (e) I want to know how big is my room, my bed, my table, the classroom, the school… | | |
| (f) There are a lot of areas they can talk about | | |
| (g) Then, you can ask them how would you write how big it is | | |
| (h) Then they will realize that expressions like "big," "small," "bigger than yours" are not mathematical | | |
| (i) In math, we learn to express area accurately. This is what you will learn | Analysis—confirm new practice | |
| (j) Then you would have explored. Then you can go on to explain and elaborate | Design—conceptualize new practice | New PCK (refine) |
| (k) You bring in the idea of units, length, and breadth, have the students to measure the area of their rooms, and suggest what they might do if they were out of space | | |
| 27. HOD | | |
| (a) If we do this, we need to restructure the specific instructional objectives | Analysis—gap in current practice | New PCK (refine) |
| (b). We will need to differentiate the learning objectives by different profiles of students | | |
| (c) What you are saying is that to engage, you can give them a scenario as an example instead of starting with K-W | | |
| (d) Then they can connect to what they know about area and what they want to know about area | | |
| (e) In our current design for engage, the engaging of motivation and interest is not there | | New PK (refine) |
| (f) Am I right? | | |
| 28. Researcher | | |
| (a) Yes | Analysis—justify new practice | New PCK (refine) |
| (b) For engage, we want to drive at interest and motivation, the connection to real life | | |
| (c) Once you engage, there will be a context for the students to talk about K-W-L | | |

confirmed the adoption of the new practice by suggesting an amendment of the lesson objectives (line 27a and 27b). She further commented that this practice addressed a gap in their current design where they did not fully consider the motivation and interest of students (line 27e).

As the team co-constructed a new frame for approaching the engagement of students with an inquiry-based pedagogy, a new practice was developed. From the process perspective, the new practice was created through the interplay of analysis-design turns that were more heavily focused on analysis to clarify and justify the new practice. The current practice of K-W-L was improved by having students engage with a new mathematical concept through a real-world scenario before reflecting on what they would like to explore further. In terms of knowledge, this new practice came about through the creation of new forms of PCK. However, to successfully adopt the change, teachers had also to create new forms of PK where they deepened their understanding of what engage meant. From viewing engage as mainly to stimulate children's curiosity, teachers appreciated that it also had a motivational aspect where students were engaged through appreciating the personal relevance of what they were about to learn.

It can be seen that there are complementary relationships between teachers designing independently and codesigning with researchers when working on pedagogical change. Researchers can potentially challenge existing pedagogical practices in ways that teachers would not when teachers are designing without researchers. However, teachers' strong contextual knowledge of school practices and policies provides the needed assessment for successful implementation. The contextual push for this project, though not overtly mentioned, remains a strong motivator pushing teachers to consider pedagogical change in both modes of lesson design.

## 6.5 Pedagogical Transformation Through Design Framing

The preceding examples show that pedagogical transformation in teachers' design of mathematics lessons presents itself as a wicked problem when teachers need to create new instructional practices. In a team-based design context, transformations occurred when the team was able to seed new design frames and develop it to a point where it could be affirmatively adopted by the team members. Unlike product development where designers tend to create and recreate frames (Schön, 1983), it appeared that lesson planning involved teachers considering the various factors involved in orchestrating the instructional activities efficiently by balancing the demands of both context and students. In group-based design, the "talk back" from the design situation occurred as teachers raised various problems with the proposed practice and used their routine expertise to predict the outcomes of the suggested new practice. The reflection-in-action highlighted by Schön occurred as teachers engaged in iterative analysis-design turns during which knowledge is created to refine the practice suggested by the design frame.

Design is a process of social co-construction. Both examples showed that during lesson planning, design occurred when an instructional leader seeded and developed the design frame. Design thinking progressed when team members are able to spur the leader with questions to push the development of design ideas. However, several differences can be observed in the design processes used by teachers. When designing among themselves, there were no design moves to clarify ideas because the teachers were conversing on common contextual vocabulary. Teachers largely engaged in a rehearsal of the new practice by reviewing potential problems as well as their predictions of students' reactions. This occurred in quick succession throughout a series of iterative analysis-design turns during which the idea was being developed. In this aspect, a design environment that is encouraging for teachers to elicit and share their routine expertise is important for ensuring design quality. This is because in study of designers, a good design practice is for designers to allow for uncertainty in design situations by playing with ideas and not seeking to pin down design solutions prematurely (Cross, 2011). As teachers designed among themselves, it can be seen that context played a key motivating factor in pushing teachers ahead the instructional design stages. One danger in such kinds of design situations is therefore the premature confirmation of ideas without sufficient time for these to emerge. In our study of teachers engaged in the design of mathematics lessons, it was found that when they focused too much on contextual considerations, this can overtake their focus on lesson design (Koh, Chai, & Tay, 2014). Therefore, in teacher-only design teams, the instructional leader plays the critical role of maintaining the tempo of the design process by knowing when context can be effectively introduced to motivate the adoption of new design frames without curtailing teachers' ideation prematurely.

