EDeR

Educational Design Research

Volume 1 | Issue 1 | 2017 | Article 02-01

Contribution Type Discussion Article

Title

Design principles as a bridge between contexts: From innovation in the science museum to transformation in formal education

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For details on the EDeR Text-Mentoring concept: uhh.de/EDeR

In Reply to

EDeR | Volume 1 | Issue 1 | 2017 | Article 02

Euler, D. (2017). Design principles as bridge between scientific knowledge production and practice design. *EDeR - Educational Design Research, 1*(1), 1-15. http://dx.doi.org/10.15460/eder.1.1.1024

Abstract

This paper responds to Euler's consideration of the use of design principles to bridge between knowledge production and practice design in the first issue of this journal; and particularly to the question he left open on how design principles should be formulated more concretely. It does so by extending the discussion of the use of Sandoval's approach of 'conjecture mapping'. In this discussion article, we reflect upon our own efforts at a related form of 'bridge building', specifically on work to span the gap in practice designs between the contexts of science museums and more formal education settings.

Museums offer opportunities for educational innovation. The evidence of impact of such innovation on the more formal learning environments, however, has been limited. Teachers in formal settings, it appears, tend to adopt individual exemplar activities, but do not transfer the innovative approaches to their wider practice. The ambition of the project we examine here was to design teacher professional learning activities that allow participants to move beyond a focus on the specifications of a specific innovation and instead appreciate - to make concrete - the design principles in use. We will argue that conjecture mapping has been useful making design principles concrete but, in doing so, will point to the need for further research.

Keywords
conjecture mapping
curriculum design
curriculum innovation
innovation labs
science communication
teacher professional learning

DOI http://dx.doi.org/10.15460/eder.1.1.1059

Citation Leonard, S.N., Fitzgerald, R.N., Kohlhagen, S. & Johnson, M.W. (2017). Design principles as a bridge between contexts: From innovation in the science museum to transformation in formal education. *EDeR - Educational Design Research, 1*(1), 1-14. http://dx.doi.org/10.15460/eder.1.1.1059

Design principles as a bridge between contexts: From innovation in the science museum to transformation in formal education

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1.0 Introduction

In the first issue of EDeR - Educational Design Research, Dieter Euler (2017) provided an excellent discussion on the important role of design principles in bridging the gap between scientific knowledge production and practice design. Euler describes the value of design principals lying in the provision of knowledge that goes 'beyond the scope of a unique individual case' but that remains limited in their generalization range. This is similar to Bereiter's (2014) argument regarding 'principled practice knowledge (PPK)' which moves beyond the immediate needs of the practitioner, but not so far beyond as to be unrecognisable.

This paper takes up that discussion, and particularly Euler's open question on how design principles should be formulated more concretely, via reflection upon our own 'bridge building' efforts. In this case the gap being spanned is not between scientific knowledge production and practice design, but rather between practice designs in the differing contexts of science museums and more formal educational settings. We see design principles as a powerful means for constructing bridges in this space too, and will expand upon our use of the co-design 'tool' of conjecture mapping (Sandoval, 2004, 2014) that was touched on by some of us in another paper in the first issue of EDeR (Leonard, Belling, Morris, & Reynolds, 2017).

Expanding the conversation further, the paper makes use of the input from the 'peer editor' from the first of EDeR's two-phase review process, who is now included as a co-author. This input is presented as 'interjections' into the paper in a way intended to reflect the interaction of the seminar room. They take what was initially very much a 'practice' paper in the direction of deeper theoretical considerations.

1.1 Bridging gaps in the landscape of design-research

Euler's (2017) discussion is made largely from the perspective of a university researcher. Noting Kieser's (2010) critique of the current era in which scientists do not 'pursue research questions that they consider important for the progress of science, but rather collect points for ranking lists' (translated in Euler, 2017, p. 2), Euler argues that there is an increasing tendency for those involved in scientific knowledge production to find themselves in monocultures lacking connection to professional application. He goes on to describe how the development of design principles through a design-based research (DBR) process can interlink the knowledge production and practice design.

Our approach is from a different position in the design-research landscape and involves the on-going attempts of a major science museum - Questacon, Australia's National Science and Technology Centre [Questacon.edu.au] - to influence science education design in formal education settings including schools and universities. The direction being promoted is heavily informed by the learning sciences, but the museum has developed its own practice design. The bridge sought is between that practice design and the practice design of formal learning and there is no direct concern from the museum for knowledge production.

The primary means of influence has been through teacher professional learning (PL) opportunities. The PL on offer has taken many forms. A consistent observation, however, has been that the PL has been highly successful in teaching the teachers some new classroom activities, but much less successful in moving their curriculum design practice. This is a well-established challenge at a global level with on-going attempts by science education researchers and experts to shift schools' design practice lacking sustainable and scalable impact, even when the research or PL is well implemented and accepted (Fishman, Penuel, Hegedus, & Roschelle, 2011).

