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Positioning Design Epistemology and its Applications in Education Technology

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ABSTRACT

This position paper proposes to broaden the conception of personal epistemology to include design epistemology that foregrounds the importance of creativity, collaboration, and design thinking. Knowledge creation process, we argue, can be explicated using Popper's ontology of three worlds of objects. In short, conceptual artifacts (World 3) like theories are products of human minds that result from personal thinking and experience (World 2) and are encrypted through language, signs and symbols on some physical media (World 1). Examined from this perspective, knowledge creation necessitates design thinking, and ICT facilitates this process by providing a historical record of the development of ideas and allows for juxtapositions of ideas to create new ideas. The implication for education is that educators and researchers should develop students' epistemic repertoires, or ways or knowing, so as to create cognitive artifacts to make sense of the problems and challenges that a student encounters.

Keywords

Design, Epistemology, Educational technology

Introduction

The challenges posed by the contemporary world on education can be succinctly summarized as the requirement to transform educational practices to prepare students of all ages for the knowledge society (Bereiter & Scardamalia, 2006; Chai, Wong, Gao, Wang, 2011; Macdonald & Hursh, 2006; Paavola & Hakkarainen, 2005). The knowledge society, sometimes known as the learning society or the knowledge economy (Valimaa & Hoffman, 2008), produces "high value-added goods and services driven by … strong innovation performance; intensive use of generic technologies…sound research and development investments; and, above all, high education standards, human resources in science and technology" (Dufour, 2010, p. 984). The foci of the education system in such a society are targeted at cultivating learners who are able to produce knowledge and associated products through transdisciplinary research. The key competency of the workers in the knowledge society is the ability to create usable knowledge, and not just knowledge that are governed by academic interests concerning the "truth" (Bereiter, 2002; Valimaa & Hoffman, 2008).

The preceding account of the educational needs of the knowledge society is now widely shared among educators and policy makers. Many national and international education policies that attempt to integrate information and communication technology (ICT) in education have the ultimate goal of empowering students' construction of knowledge with ICT (e.g., Anderson, 2010; Partnership for 21st century skills, 2011). Classroom realities, however, often fall short of realising these policy objectives. This is especially so in the Asia Pacific region when teacher's use of ICT for students' knowledge construction is not prominent (Bate, 2010; Hogan & Gopinathan, 2008; Hsu, 2011; Law, Lee & Yuen, 2009). While the advancement of networked technology, along with the development of myriad e-learning platforms and social networks, has broadened the scope for ideas, insights, experiences, and knowledge to be articulated, constructed, shared, and distributed (Chai & Lim, 2011), it is now generally recognized that true transformation of education has to happen at a deeper level (Bruner, 1996; Castell, 2005; Ertmer, 2005; Bereiter & Scardamalia , 2010; Yang & Tsai, 2010). Current education systems have been based primarily on traditional epistemological beliefs and the needs and infrastructures of the Industrial Age (Bereiter & Scardamalia, 2006; Macdonald & Hursh, 2006). To meet the challenges posed by the knowledge society and to harvest the pedagogical affordances of ever more powerful ICT, it is imperative to re-conceptualize what education is about; in particular, to collectively (i.e., involving all levels of educators) examine the epistemic foundations and purpose of schooling. Our purpose in this paper is to reflect on a lesser known area of research in personal epistemology, namely design epistemology, and to argue for its relevance in ongoing efforts to address the epistemological bases of

education reform. In the following sections, we argue for the need of fostering design epistemology among teachers and students and the roles of ICT in this process.

Design epistemology

Epistemology is an important field within philosophy that deals with the nature and the justification of knowledge. Regardless of which perspectives of learning an educator holds, whether learning as acquisition of knowledge or knowledge creation (Paavola & Hakkarainen, 2005), one cannot avoid engagement with issues about the nature of knowledge and ways of knowing. In terms of education reform in the context of knowledge society, it would be pertinent for teachers to be acquainted with epistemology supported by personal experiences in creating knowledge.

Since 1970s, there has been growing interest among educational psychologists in the study of students' and teachers' personal epistemology. The core dimensions of personal epistemology include the nature of knowledge (whether knowledge is certain or tentative, for example) and the source of knowledge (for example, whether knowledge is from an authorititative source or is personally constructed) (Hofer & Pintrich, 1997). Relationships between personal epistemology and various learning outcomes, such as learning approaches, reading comprehension, conceptual learning and learning strategies have been established (Schommer-Aikins, Bird, & Bakken, 2010).