When designing with the researcher, it can be observed that the role of instructional leadership was subtly shifted to the researcher who provided the team with a new pedagogical language. In such a context, many design moves were used by the teachers to clarify both the old and new design frames. This finding mirrors the kinds of design tensions described by Penuel, Roschelle, and Shechtman (2007) where the pedagogical understandings between the teachers and researchers need to be bridged during codesign. In our example, the researcher contributed new vocabularies that perturbed the teachers' current pedagogical understanding of inquiry-based learning. Co-construction between the teachers and the researcher could only be carried out meaningfully when the gaps between their pedagogical understandings were bridged. Multiple moves to clarify the new practice were initiated by the teachers. As the researcher clarified and justified the new practice with lesson examples, his articulation of the envisioned pedagogical knowledge also became clearer. The new practice therefore emerged through these kinds of iterative analysis-design turns. This is contrasted with the analysis-design turns when teachers carried out design among themselves where the rehearsal of problems expected with the new practice was used as a basis of analysis. Researchers or members outside teachers' normal context can therefore bring in pedagogical vocabularies as new design frames. In this example, the final practice adopted was an amalgamation of both the teachers' and researchers' suggestions. This suggests that effective management of the epistemic leaps involved in such kinds of perturbations is an important aspect to consider during teacher-researcher codesign. It appeared that a gradual change of instructional practices may be a more manageable way of ensuring a reasonable epistemic leap for teachers in this study as they sought to balance the effects of this change on the different academic profiles of students.

It can be seen that the influences of teachers' design framing are complex and multifaceted. In fact, the design of instruction can be considered as occurring in multiple layers, each with its unique sets of considerations (Gibbons, Botturi, Boot, & Nelson, 2008). The emergent nature of design makes it difficult to be routinized, and this may constitute a problem for teachers. Through the management of design framing, teachers can potentially transform contextual constraints into opportunities. This is a kind of design capacity that teachers need to build as this has been identified as a third-order barrier against teachers' ability to enact educational innovations (Tsai & Chai, 2012). It is therefore important to further understand the factors that facilitate teachers to develop and modify frames when designing educational innovations, especially how they make the epistemic leaps beyond their routine expertise. This is a critical challenge confronting in-service teachers (Marra, 2005).

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# Chapter 7
# Developing and Evaluating Design Thinking

## 7.1 Introduction

In the previous chapters, we have discussed the role played by design in education and explored empirical examples of students', preservice teachers', and in-service teachers' engagement with design thinking. These examples show design to be a complex process whereby the solutions to design problems emerge from continual idea generation and improvement. From a utility standpoint, it may seem apparent to evaluate just the quality of the products designed. However, the previous chapters show that the quality of design thinking is also dictated by *how* the design process is being carried out. In team-based design especially, the quality of design talk influences the design process and, consequently, its outcomes. How design thinking can be developed is therefore an issue warranting further consideration. The evaluation of design thinking in education also remains challenging at present moment largely because validated design-thinking assessments still do not exist (Razzouk & Shute, 2012).

In this chapter, we review the conceptions of design-thinking competencies in educational contexts and propose how it can be developed for teachers and students. We also explore methods for evaluating design thinking from designers' perceptions, design process, as well as educational products designed. Implications for the development and evaluation of design thinking for teachers and students will be discussed.

## 7.2 Development in Design Thinking

The lack of agreement of what constitutes design thinking complicates the issue of its development (Razzouk & Shute, 2012). This led Hoadley and Cox (2009) to call for a proper definition of what is meant by the knowledge to design. With respect to



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the design of learning technologies, these authors identified different kinds of critical knowledge including the knowledge of design stages and the knowledge of design principles and techniques. These correspond to Razzouk and Shute's proposal of design-thinking competencies as comprising the skills for locating resources, undertaking iterative design cycles, and designing for innovation. Razzouk and Shute emphasize the need to develop design-thinking behaviors such as persistence and adaptation which largely correspond to Hoadley and Cox's idea of design psychology, or the knowledge to manage problems encountered during design work. In addition, Hoadley and Cox also propose other competencies such as the knowledge of the values and philosophies undergirding designers' design choices, knowledge of patterns across design problems, and knowledge of the roles that designers can play within a design team. Therefore, design thinking not only involves the knowledge of design problems, design processes, and practices, it also embodies the dispositions to undertake design.

### *7.2.1 Design Practices of Expert and Novice Designers*

One way of understanding how designers develop is to study the differences between novice and expert designers. While the theoretical studies described in the previous section attempt to categorize the facets of design knowledge, empirical studies of designers have focused on the design practices of novice and expert designers. Dorst and Reymen (2004) propose that design expertise can be broken into several levels where designers achieve "proficiency" when they are able to prioritize design issues and "expertise" when problem solving and design reasoning become more automatized. From studies conducted in the fields of engineering and architecture, one key difference observed between novice and expert designers is their approach to problem solving. Expert designers tend to use a breadth-first strategy where they identify problem subcomponents before considering the subcomponents in detail, whereas novices use a depth-first strategy by doing detailed problem solving for one subcomponent before moving to the next (Cross, 2004; Ho, 2001). Another difference is that expert designers tend to mentally evaluate their proposed solutions before implementation, especially for conflicts between its subcomponents. Novices, however, tend to test their ideas through trial and error during implementation (Ahmed, Wallace, & Blessing, 2003; Ho, 2001). A third difference between novice and experts is that experts tend to have clear rationales undergirding their design decisions, whereas this did not emerge among novice designers (Ahmed et al., 2003). Finally, expert designers possess greater repositories of problem solutions from their design experiences. Therefore, they tend to adopt inductive methods of problem solving where solutions from previously encountered problems are being prescribed as solutions to the problems on hand (Lloyd & Scott, 1994).