The challenges encountered in this endeavour, we suggest, are strongly linked to the pressures on university research scientists to focus on research metrics over and above progressing scientific discovery, so well described by Euler. This pressure has been brought about by the application of so-called 'neoliberal' modes of governance to the work of university-based scientists (Lingard, 2011). The professional colleagues of educational research scientists, the teachers, have faced a similar suite of pressures, particularly in the anglophile world (Connell, 2013). Under these pressures teachers are increasingly being held publicly accountable for the 'results' of their students, most visibly in basic skills testing and to prescribed 'standards'. Evidence, now longstanding, is showing this leads to a narrowing of curriculum (Berliner, 2009) and the adoption of teacher practices that put rankings in such tests ahead of the overall progress of the student (Ball, 2003). Further, it is redefining teacher identity (Hall, Gunter, & Bragg, 2012; Leonard & Roberts, 2014) within a 'competency' based monoculture displacing previous teacher identities such as the 'scholar-practitioner' (Leonard & Roberts, 2016; Moore, 2004).

These pressures present an enormous challenge for those seeking to influence teacher practice towards designs intended to promote higher-order thinking, creativity and difficult-to-test skills such as problem solving and collaboration. From our perspective this is a shame, because science education should capture the imagination. Science education is truly epic – the study of life, the universe, and everything! It delves into fourteen billion years or so of stuff happening. In the results driven era we work in, however, capturing the epic scale of science - capturing its real significance - can be a difficult thing to do within the school environment. Sadly the central professional question of school teachers seems to have become 'what can we do to improve our students' performance on the next test?', rather than 'what can we do that is actually worth our students' time, effort and attention'? These two questions imply a purpose that lead to very different ways of teaching and learning.

With ample evidence that student interest in the study of science, or at least science as it is taught in most schools, is on the wane across most of the OECD (Sjøberg & Schreiner, 2010) there appears to be a need for innovation. In this era of high accountability and neoliberal governance, however, innovation is professionally risky. If a new intervention does not 'work', or at least if it does not work in a way that shows up on the next test, then teachers risk being seen as, or even formally evaluated as, ineffective. Not surprisingly then, a lot of the innovation we see occurs in the extra-curricula space, or is only available to the 'better' students as 'extension' work. Innovation that is transformative and available to all students is far less common.

Noting the inherent risks of innovation in practice, an approach to innovation that education might borrow from other sectors is the use of 'innovation labs'. Such labs are resourced centres where risk taking is acceptable and where failure is part of the iterative design process that leads to improvement. In science education, science museums appear to have the potential to fill this role. In recent years Questacon, Australia's National Science and Technology Centre, has been exploring its capacity to fulfil this potential. While first and foremost a world-renowned experiential science museum known for engaging the public in science phenomena and for showcasing of Australian innovation, the open-ended nature of Questacon's purpose also makes it an ideal place for research and development of innovation in science education. Aiming to raise understanding and awareness of science, Questacon is not driven by the 'next test', so it can afford to engage in long-term development and can more easily treat the occasional failure as an opportunity to learn.

Implementing the innovative work of Questacon in sustainable and scalable ways, however, is no simple matter. The human and physical resources of Questacon are unique in Australia, and rare in the world. The staff team draws together a diverse mix of knowledge and skills in science, technology, design, performance, communication, and education in a way that allows for significant collaboration on projects. Questacon's infrastructure allows the rapid fabrication of demonstrations, development of high-end graphics and media, and extensive use of digital platforms. Apart from lacking the same resources and infrastructure, it is well established that schools are, on the whole, highly resistant to change working to a now well entrenched 'grammar' of their own (Tyack & Tobin, 1994). For those involved in teacher professional development, the design and research problems that flow from this intersection are numerous. How, for example, can the approaches of a place like Questacon be useful in settings that do not have its resources and diverse staff mix? What aspects of the approach rely on the 'wow' factor that Questacon can provide and what aspects can be used in any setting? How can Questacon move beyond measures of attendance and develop an 'expanded' suite of metrics that tell a more complex story of engagement, impact and esteem? And how can teachers from formal settings be supported in looking past the 'wow' factor of the activities that museums develop and learn the underlying design principles in a useful way?

A co-design tool we have used in this work to make design principles concrete, and so promote their transfer, is the development of conjecture maps (Sandoval, 2004, 2014) and facilitation of conversation around those maps. We present the discussion below to further the consideration in this journal of how design principles can be made concrete, and to suggest directions for further research to support this endeavour.