Wong and Chai (2010) argued that prevailing conceptions of knowledge, based on traditional notions of epistemology and the popular views of the scientific method, are unduly limiting. Etymologically, the Greek term *episteme* translates into *scientia* in Latin to give us the modern word for *science*. Traditionally, *episteme* in Greek has often been used in contrast to *techne* (art or craft), *poiesis* (making or inventing) and *praxis* (doing). Due to this traditional bias, current conceptions of epistemology tend to privilege scientific knowledge or propositional forms of knowledge. With the emphasis on innovation, creativity and the use of technology in the knowledge economy, it opens the way for a more dynamic, comprehensive conception of knowledge construction that cuts across not only various disciplines but also across domains of skills, practices, and even dispositions (Schön, 1983; Caws, 1997; Simon, 1996, Rowland, 2004, Pink, 2006, Cross, 2006, Edwards, 2008; Fry, 2009; Martin, 2009; Brown, 2009).

We therefore argue for a broader conception of personal epistemology that foreground the importance of creativity, collaboration, and design thinking for future research. In other words, we propose a conception of design epistemology that is not divorced from traditional epistemology, but one that emphasizes the dynamic, social, and creative aspects of knowing and knowledge construction. Focusing on this area of personal epistemology is, in our opinion, crucial to the transformation of education, especially in the Asia Pacific region, which is culturally more oriented to collectivism and traditional teacher-centric pedagogy. Design epistemology could leverage the communitarian aspects of Asian culture to promote a more creative and dynamic approach to teaching and learning.

The design approach to knowledge

Nigel Cross (2006) suggested a useful way to characterize the design approach to knowledge. According to Cross, human knowledge can be broadly divided into three realms-- namely the sciences, the humanities, and design—each with its unique focus of study, methods and set of values and dispositions.

The main focus of study for the sciences is the natural world. The methods employed by the sciences include controlled experiments, classification, and analysis. The values corresponding to scientific inquiry are objectivity, rationality, neutrality, and a concern for truth. The arts and humanities focus on human experiences and employ tools such as analogies and metaphors to understand and to give expression to the world of human experiences. This realm of human knowledge values human subjectivity and imagination, and is often propelled by concerns for justice. *Design* realm of knowledge focuses on the artificial world, and employs methods such as modeling, pattern-formation, and synthesis. Practicality, ingenuity, empathy, and a concern for appropriateness are paramount for design realm of knowledge. The ability to synthesis disparate knowledge and information is widely held to be a central feature of design thinking (Cross, 2006; Pink, 2006; Simon, 1996). In addition to modeling, the use of simulation and prototyping are typical tools to experiment with new ideas. Not only do these tools enable the realization of abstract ideas, but they could also serve as vehicles for the discovery of new knowledge and facilitation of thinking (Simon, 1996; Brown, 2009).

The division of knowledge into these three realms is, of course, a human creation –a product of design thinking, so to speak. In actuality, all three realms of knowledge are intimately related in the act of thinking and doing in a creative fashion. While it is focused on the production of material and conceptual artifacts, design thinking cannot take place without the necessary supports of the arts and sciences. In addition, we would argue that design thinking is critical to all three forms of knowing. Artists design the stories they want to tell about human experiences. Scientists design the theoretical frameworks and the empirical experimentations about the phenomena they encounter. Technologists design products that interface between the users and the objects to be worked on. Regardless of the professional emphases, the viability of what is created has to be judged and assessed by potential users. The creation of a science fiction movie such as the Star Wars series illustrates how these three forms of knowledge are tightly woven together through design to produce an artifact that has been well received by movie lovers. The success of Apple's iphone with its growing number of apps is another case in point.

Design thinking is likely to be more fruitful in a collaborative environment. Project teams comprising members with different skills and expertise are crucial for design in the knowledge age. The creative potential of the team is based on its capacity to collaborate across disciplines and realms of practice. In educational terms, such collaborative efforts point to the desirability of fostering "T-shaped" individuals (Brown, 2009). The vertical axis of the letter refers to the depth of skill and knowledge that allows a person to make tangible contributions to the outcome of the project. The horizontal axis refers to the capacity to pursue a wide spectrum of interests outside of one's professional, technical, or academic specialty.

Ultimately, design is aimed at meeting human needs and purposes, and as such, design is guided by a normative goal. Since design thinking aims to produce artifacts or ideas useful and meaningful to life, the logic of their enterprise has ethical implications on their participants. Thus, in addition to "the arts of planning, inventing, making and doing" (Cross, 2006, p.17), the design approach fosters the development of empathy, tolerance for ambiguity, positive attitudes towards failure or error, and bias towards service and responsibility (Rowland, 2004). This is also quite different from scientific thinking, which often considers uncertainty as a threat for knowledge development (Duschl, 1990). Last but not least, design thinking understood in this context also promotes a high degree of reflexivity, in which the agent grows in self-awareness and social consciousness through interacting with others in the process of producing goods and services that transform the social and physical environment.