### 7.2.2 *Design Dispositions of Expert and Novice Designers*

Another issue to consider in design education is the importance of developing the dispositions that are amenable to supporting design work. This is because certain dispositions were found to better characterize expert designers. Using a grounded analysis of 14 designers who were involved in product design, branding design, and training design, Michlewski (2008) found that designers tend to be comfortable with analyzing and synthesizing, turning ideas into concrete solutions, embracing open-ended situations without predetermined outcomes, being empathetic to the needs of clients and peers, and engaging in exploration. These results correspond with Cross (2011) who found that design thinking is more effectively displayed by designers who are comfortable with managing uncertainty, taking calculated risks, and learning from failures. In addition, Cross found that expert designers tend to be more confident of analyzing problems from personal judgment rather than accepting existing solutions. An open-mindedness to embrace inputs from multiple disciplines and sources is another characteristic of expert designers (Lawson, 1997). These studies conducted in fields such as industrial design and architecture show that design dispositions could be related to design practices that designers adopt. There is some supporting evidence for this observation in the field of education. Our recent survey of 201 Singapore teachers found that their perceptions of design dispositions had positive influence on their perceptions of practices for designing technology-integrated lessons (Koh, Chai, Hong, & Tsai, in press).

It is important to consider both the design dispositions and design practices of teachers and students. Obviously, design involves designers drawing upon the design knowledge described by studies such as Hoadley and Cox (2009) and Razzouk and Shute (2012) to support their design practices. Design thinking is therefore developed when teachers and students are supported to translate their design knowledge into the desired design practices. It is also needful to help teachers and students develop the kinds of dispositions that are amenable for design work as it could be a factor influencing their ability to develop the desired design practices.

## 7.3 Methods for Developing Design Thinking

A common method used to develop design thinking in the education of professionals such as architects is through studio-based strategies where novices work alongside experts in design projects across a period of time. Novices typically develop design knowledge through the feedback and guidance of the expert or via personal observation and reflection. This is akin to conceptions of cognitive apprenticeship where skills and knowledge are being learned in situated contexts (Brown, Collins, & Duguid, 1989). In the studio-based approach which emphasizes learning through experience and apprenticeship, novices largely experience the design process, but there may not be structured instructional experiences to help them explicate specific design knowledge and design reasoning from their experiences. In the end, novices' design thinking may fail to develop beyond the notion of "creative design as a black box" (Oxman, 1999, p. 106).

Beyond these professional courses, design projects are used more generally to provide a means to learn specific subjects or professional knowledge. Examples of such kinds of design experiences are projects for teachers to learn the processes for designing specific kinds of ICT lessons (e.g., Koh & Divaharan, 2011), or the engagement of students in design projects to learn subject-specific knowledge as described in Chap. 4. In these educational studies, how learners are being supported to develop design thinking throughout their engagement with the design projects tend not to be explicated thoroughly. To better foster design thinking, we propose the need to consider how design experiences are being designed as well as how design reasoning and design dispositions can be fostered during design projects.

### *7.3.1 Designing Learners' Design Experience*

In the field of education, teachers, for example, are taught specific models of lesson design that explicate the steps of the process (e.g., Heinich, Molenda, Russell, & Smaldino, 1999). As detailed in Chap. 6, actual design work rarely proceeds in the systematic and defined steps outlined in these lesson design models. More often than not, teachers need to integrate information related to each design step as they design lessons. Design work, therefore, has the characteristic of complex learning described by Van Merriënboer, Clark, and De Croock (2002) which involves the integration of different composite skills during task performance. For such kinds of learning, these authors propose that learners need to experience multiple cycles of task performance where each cycle confronts them with increasingly complex versions of the task.

Design patterns describe the common solutions to common problems faced in a field and was first explicated by Alexander (1964) for architectural problems. It provides the language structure for design practice within a field (Gibbons, Botturi, Boot, & Nelson, 2008). In recent years, researchers have started to formulate design patterns that can guide the design of educational interventions. Using an example for the design of networked learning, McAndrew, Goodyear, and Dalziel (2006) proposed that considerations of its learning outcomes, learning activities, place of execution, and community can be used to articulate the design patterns for various contexts. For example, McAndrew et al. suggested that when designing networked learning, a basic pattern would be to consider the interactions between learning tasks, learning communities, the spaces for learning, and how these influence learning outcomes. Knowledge of design patterns can help designers solve problems more effectively and is identified by Hoadley and Cox (2009) as an important source of design knowledge for educational designers. Therefore, design projects can firstly be structured to expose learners to the important design patterns in their respective fields of practice. Drawing reference from Van Merriënboer et al. (2002), instructors firstly need to purposively select the kinds of design patterns that they want learners to experience and structure each as a design task. The second step is then to carefully sequence learners' design tasks so that they can experience design problems of increasing complexities in gradual succession.

A basic structure for helping learners to develop context-based design knowledge is laid when design tasks are purposively selected and sequenced using design patterns. We can then move on to facilitate learners' understanding of the design thinking that undergirds each design pattern.

### *7.3.2 Developing Understanding of Design Thinking*

It is important that the *doing* of design is supported by an understanding of the *thinking* that drives design decisions (Oxman, 1999; Shambaugh & Magliaro, 2001). In the field of education, studies related to the understanding of thinking are largely found in the area of teacher education where the use of reflection supports teachers to develop knowledge about their teaching practices (Conway, 2001). It is believed that teachers can be more competent in solving problems related to their teaching practice when they develop the competencies of reflective practitioners as described by Schön (1983). Nevertheless, in practice, reflection activities tend to focus on teachers' articulation of beliefs, whereas the review and critique of teaching practices appeared to be weak (Marcos, Sanchez, & Tillema, 2011). When explicating how Schön's conception of reflection-in-action can be applied to teachers during lesson design, Wieringa (2011) visualized it as a means of helping teachers to understand the kinds of teaching knowledge that they can generate through lesson design. This thesis is supported by Jang and Chen (2010) who found that when preservice teachers are guided to reflect upon what they learned from the design and implementation of specific ICT lessons, they developed deeper appreciations of the kinds of technology-integrated pedagogies that better supported different kinds of science content. Therefore, reflection activities must be directed towards helping designers to develop knowledge of the conditions for using different kinds of design solutions. Design thinking is therefore developed as designers are being scaffolded to rationalize their design decisions and to consolidate their repository of design solutions through reflection.

Design thinking can also be developed when the cognitive structures employed by designers during design are being explicated (Oxman, 1999). One way of scaffolding reflection activities is through tools that help designers to represent their design decisions. In design fields, it is typical for designers to externalize their design thinking through the development of artifacts such as prototypes or model drawings (Cross, 2004; Lawson, 1997). By analyzing their artifacts, designers are able to develop their design thinking by reflecting upon the efficacy of their design decisions. As described in Chap. 4, digital tools can be used to support students in this aspect. When teachers create and refine their lesson conceptions using systems such as the Learning Activity Management System (LAMS) (Cameron, 2006), they can potentially use these to support the reflection of their design decisions and processes.

### *7.3.3 Developing Design Dispositions*

Whether designers are born or made remains a debatable issue. Nevertheless, our studies of teachers show that their perceived confidence in design dispositions had significant positive influence on their perceived confidence for ICT lesson design practices (Koh et al., in press). While design thinking is associated with the practices and strategies employed to design, designers' dispositions are affective considerations that could influence how they approach design. For example, teachers' beliefs could constitute greater barriers for the integration of ICT as compared to barriers related to the lack of resources or equipment (Ertmer, 2005). In teacher training, strategies such as instructor modeling and hands-on practice are important for building teachers' acceptance and confidence for using ICT tools (Brush et al., 2003; Koh & Divaharan, 2011). Koh, Chai, and Lee (2013) found that multiple design cycles are useful for influencing teachers' confidence to design. For designers such as teachers and students who may have apprehensions towards design, these strategies may be useful in helping them to build confidence for engaging in design work. Across time, this may have positive influence in changing their dispositions to design.

In summary, several methods appear to be important for developing design thinking. There is a need for clear articulation and sequencing of design problems to promote recognition of design patterns, multiple opportunities to design, reflection activities that help designers to create understanding of their design decisions as well as instructional strategies to support the development of confidence, and dispositions for design work.

## 7.4 Evaluating Design Thinking

The evaluation of design thinking is a means to characterize varying degrees of design expertise. Given the nature of design thinking, it appears that a multi-prong approach needs to be adopted when seeking to evaluate its efficacy. This is because design outcomes are determined by the design processes adopted. Yet, designers' perceptions of confidence with design practices could shape how they interpret design problems as well as the kinds of design processes they adopt. The three aspects of perceptions, processes, and outcomes are therefore important for understanding and developing design thinking.

### 7.4.1 Perceptions of Design

Designers' perception of their design practices can be used to provide insights about the extent they are able to think like designers. In a study of 32 undergraduate design students, the measures of design (MOD) protocol was used to characterize their design conceptions (Carmel-Gilfilen & Portillo, 2010). This protocol comprises nine essay questions to elicit comments about respondents' perceptions of areas such as design processes, project perceptions, and design evaluation. Using trained raters, the respondents' answers were rated to determine the extent to which they were what Perry (1968) described as dualistic thinkers who were more comfortable with defined options for design or multiplistic thinkers who preferred exploring multiple options and challenging constraints. The study found that multiplistic thinkers tend to have better studio performance.

Such general classifications of design expertise have not been used in educational studies where surveys are more often being used. Koehler and Mishra (2005) studied the design behaviors of four faculty and 14 graduate students through progress surveys as they designed online learning courses. The 33 Likert-scale items of the survey examined the respondents' perceptions of their course experiences with respect to the learning environment, time and effort spent on design project, learning and enjoyment, group functioning, beliefs about online education, and the extent to which the respondents considered technological, pedagogical, and content issues both individually and as a group. It was found that the groups progressed from initial discomfort with the open-endedness and messiness of the design project to finding it a fulfilling learning process. Consequently, the respondents also reported improved perceptions about being able to consider technological, pedagogical, and content issues integratively as they design. Obviously, such kinds of evaluation can provide in-depth understanding of the shifts in learners' design experiences and are informative for helping instructors to support the stress and strains that learners experience during design. Nevertheless, such kinds of measurements are course specific, and there is limited scope for generalization and comparison across different course contexts.