The preceding outline of the main features of the design approach to knowledge shows that design thinking is more than what has been considered in the traditional research of personal epistemology. To date, studies in personal epistemology is mainly based on classroom phenomena in general. This, in turn, is based on the belief mode of thinking that is focused on the truth value of knowledge claims (Bereiter & Scardamalia, 2006). Consequently, there is little we know about how teachers and students understand knowledge creation in the context of knowledge society. However, before we discuss possible ways of fostering knowledge creation in the classrooms, it would be beneficial to explicate a possible ontological foundation to engender knowledge creation in classrooms. To this end, we turn to Popper's postulation of three worlds.

Popper's three worlds and knowledge creation

Popper conceptualized a pluralistic view of the universe consisting of three worlds to explain how civilization progresses. World 1 consists of the world of physical things and events. World 2 refers to the subjective world of experiences, and Popper regarded this as especially important as it includes the world of moral experiences. World 3 is made up of the products of the human mind. As products of the human mind, World 3 objects can also be referred to as conceptual or cognitive artifacts (Bereiter, 1994). World 3 objects are primarily embodied or physically realized in world 1 physical objects. For example, Beethoven's Fifth Symphony is a World 3 artifact that is realized or embodied in various performances or recordings of those performances, which are events or things occurring in World 1. The experience and appreciation of a live or recorded performance takes place in World 2, and is experienced differently by different listeners who can then engage in informed or critical discussion of the merits of the performance. It may seem surprising that this interaction of the three worlds may well lead to changes in the elements of the symphony to improve or enhance its performance.

The contemporary significance of Popper's three worlds to research and development community lies in the potential of tentative theories or designs being articulated and/or improved over time as they are being subjected to criticism,

error elimination and/or refutation. An example of such a process is the Wright brothers' effort in building a plane that took place as a theory about flight control was concurrently being developed and articulated (Bereiter, 2009). To work on an epistemic object with the intention of producing a good or service and advancing its utility is, in essence, the kind of innovative work today's knowledge worker is engaged in. In other words, the interaction of the three worlds is part and parcel of what it means to be engaged in knowledge creation.

The main point of World 3 objects is that they are human creations and therefore they can be improved for the most part through the dynamic interaction the three worlds. Treated as such, the ideas, theories and designs created by knowledge workers such as scientists, engineers and architects are assessed less for their truth value but more for their utility or pragmatic value. Moreover, these theories and ideas, once created, have a life of their own in that they can and should be improved and transformed by people who interact with them. They are treated as tentative ideas that should be subjected to error elimination under Popper's schema or idea refinement from Bereiter's perspective. In other words, all created knowledge is open to further inquiry and improvement. Design thinking is more concerned with notions of utility and significance than with the question of truth (Pink, 2006). Even so the material or conceptual artifacts of the design process do not "ignore or violate the laws of nature" (Simon, 1996, p. 3); indeed, it could be said that the success in simulating, modeling or prototyping an artifact points to underlying truths about the ideas that inform its production. This would be in keeping with the realism informing Popper's conception of World 3 objects.

Popper's three worlds provide educators with alternative ways to re-conceptualize what education should be about. Bereiter (2002) has successfully employed this paradigm as a foundation for the pedagogical model of knowledge building community. Bereiter (2002) criticizes current education systems for focusing too much on changing the World 2 of students (i.e., the students' mind) and often neglecting the enculturation of students' competencies to work in World 3. Bereiter therefore advocates that school should shift the focus of classroom students' work to include as much emphasis on World 3 objects. Bereiter and Scardamalia (2006) described this shift as resulting in pedagogies reflecting the design mode of thinking. According to Bereiter and Scardamalia, in a knowledge building community that employs the design mode of thinking, it is essential to guide students to ask questions such as: (1) What is this idea good for? (2) What does it do/fail to do? And (3) how can it be improved? In other words, the guiding concerns are not necessary those associated with academic pursuit of truth, but with issues of practical constraints confronting proposed solutions to real world problems. In assessing the value or success of ideas, designers appeal to criteria such as feasibilty ("what is functionally possible within the foreseeable future"), viability ("what is likely to become part of a sustainable business [or social] model"); and desirability ("what makes sense to people and for people") (Brown, 2009, pp.18-19).

The last criterion points to a fundamental strength of the design approach: its emphasis on the human-centered nature of idea generation and knowledge construction. In so doing, the design approach highlights the normative and ethical aspects of the aim of producing and improving ideas that benefit individuals and society. As design approach seeks to find practical solutions to complex and at times wicked problems, it promotes and develops the capacity for judgment, and hence self-reflection. As Rowland (2004) observed, designers

> do not confront decisions that are clearly correct or incorrect, right or wrong. Instead they 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).

In light of the complex nature of challenges and problems of the 21st century, the development of mature judgment complements efforts to educate for responsible local as well as global citizenship.