Koh et al. (in press) developed an 18-item survey to assess teachers' perceptions of their design dispositions, lesson design practices for supporting constructivist-oriented ICT integration, and knowledge of ICT integration or TPACK. The survey was validated with confirmatory factor analysis with 201 Singapore teachers. Structural equation modeling showed that teachers' perceptions of ICT lesson design practices had stronger positive influence on their TPACK than their design dispositions. These findings suggest that teachers' confidence of their TPACK is better enhanced by raising their confidence for engaging in the ICT lesson design practices that support constructivist learning rather than influencing their design dispositions. The findings also imply that ICT education for teachers needs to focus on the methods that develop teachers' confidence to engage in the desired lesson design practices. This validated survey lends itself to easy replication across course contexts where respondents' ratings could be measured and compared. Yet, it still suffers from the limitation common to self-reported data—that perception may not be representative of practice. Design perceptions alone cannot fully characterize design expertise.

### *7.4.2 Design Process*

The importance of studying design processes has been recognized, but the challenge faced is in its representation and interpretation. To characterize the design processes undertaken by groups of graduate students who were designing lessons for e-learning, Koehler, Mishra, and Yahya (2007) used content analysis to map their design discussions. By tabulating the content, the length, and the turns of conversation within these discussions, these authors found that their design processes were influenced by the presence of different group members as well as the interpersonal dynamics within the team. Koh, Chai, and Tay (2014) also used content analysis to code the design talk collected from three teacher groups throughout a school year with respect to the issues discussed. They used chi-square analysis to examine the statistical differences among the coded categories and found that when logistical issues dominated teachers' talk, it curtailed the group's propensity to engage in lesson design. Furthermore, the facilitators and profile of group members influenced the extent to which the group was able to engage in productive design.

The two studies described so far show attempts to understand the process of design thinking in educational contexts. Through content analysis, some insights have been gained regarding the kinds of design issues and the processes of group-based lesson design. Nevertheless, the characterization and identification of effective design processes remain challenging. In design fields, the technique of linkography has been used in protocol analysis to examine how designers generate ideas (Goldschmidt & Weil, 1998). This is done by breaking down design conversations into design moves which are defined as steps that advance the design situation (Goldschmidt, 1995). Linkographs are then created by determining if there are backlinks (connections to previous moves) or forelinks (connections to subsequent moves) behind design moves. Graphical representations of the design process can then be made, and link indexes comprising ratios between the number of links and number of moves can be computed to describe design activity. As compared to the statistical approach adopted by Koh et al. (2014), linkography has the advantage where the number of designers and the quantity of talk contributed by each designer does not affect the frequency of moves coded (Kan & Gero, 2008). This is because linkographs are concerned with discerning important moves and the relationships among moves. While linkographs provide some promise for the representation and evaluation of design processes, the development and interpretation of link indexes with respect to different kinds of design activities are still in progress (Kan & Gero, 2005). It nevertheless is a method that can provide some insights about how the productivity of the design can be characterized.

### *7.4.3 Design Outcomes*

In fields such as product design, design outcomes are typically apparent through information on customer satisfaction or product sales. In the field of education where design tends to be a means of learning professional or content knowledge, the design outcomes to be measured are tied to the educational aims of lesson activities. For example, for students, this could typically comprise their understanding of content knowledge and perhaps the display of important social and collaborative skills if the design project is group based. Therefore, evaluations of design outcomes in such cases are contextually driven. A larger aim of learning by design is content mastery. At times, student's exam performance can also become an important indicator of design outcomes.

In terms of teachers, design outcomes can be assessed through ratings of their lesson plans or the implementation of the designed lessons. Rubrics provide some form of design goals and can also be used as a means to help teachers steer their design decisions towards the desired kinds of design practice. An example can be found in Angeli and Valanides' (2009) guidelines for assessing the design of ICT lessons. These authors assert that the integration of ICT tools have more impact when used with content areas that are challenging for students. Their guidelines therefore emphasize the need to select ICT tools by identifying the kinds of content transformations it can potentially bring to the lesson. Another example can be found in Collins and Halverson's (2010) rubric that was described in Chap. 5. This rubric describes the kinds of activities associated with didactic- and constructivist-oriented lessons. It allows one to assess the extent to which teachers are able to conceptualize constructivist-oriented lessons. A third example of lesson design rubrics is Koh's (2013) articulation of the guidelines for assessing the five dimensions of meaningful learning (active, constructive, intentional, cooperative, and authentic) with ICT developed by Howland, Jonassen, and Marra (2012). These dimensions emphasize that meaningful learning occurs through learners actively directing their own learning by manipulating data and ICT tools to construct meaning either individually or in a group. The rubric provides guidelines of how each dimension can be implemented at different levels. It establishes guidance for the design of ICT lessons by suggesting that teachers can choose to implement one dimension (e.g., intentional learning) at a higher level than another (e.g., collaborative learning). One advantage of using rubrics to assess lesson design is that the same rubrics can also be used to guide the assessment of lesson implementation. In this way, the chain of design activities from design to implementation can be assessed consistently.

In summary, design thinking has been evaluated from various facets including designers' perceptions, the processes they go through, as well as the outcomes of design. In educational contexts, there appear to be no commonly accepted methods for evaluating these three aspects.

## 7.5 Issues and Challenges

From the preceding review, it appears that no uniform guidelines are available to inform the development and evaluation of design thinking. One reason for this difficulty is the contextualized nature of design which makes it challenging to prescribe a universal definition of design thinking. This results in several issues and challenges. Firstly, how design thinking can benefit the education of teachers and students needs to be given further consideration. While design thinking remains a fairly new conception in the field of education, it can be seen that there are more studies related to teachers' design processes rather than that for students. For teachers, design projects are clearly used as means for them to develop their professional knowledge of teaching. The aims for students' involvement in design projects tend to be more varied as it could be invariably linked to mastery of subject matter. Therefore, the field needs to develop more contextualized definitions of design thinking for these two groups. In addition, the design competencies proposed by Hoadley and Cox (2009) and Razzouk and Shute (2012) need to be further interpreted within various subject areas and disciplines, especially to identify the kinds of design knowledge that may be more critical for teachers and students.

Secondly, there are obvious differences between the design practices and design dispositions of novice and expert practices and design dispositions of novice and expert designers. Knowing how to design is an important competency contributing to design outcomes. While design projects are being used as a means for learning, the processes to effectively scaffold these design activities remain unclear. We suggest that this could be developed through the purposive design of design problems and how these are being experienced, the overt guidance of teachers and students to reflect and articulate their design reasoning, as well as the incorporation of instructor modeling to develop confidence and dispositions for undertaking design work. These suggestions provide some broad guidelines for how the design experiences of teachers and students can be better supported. Yet, much work remains in articulating how these guidelines can be implemented within specific disciplines and subject areas.

The methods for developing design thinking as well as its methods for evaluation are intricately related. Both aspects are important for improving design practice. This review shows that to fully understand the development of design thinking, evaluation needs to be undertaken from multiple perspectives including perceptions, processes, and outcomes. We have also presented examples of how each could be evaluated. It is recognized that further work still needs to be done to develop and validate these evaluation instruments. A challenge involved in adopting such a multi-prong approach is the time and effort involved. Therefore, it is needful to consider how the evaluation of design thinking can be used to inform its development strategies. In this way, the kinds of evaluation to be adopted can be better selected and prioritized.

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# Chapter 8
# Conclusion

## 8.1 What Is Design Thinking in Education?

Design thinking is increasingly being embraced in fields such as product design, engineering, and business as a strategy for enhancing innovation and creative practice (Dorst, 2006; Dym, Agogino, Eris, Frey, & Leifer, 2005). In the field of education, design epistemology, or the means of knowing whereby ideas are being generated and worked upon to solve practical problems, has been proposed as an extension of personal epistemology (Tsai, Chai, Wong, Hong, & Tan, 2013). Design thinking, or the cognitive activity underlying design work, supports the development of design epistemology in both students and teachers. From our studies, we observe several characteristics of design thinking when used in educational contexts. Firstly, it emerges out of social processes where ideas are being generated, clarified, and improved. Our studies of children and teachers in Chaps. 4, 5, and 6 show that collaboration is an important foundation for design work in educational contexts. Secondly, design thinking involves knowledge creation. Our study of in-service teachers in Chap. 6 shows that design thinking is more closely characterized by iterative cycles of reflection-in-action as suggested by Schön (1983). As teachers designed their lessons in each cycle, they used their existing classroom knowledge to make reasoned evaluations of their current design ideas in order to improve upon them. Our findings in Chap. 6 also show a third characteristic of design thinking to be the absence of well-ordered and well-defined design stages as observed by Summerville and Reid-Griffin (2008). It is rather a process whereby social exchanges move ideas forward and backward until these are fully accepted by the team. While the application of design thinking in the field of education is still at a rudimentary stage, we suggest several ways where it can potentially be exploited to benefit students and teachers.



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## 8.2 Uses of Design Thinking in Education

### *8.2.1 For Students*

Our review in Chap. 4 shows that design work has been introduced in K–12 contexts through the design of digital artifacts in programming environments, learning by design in science, design and technology courses emphasizing product design, and the design of theories through knowledge building. The case studies in this chapter show that when students are engaged in designing solutions for open-ended real-world problems, they are being challenged to integrate disciplinary knowledge, think critically to analyze problems, and engage in metacognitive evaluation to determine how their work processes could be improved. Interestingly, the students adopted various kinds of technological tools to design their floor plans, some of which were outside those recommended by their teachers. Team-based design also provided the context for students to evaluate their social-cultural competencies. Therefore, it can be seen that design work situates students in contexts that require them to demonstrate the various twenty-first-century learning dimensions described in Chap. 3. Their design thinking is encapsulated in the cognitive, metacognitive, social-cultural, productivity, and technological approaches used to solve design problems.