Building on the foregoing arguments, we would like to point out that Popper's model can be applied in wide contexts of other models of knowledge creation, which could include the knowledge spiral that is realized through the processes of socialization, externalization, combination and internalization (SECI) (Nonaka & Takeuchi, 1995); the expansive learning framework that is undergirded by cultural-historical activity theory (Engestrom, 1999); and "designerly" ways of knowing (Cross, 2006). These models of knowledge creation, together with the knowledge building community (Scardamalia & Bereiter, 2006), were constructed based on research in different social-cultural contexts and therefore emphasize different aspects of knowledge creation. For example, the knowledge spiral was based on studies of Japanese firms; the designerly ways of knowing were based on research in the context of western industrial design; expansive learning originated from studies of traditional craft and is concerned with innovating

practices; while the knowledge building community is practiced in classrooms focusing on students' creation of theories and knowledge (for review, see Paavola, Lipponen & Hakkarinen, 2004). Despite their differences, the common mode of knowledge creation is arguably design thinking in the broadest sense, that is, to pursue fruitful and generative ideas resulting in the production of goods, services, or solutions for authentic problems and challenges within their respective social cultural contexts. Design epistemology is thus the study of the dynamic, collaborative and holistic aspect of this process of knowledge creation that yields useful practice, products, and services. We suggest these models and Popper's view of three worlds as a generic knowledge creation model that could be applied to a wide range of disciplines and practices and therefore to a wide range of classroom contexts. Figure 1 depicts how various models of knowledge creations could be employed to mediate the relations between the three worlds.