Unlike traditional learning which requires students to execute the prescribed set of knowledge and skills planned for particular lessons, design problems challenge students to apply a whole range of content knowledge and social, technological, and metacognitive skills, some of which may be beyond the lesson requirements. For students, therefore, design thinking can be used as a means to support interdisciplinary learning and to build their dispositions for complex problem solving. Such experiences play an important part in preparing students for the twenty-first-century workplace.

### *8.2.2 For Teachers*

Our studies in Chaps. 5 and 6 show that design thinking can be used as a means for teacher development. Shulman (1986) argued that teachers' professional knowledge, or pedagogical content knowledge, can be observed in their ability to tailor particular instructional solutions for particular groups of students. As discussed in Chap. 3, studies of teachers designing ICT lessons found that such kinds of knowledge emerge through their involvement in design work (e.g., Koehler, Mishra, & Yahya, 2007). For teachers, therefore, design thinking resides within the reasoning processes that are being used to formulate their lesson strategies. The second case study in Chap. 5 demonstrates that for preservice teachers, a knowledge-building approach where ideas are being improved through peer collaboration influenced how they designed and implemented their lessons. In particular, the knowledge-building process moved their lesson design and implementation from a preference for didactic-oriented activities to a preference for constructivist-oriented activities. With the appropriate scaffolding to manage idea improvement, design work can be used as a means to help preservice teachers develop their pedagogical repertoire. This is important for preparing them to meet the design challenges that they are expected to face when they become in-service teachers. Chapter 6 demonstrates that in-service teachers need to grapple with a wide range of considerations including student profile and school practices. The design talk occurring as teachers design in teams is their means of creating the new pedagogical languages for improving their teaching practices. Design thinking not only drives teachers' design talk but is also improved by it. Knowing how to design is therefore a critical teacher competency that can be used to create the innovation and change needed to support twenty-first-century learning in schools.

## 8.3 Challenges with Applying Design Thinking

### *8.3.1 Curriculum Fit*

Despite its potential uses, the application of design thinking in the field of education is not without its challenges. Design is a dynamic process that can sometimes require designers to draw upon knowledge and skills from different disciplines. As it was alluded to in Chap. 4, design can lead students to learn beyond lesson objectives (Resnick, 1998). While this is generally regarded positively, the more worrying outcome of design is whether the design thinking developed through problem solving can address the content objectives of the lesson (Apeddoe & Schunn, 2013). Especially for school systems characterized by high-stakes examinations, whether the competencies for solving design problems could be translated to exam performance can become a potential dilemma. The lack of clear linkages between design thinking and content mastery in curriculums is an implementation challenge.

### *8.3.2 Scaffolding Design Work*

Design is cognitively demanding, both for students and teachers. The learning-by-design studies we examined in Chap. 4 reveal that students required modeling and support from teachers, whereas teachers required multiple rounds of practice to do so effectively (Kolodner et al., 2003; Puntambekar & Kolodner, 2005). In Chap. 5, the case studies show that there was still much room for preservice teachers to improve their design ideas after multiple rounds of practice with knowledge building. Even for the experienced in-service teachers in Chap. 6, expert input still had a substantial role in influencing their ability to design for pedagogical innovation. These examples suggest that even though design has always been part and parcel of mankind's endeavor for improvement, knowing how to design well is something that cannot be assumed. It appears that the art and craft of designing well needs to be scaffolded. However, the ways that design work can be effectively scaffolded are not well understood or articulated for both students and teachers.

### *8.3.3 Engaging in Design Talk*

From Chap. 6, it can be seen that design talk is an important vehicle for the expression and development of design thinking. It constitutes the reflection-in-action (Schön, 1983) that occurs during the design process. While design talk can be analyzed with methods such as content analysis, protocol analysis, and linkography, there are yet no clear standards for determining what constitutes effective design talk. Another related issue is how students and teachers can better manage design framing while engaging in design talk. There is generally a paucity of research in this area. One difficulty faced is that such kinds of talk are contextualized to the design situation and can be hard to compare.

## 8.4 Future Directions

The challenges faced in the current implementation of design thinking in education suggest that several areas of work can be considered.

### *8.4.1 Develop Linkages Between Design Thinking and Curriculum*

Educational systems need to rationalize the linkages between content knowledge, design thinking, and twenty-first-century competencies. This can help to clarify the curriculum fit of design thinking. Given its interdisciplinary nature, design activities may sit better with such kinds of curriculum units. More support could also be needed to help teachers understand and plan for design activities.

### *8.4.2 Conduct Research About Design Scaffolding*

More research on the scaffolding of design work is needed. Puntambekar and Kolodner (2005) suggest that for students, multiple scaffolding strategies such as teacher facilitation, writing design diaries, as well as prompts to help them articulate and justify design ideas were needed to facilitate their engagement in design work. As outlined in Chap. 5, peer collaboration through knowledge building can be one way of scaffolding preservice teachers' design work. Other possible methods could be tutor modeling, product critiques, and peer sharing (e.g., Koh & Divaharan, 2011). More efforts need to be spent on understanding the particular design difficulties of teachers and students as well as the efficacy of different strategies for scaffolding design work in different content areas.