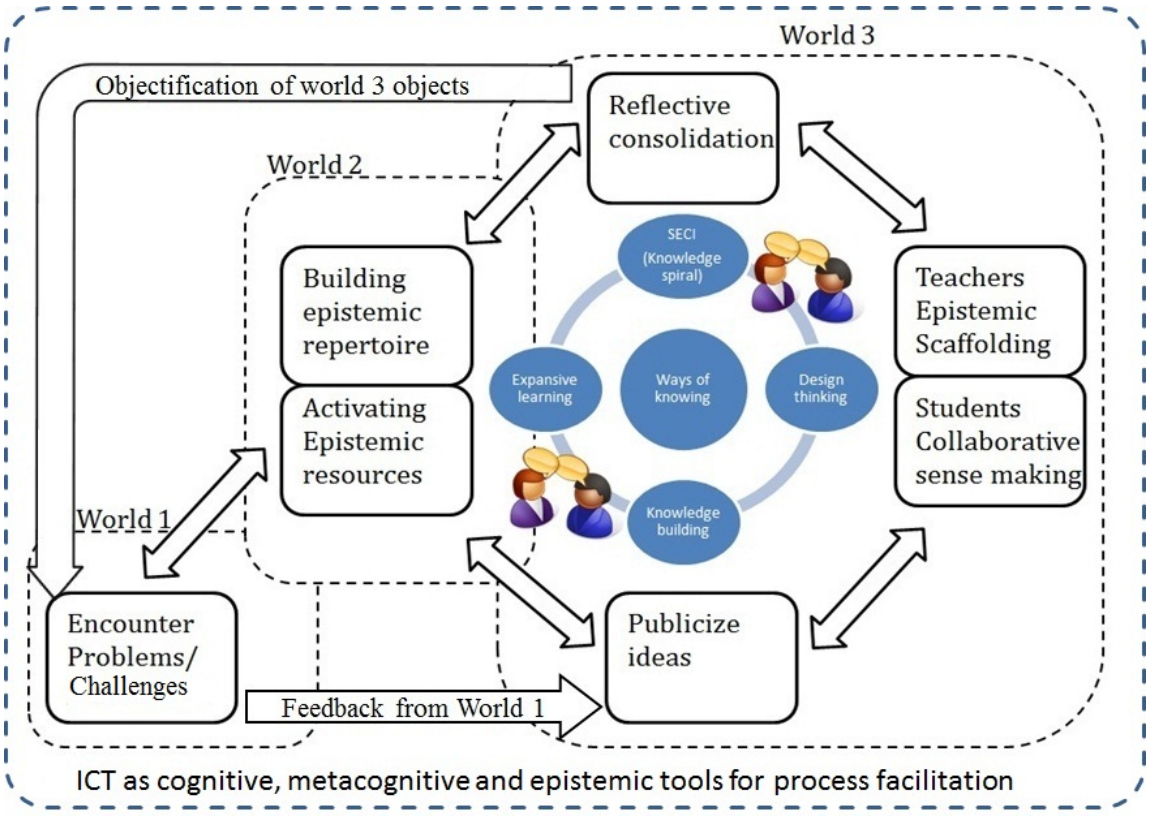

Figure 1. A knowledge creation model

Our model sees knowledge creation as a process that begins with the encountering of challenges or problem in their lived world (World 1). Encounter with challenges or problems that cause cognitive and affective dissonance are likely to drive individuals to seek resolutions. Resolution begins with the process of forming initial ideas (including problem representations and possible solutions). These initial ideas are likely to be formed through the activation of the initial epistemological resources, which refers to prior knowledge and everyday ways of knowing (see Hammer & Elby, 2002). Through articulation of the initial ideas (World 3) in a community (World 1 & 2) who share common interest and co-own the problem, various ways of knowing, acting, and making can be brought to bear and guide the knowledge creators to model and perform iterations of potential solutions. The initial articulation of ideas would also introduce diverse ways of understanding the problems and challenges, which would create multiple zones of proximal development to engage members in the community in interaction (Oshima, 1998). Through distributed and the collaborative sense making processes, the ideas are refined and some designed solutions are formed. This process in turns fosters the development of new epistemological resources for students. Through self-directed reflective activities, the epistemological resources that emerge during the process of idea improvement can be consolidated as epistemic repertoire or ways of knowing that can be drawn upon for future collaborative sense making. Elby and Hammer (2010) proposed similar approaches as they also see the possibilities of the development of coherent epistemological beliefs "as a progressive construction of patterns of resource activation" (p. 413).

In essence, as depicted in figure 1, we propose that the three worlds of Popper are interconnected through the conscious human mind (World 2) and they interact with one another reciprocally. Changes in one world invariably influence another ecologically. The key task of educators is to help learners appreciate the problems and challenges at hand and nudge the learners to adopt appropriate epistemic frames (Elby & Hammer, 2010) for collaborative knowledge construction. For example, when students are struggling to understand a natural phenomenon, the knowledge building approach is likely to be an appropriate approach in that it seeks to construct theories from students' prior knowledge and these theories are subjected to community refinement based on extensive range of epistemic activities which include both empirical research and literature review (see Zhang, Hong, Scardamalia, Teo & Morley, 2011). On the other hand, in dealing with problems pertaining to some social practices, it may be more fruitful to draw upon an expansive learning model as such a model was designed to innovate human activity system (Engestrom, 1999). In this proposed model, all legitimate ways of knowing developed to date can and should be drawn upon to improve enrich the social environment. . In addition, all World 3 objects are epistemic resources and they should be treated as improvable ideas (Bereiter, 2002; Elby & Hammer, 2010). We propose that when teaching and learning are framed from this ontological perspective, the epistemic nature of classroom would be dramatically transformed.

The role of ICT for design epistemology

ICT, in recent decade, has been used widely as a cognitive and metacognitive tool (Jonassen, 2000; Jonassen et al., 2008). In light of this perspective, the main objectives of ICT-assisted instruction are to help learners construct knowledge and develop relevant skills, learn how to re-organize knowledge and learn how to learn. Some educators (e.g., Tsai, 2004) also proposed that ICT can promote epistemic development by acting as an epistemic tool. When ICT is utilized as an epistemic tool for instruction, learners are encouraged to evaluate the merits of perspectives, information and knowledge acquired from ICT-supported environments, and to probe the nature of learning and knowledge construction.

Similarly, we believe that ICT can be an adequate tool for promoting learners' design epistemology. With rapid advances in ICT, more creative learning and knowledge construction become possible (Stahl, Koschmann, & Suthers, 2006). In fact, it is difficult to imagine any current professional involved in creating knowledge not using multiple affordances of ICT. Similarly, if teachers engage students in knowledge creation, ICT integration would become a norm in classrooms. A major affordance of ICT in fostering design epistemology lies in the fact that ICT encourages user to play with ideas. Computers can store many versions of the idea in the idea improvement processes and help track the historical development of ideas, for example, in an online forum. In addition, the ease of juxtaposing parts from different sources together and remixing these parts to form new ideas also encourages users to look at ideas from a new perspective. Researchers have articulated a range of technological affordances that support the cognitive, metacognitive, collaborative and epistemic aspects knowledge creation (Chai & Lim, 2011; Jonassen, Howland, Marra, & Crismond, 2008; Scardamalia & Bereiter, 2006; Tsai, 2004).

Possible research for design epistemology

Drawing upon the various knowledge creation models reviewed above, the common demand of these models can be summarized as nurturing learners' "*epistemic repertoire*." By epistemic repertoire, we refer to a range of ways of knowing that enable an individual to develop viable cognitive artifacts to make sense of the problems and challenges that he or she encounters. Emerging problems and challenges in the current world originate from all areas of our live, and they are necessarily addressed through multiple ways of knowing. These ways of knowing, which are often associated with discipline-based or inter-disciplinary approach to knowledge creation, offer different and competing perspectives and solutions to the problems. In essence, we see the key challenge of today's education as building an individual's epistemic repertoire that could facilitate in-depth understanding of the cognitively (and likely to be affectively) challenging encounters and formulation of innovative/creative responses to address these challenges.

Knowledge creation and design thinking are complex processes that defy simple reduction. To date, studies in personal epistemology have drawn upon various methodologies to address different level of analysis (see Bendixen & Feucht, 2010). However, many gaps in understanding still exists and the findings are at time contradictory (Hofer, 2010). To achieve comprehensive and coherent understanding of personal design epistemology, we would therefore

advocate that multiple methods be brought to bear on this area of research. A review by Deng, Chen, Tsai and Chai (2011) of research on scientific epistemology has illustrated how multiple methods illuminate different aspects of students' beliefs. It is therefore necessary to design questionnaire to survey general epistemic outlooks especially on the aspects of individual's view about design thinking and knowledge as human construction or viable improvable ideas. In addition, interviewing all levels of knowledge creators would help to piece the puzzle together. However, instead of beginning research of design epistemology with what people say or believe in, we would suggest that a better foundation to build understanding about personal epistemology is on what people do during the act of constructing knowledge through the design mode of thinking. In other words, we argue that researching individual epistemic repertoire should begin with how they are enacted.

Work by Hammer and Elby (2002) on epistemological resources could give us a more concrete handle in terms of what epistemological repertoire consists in and how it can be investigated. Epistemological resources are regarded as fine-grained knowledge elements possessed by a student, which can be activated by different contexts (see also p-prim theory by diSessa (1993), that is, they are by nature World 2 elements stored in the mind of the students. Hammer and Elby propose four categories of epistemological resources:

- The general nature of knowledge and how it originates (e.g., knowledge as propagated stuff; knowledge as constructed, knowledge as fabricated…)
- Resources for understanding epistemological activities and forms (e.g., brain-storming, building or making to think, and lists)
- Epistemic games and epistemic forms (we would also include modeling, or prototyping)
- Resources for understanding stances one may take towards knowledge (e.g., doubting and accepting)

In classroom situations, depending on how the pedagogical intentions are framed epistemologically by the teachers, students discursively activate various aspects of his or her epistemological resources to deal with the problems at hand. Elby and Hammer (2010) view the activation of as locally coherent (e.g., sometimes across contexts) rather than haphazard and incoherent. In addition, they proposed students' "development as a progressive construction of patterns of resource activation" (p. 413). However, the contextually activated resources may not be appropriate to the epistemic task at hand and this would hamper students' effort or distort the teachers' epistemic framing of the task (see for example, Rosenberg, Hammer, & Phelan, 2006). In other words, students may activate inappropriate World 2 or World 1 objects to work on a World 3 object, or vice versa. A teacher's job would then be to reframe students' effort through epistemic scaffold. Beyond such one-to-one epistemic scaffolding, it is clear that teachers need to shape and reshape the epistemic climate of the class, represent subject matter as World 3 objects to be improved upon; steer the metacognition of the class towards coordinating multiple perspectives for idea improvement and engage students in using appropriate ICT tools to support the complex problem solving processes.

Assuming that the teacher could successfully achieve the above, what, how and why students' epistemic repertoire are formed and changed would be of great interest to researchers. However, as portrayed in Figure 1, to study students' epistemic repertoire in isolation is to confine it to World 2 exclusively. This is likely to distort understanding rather than unpack the emergence of epistemic repertoire. We therefore suggest that regardless of the researcher's approach to the study of design epistemology, sufficient characterization of the World 1 and the World 3 is also necessary.

Conclusion

In this paper, we argue for design epistemology, an extension of personal epistemology, as the epistemological basis for educational reform to prepare our students for the Knowledge society. We elaborate the construct of design thinking and its roles in knowledge creation from two key perspectives: Nigel Cross's design realm of knowledge and its relation to science and humanities realm of knowledge, and Popper's three ontological worlds of objects. Educational technologies, we suggest, play an important role in supporting knowledge creation by reifying conceptual artifacts, tracking historical development of conceptual artifacts, and juxtaposing these artifacts for creation of new artifacts. Most importantly, we argue that in this Knowledge Age, developing students' epistemic repertoires, or ways of knowing, should be the key educational reform effort and research agenda.

Moving forward, we propose a few key research agenda and directions anchored on design epistemology. Our arguments, we hope, serve as World 3 objects that could trigger further discussion and research effort for the benefit

of our students, who are the future pillars of the knowledge society. Researchers can further explore how educational technologies can play an essential role in this respect.

Note

All of the authors contribute to the paper equally.

References

Anderson, J. (2010). *ICT transforming education.* Bangkok, Thailand: UNESCO.