### *8.4.3 Develop Tools for Scaffolding Design*

From Chap. 4, it can be seen that students' design thinking is partly facilitated through their externalization of ideas as design artifacts such as floor plans. These artifacts are then used as a means to evaluate and improve upon their design decisions. Software tools like *Logo* and *Scratch* are examples of how programming can be made accessible to children through simplified tools. The development of student-friendly tools to facilitate design processes such as idea generation, prototyping, and design evaluation can possibly be used to scaffold design work in K–12 contexts. As discussed in Chap. 7, tools such as *LAMS* can be used to scaffold teachers' lesson design. Besides technology tools, another example of design scaffold would be TPACK activity types (Harris, Mishra, & Koehler, 2009). These are descriptions of how ICT can be incorporated in generic lesson activities within a subject area. Rather than starting their lesson design from scratch, these activity types provide teachers with the starter resources to "mix and match" according to their lesson objectives. Another example is Koh's (2013) lesson design rubric which provides guidelines for designing various aspects of meaningful learning with ICT. These kinds of design tools can potentially scaffold teachers' design thinking by widening the scope of their lesson ideas. The development of tools for scaffolding the design work of teachers and students as well as the efficacy of these tools can be given more consideration in research related to design thinking and education.

### *8.4.4 Study Patterns of Design Talk*

Given the dearth of research on design talk, another area needing much work is the characterization of design talk in educational contexts. It is especially important to understand the patterns and nuances of design talk in order to identify the effective ones. Only when such patterns are expressly pinpointed can they be used for the development of design practices. Learning how to engage in and to facilitate effective design talk is critical for in-service teachers who largely engage in design work through work-based design teams. It can also be used to develop the design epistemologies of preservice teachers. The analysis of design talk through content analysis (e.g., Koh, Chai, & Tay, 2014) and methods such as linkography (Goldschmidt & Weil, 1998) can also be developed further. Particularly, more educational studies to benchmark link indexes through linkography would help us better understand the patterns and processes underlying design talk.

### 8.4.5 Conduct Multi-prong Design Evaluation

The preceding recommendations address how design-thinking competencies can be better developed. Our review in Chap. 7 points out that the development of design thinking needs to be supported with methodologies of evaluation. Particularly, these evaluation methodologies need to create clear linkages between design activities and their outcomes. In this way, design activities can be better positioned towards its desired educational outcomes. As outlined in Chap. 7, we suggest a multi-prong approach where the designer perceptions, design processes, as well as design outcomes are being measured. This calls for the development of instruments such as surveys, rubrics, as well as indices for assessing the different aspects of the design chain. It also requires the careful consideration of how these instruments can be contextualized for the design work of students and teachers, and possibly even for different content areas.

### 8.4.6 Educators to Reflect on the Norms and Ethics of Design

Design thinking no doubt opens new and exciting opportunities for education. But as Chap. 2 has tried to show, the advocates of design and design thinking should not ignore the normative and ethical issues that may inhere in the domain of design. In the first place, a bit of humility may be in place in theorizing about the nature and scope of design. The term design can be used to encompass the world of artifacts both material and conceptual throughout human history. It is safe to say that no one human person or group has the ability and capacity to know all about human culture and creativity. Even within specific domains of knowledge or practice, there are differences of opinion regarding what the design is and what it can accomplish. Yet, it is very rare to find writers explicitly acknowledging the limits of what they know about the universe of design.

When making the case for design, advocates should not be so quick to go beyond the boundaries of what they know or are competent in. As we live in a world that is highly connected and integrated, interventions in areas which we know about may have repercussions in areas where we have little or no knowledge. Those who emphasize innovation and change should be always alert to problems of unintended consequences. They should keep in mind that the path to hell is often paved with good intentions. Just because we did not intend something to happen does not mean that we would not be morally tainted by it when it happens.

As Simon (1996) says, anyone who designs aims to change existing situations into preferred ones. We want to change things for the better. But here we need to be very clear about what we mean by changing things for the better. Better in what respects? Better for whom? Underlying these questions are the enduring questions about the human quest for the good, the true, and the beautiful. Advocates in their enthusiasm for the creative potential of design thinking should not presume to know what is good for all. And if they are prepared to bring about change, they should be prepared to deal with the moral implications of their acting in the world.

These reflections on the moral challenges of design thinking are not meant to discourage its use. But they help to show that the teaching of ethics cannot be divorced from the use of design and design thinking especially in the education context. Indeed, the teaching of ethics or the cultivation of the proper ethical dispositions should be an integral part of the pedagogy of design and design thinking.

While design occurs in many specific forms in fields such as product development, architecture, software development, and graphic design, we have chosen in this book to explore how design thinking could be relevant for the field of education by presenting examples of design thinking from the perspectives of both students and teachers. Educators need to further consider how the ideas presented may be applicable, adapted, or even redesigned for different content and subject areas. This is because design is a highly contextualized activity whereby effective strategies and design scaffolds differ according to problem situations. Generic models of design thinking are better treated as starting points for the generation of new design practices suitable for particular contexts of use.

For design thinking to be more deeply entrenched within the field of education, the relevance of design as an epistemology and ethical practice for both students and teachers need to be established for different subject areas. At systemic levels, design thinking can also be applied by school leaders and policy makers to strategize educational goals, systems, and processes. These are areas that can be considered and developed by educators in future design-thinking work.

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