Bate, F. (2010). A bridge too far? Explaining beginning teachers' use of ICT in Australian schools. *Australasian Journal of Educational Technology, 26*(7), 1042-1061.

Bendixen, L. D., & Feucht. F. C. (Eds.) (2010). *Personal epistemology in the classroom: Theory, research and implications for practice.* UK, Cambridge: Cambridge University Press.

Bereiter, C. (1994). Constructivism, socioculturalism, and Popper's world 3. *Educational Researcher, 23*(7), 21-23.

Bereiter, C. (2002). *Education and mind in the knowledge age*. Mahwah, NJ: Lawrence Erlbaum.

Bereiter, C. (2009). Innovation in the absence of principled knowledge: The case of the Wright Brothers. *Creativity and Innovation Management, 18*(3), 234-241.

Bereiter, C., & Scardamalia, M. (2006). Education for the knowledge age. In P. A. Alexander & P. H. Winne (Eds.), *Handbook of Educational Psychology* (2nd ed., pp. 695-713). Mahwah, NJ : Lawrence Erlbaum.

Bereiter, C. & Scardmalia, M. (2010). Can children really create knowledge? *Canadian Journal of Learning and Technology, 36*(1). Retrieved from www.cjlt.ca/index.php/cjlt/article/download/585/289

Brown, T. (2009). Change by design: How design thinking transforms organizations and inspires innovation. New York, NY: HarperCollins.

Bruner, J. (1996). *The culture of education*. Cambridge, MA: Harvard University Press.

Castells, M. (2005). The network society: From knowledge to policy. In M. Castells & G. Cardoso (Eds.), *The Network Society: From Knowledge to Policy* (pp. 3-22). Washington, DC: Johns Hopkins Center for Transatlantic Relations

Caws, P. (1997). *Yorick's World: Science and the knowing subject.* Berkeley, CA: University of California Press.

Chai, C. S., & Lim, C. P. (2011). The internet and teacher education: Traversing between the digitized world and schools. *The Internet and Higher Education, 14*, 3-9.

Chai, C. S., Wong, L. H., Gao, P., & Wang, Q. (2011). Towards a new era of knowledge creation: A brief discussion of the epistemology for knowledge creation. *International Journal of Continuing Engineering Education and Life-long Learning, 21*(1), 1-12.

Cross, N. (2006). *Designerly ways of knowing.* Boston, MA: Birkhauser.

Deng, F., Chen, D., Tsai, C.-C., & Chai, C. S. (2011). Students' views of the nature of science: A critical review of research. *Science Education, 95,* 961-999.

diSessa, A. (1993). Towards an epistemology of physics. *Cognition and Instruction, 10*, 105-225.

Dufour, P. (2010). Supplying demand for Canada's knowledge society: A warmer future for a cold climate? *American Behavioral Scientist, 53*(7), 983-996.

Duschl, R.A. (1990). *Restructuring science education.* New York, NY: Teachers College Press.

Edwards, D. (2008). Artscience: Creativity in the post-google generation. Cambridge, MA: Harvard University Press.

Elby, A., & Hammer, D. (2010). Teachers' personal epistemology and its impact on classroom teaching. In L. D. Bendixen & F. C. Feucht (Eds.), *Personal epistemology in the classroom: Theory, research, and implications for practice* (pp. 409-434). Cambridge, MA: Cambridge University Press.

Engestrom, Y. (1999). Activity theory and individual and social transformation. In Y. Engestrom, R. Miettinen, & R. L. Punamaki (Eds.), *Perspectives on activity theory* (pp. 19–38). Cambridge, MA: Cambridge University Press.

Ertmer, P. A. (2005). Teacher pedagogical beliefs: The final frontier in our quest for technology integration. *Educational Technology Research and Development, 53*(4), 25—39.

Fry, T. (2009). Design futuring: Sustainability, ethics, and new practice. Oxford, UK: Berg.

Granovetter, M. (1983). The strength of weak ties: A network theory revisited. *Sociological theory, 1*, 201-233.

Hammer, D. M., & Elby, A. (2002). On the form of a personal epistemology. In B. K. Hofer & P. R. Pintrich (Eds.), *Personal epistemology: The psychology of beliefs about knowledge and knowing* (pp. 169-190). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Hogan, D., & Gopinathan, S. (2008). Knowledge management, sustainable innovation, and pre-service teacher education in Singapore. *Teachers and Teaching: Theory and Practice, 14*(4), 369-384.

Hofer, B. K., & Pintrich, P. R. (1997). The development of epistemological theories: Beliefs about knowledge and knowing and their relation to learning. *Review of Educational Research, 67*(1), 88-140.

Hofer, B. K., & Pintrich, P. R. (1997). The development of epistemological theories: Beliefs about knowledge and knowing and their relation to learning. *Review of Educational Research, 67*(1), 88-140.

Hofer, B. K. (2010). Personal epistemology in Asia: Burgeoning research and future directions. *The Asia-Pacific Education Researcher, 19*(1), 179-184.

Hsu, S. (2011). Who assigns the most ICT activities? Examining the relationship between teacher and student usage. *Computers & Education, 56*(3), 847-855.

Jonassen D. H. (2000). *Computers as mindtools for schools*. Upper Saddle River, NJ: Merrill.

Jonassen, D.H., Howland, J., Marra, R., & Crismond, D. (2008). *Meaningful learning with technology* (3rd ed.). Upper Saddle River, NJ: Pearson.

Law, N., Lee, Y., & Yuen, H. K. (2009). The impact of ICT in education policies on teacher practices and student outcomes in Hong Kong. In F. Scheuermann & F. Pedro, *Assesing the effects of ICT in education– Indicators, criteria and benchmarks for international comparisons* (pp. 143-164). European Union, France: OECD.

Martin, R. (2009). The opposable mind: Winning through integrative thinking. Boston, MA: Harvard Business Press.

Macdonald, G., & Hursh, D. (2006). *Twenty-first century schools: Knowledge, networks and new economies*. Rotterdam, The Netherlands: Sense Publication.

Nonaka, I., & Takeuchi, H. (1995). *The knowledge-creating company*. New York, NY: Oxford University Press.

Oshima J. (1998). Differences in knowledge-building between two types of networked learning environments: An information analysis. *Journal of Educational Computing Research, 19*(3), 329-351.

Paavola, S., & Hakkarainen, K. (2005). The knowledge creation metaphor- An emergent epistemological approach to learning. *Science & Education, 14,* 535-557.

Paavola, S., Lipponen, L., & Hakkarainen, K. (2004). Models of innovative knowledge communities and three metaphors of learning. *Review of Educational Research, 74*(4), 557-577.

Partnership for 21st century skills, (2011). *Framework for 21st Century Learning*. Retrieved from http://www.p21.org/overview/skills-framework

Pink, D. H. (2006). *A whole new mind: Why right-brainers will rule the future.* New York, NY: Riverhead.

Popper, K. (1978). *Three worlds.* Retrieved from The University of Utah, Tanner Humanities Center website: http://www.tannerlectures.utah.edu/lectures/documents/popper80.pdf

Rosenberg, S., Hammer, D., & Phelan, J. (2006). Multiple epistemological coherences in an eighth-grade discussion of the rock cycle. *The Journal of the Learning Sciences, 15*(2), 261-292.

Rowland, G. (2004). Shall we dance? A design epistemology for organizational learning and performance. *Educational Technology Research and Development, 52*(1), 33-48.

Scardamalia, M., & Bereiter, C. (2006). Knowledge building: Theory, pedagogy, and technology. In K. Sawyer (Ed.), *The Cambridge Handbook of the Learning Sciences* (pp. 97-115). New York, NY: Cambridge University Press.

Schommer-Aikins, M., Bird, M., & Bakken, L. (2010). Manifestations of an epistemological belief nsystem in preschool to grade twelve classrooms. In L. D. Bendixen & F. C. Feucht (Eds.). *Personal epistemology in the classroom: Theory, research and implications for practice* (pp. 124-162). UK, Cambridge: Cambridge University Press.

Schön, D. (1983). The Reflective Practitioner. London, UK: Temple Smith.

Simon, H. (1996). *The Sciences of the Artificial* (3rd ed). Cambridge, MA: MIT Press.

Stahl, G., Koschmann, T., & Suthers, D. (2006). Computer-supported collaborative learning. In Sawyer (Ed.), *Cambridge handbook of the learning sciences* (pp. 409-426). New York, NY: Cambridge University Press.

Tsai, C.-C. (2004). Beyond cognitive and metacognitive tools: The use of the Internet as an "epistemological" tool for instruction. *British Journal of Educational Technology, 35*, 525-536.

Valimma, J., & Hoffman, D. (2008). Knolwegde society discourse and higher education. *Higher Education, 56*, 265-285.

Wong, B., & Chai, C. S. (2010). Asian personal epistemologies and beyond: Overview and some reflections. *The Asia-Pacific Education Researcher, 19*(1), 1-6.

Yang, F.-Y., & Tsai, C.-C. (2010). An epistemic framework for scientific reasoning in informal contexts. In L. D. Bendixen & F. C. Feucht (Eds.), *Personal epistemology in the classroom: Theory, research and implications for practice* (pp. 124-162). Cambridge, UK: Cambridge University Press.

Zhang, J., Hong, H.-Y., Scardamalia, M., Teo C. L., & Morle, E. A. (2011). Sustaining knowledge building as a principle-based innovation at an elementary school. *Journal of Learning Sciences, 20*(2), 262-307.