2.0 Conjecture mapping: A (co)design-research tool

Conjecture mapping (Sandoval, 2004, 2014) is an approach that assists in fully articulating the purpose of, and decision-making within, an educational design. This articulation of what was supposed to work, and how it was supposed to work, provides a fixed point for analysis within the complexity of an educational environment. Sandoval's approach starts with the assumption that educational designs and educational environments are inherently theoretical and intrinsically embody (or 'concretize' as Euler, 2017, suggests) hypotheses about how learning happens. Conjecture mapping is an effort to make these hypotheses explicit and transparent. They allow for the visual mapping from high-level hypotheses to their embodiment in educational designs and environments by way of identifying the mediating processes educational designs are intended to elicit and, in turn, the learning outcomes that should be derived from those mediating processes. The intended move from design to mediating process Sandoval refers to as a 'design conjecture', while the intended move from mediating process to outcome he refers to as a 'theoretical conjecture'.

We have briefly examined the use of conjecture maps in a previous contribution to this journal (Leonard et al., 2017) where the teachers we were working with found the apparently simple science activity of observing rust form in different conditions is actually a very complex pedagogical (didactic) task. To explain the process a little further, let us consider another well-known example in science education: a student investigation into acid-base reactions. We might do this with the design conjecture that students will test a variety of substances for evidence of a reaction (observable interactions between student and design), and that the students will create records of those reactions (participant artefacts). Our design conjecture might be that the students will observe and discern the relevant evidence of a reaction such as the emission of a gas. To encourage students to discern the most pertinent evidence, many teachers will include in their design explicit information on what to look out for. Of course, what students will actually do is conjecture. Students may choose to mix all the reactants together all at once just to see what happens, or they may focus on the colour of some reactants because they find them pretty, or they may decide to investigate the effects of drinking an acid!

Even if the design creates entirely the desired activity, the translation of the process to learning also involves conjecture. Embodied in the activities teachers design are the theoretical conjectures teachers have about how a concept is learned, or on the order in which concepts ought be learned, or perhaps on what motivates students to learn. In our acid-base example, we may have a working theory that students will construct a more complete understanding of the acid-base reaction through combining direct observation with theoretical knowledge and, further, that the observation of multiple examples of the reaction will allow them to draw a generalisation. Notably once this conjecture is articulated, then assessment might reasonably be seen as a test of teachers' conjecture and design rather than of the students' ability (Hattie & Yates, 2014).

Important in the use of conjecture maps is the understanding that students will regularly take paths and detours not found on the teacher's map. Conjecture maps provide a guide to what is implied in an educational design such as a curriculum, a resource or a technology. They do not provide a guarantee of what will actually occur. In providing a clear articulation of intention, however, they provide a basis for systematically investigating the ways in which students interact with the design, and the role of context in the interaction. Conjecture maps do not allow researchers to fix or control points of complexity or uncertainty, but they do assist in discerning the most pertinent aspects of an educational design working within an educational environment. They provide a starting point to examine the success or otherwise of educational designs, as well as a place to start the examination of what unexpected variables diverted the design intent. In doing so, conjecture maps can lead to the identification of design principles that might be transferable to other educational designs or environments.

It is the capacity of this method to identify design principles that has promise as a tool for transferring innovation from labs such as Questacon into the wider field of STEM education. As noted already, the context of Questacon is difficult to replicate. The conjecture maps of educational designs, however, can be drawn across other contexts leading, perhaps, to similar although unique designs. The resulting 'cartography' may be rough, but it may provide enough guidance to discover new educational places and spaces.

2.1 An 'interjection' on conversation

As we noted earlier, our peer-editor and now co-author (M.W. Johnson), read an earlier version of this paper and responded with a series of questions. Here we add this contribution to the discussion:

> The conjecture mapping idea is interesting because, like all interventions of this kind, it may create the conditions for conversation and a way of coordinating it. I would also like

to ask what kind of a conversation is this? Most critically, I would like to know if this is a conversation that reveals the uncertainty of the teacher? Is it a conversation that leads to the asking of what von Foerster calls 'legitimate questions' – that is, questions to which nobody knows the answer? Or is it a conversation that leads to the asking of 'illegitimate questions' – the standard stuff of the science curriculum (M.W. Johnson, personal communication, January, 2017)?

3.0 Design conjecture and conversation

Johnson's thinking on the coordination of conversation is really interesting here, and is something he has expanded upon in his blog post on the work of Everett Hughes in the area of organizational risk in health and education (Johnson, 2017). Noting the work of Hughes and others form the Chicago School of Sociology on 'ecological' understandings of social institutions, Johnson (2017) points out the need for 'coordinated diversity' in an era when 'technologically-mediated metricisation' is eliminating diversity from institutions. We have already touched on the issues of metricisation above in noting the measurement pressures upon both research scientists and teachers, and so we have found Johnson's notion of 'coordination' in response compelling. We have written elsewhere (Leonard & Roberts, 2016) of the limitations of so many researchers simply using the term 'neoliberal' as a catch-all phrase for something negative without offering alternatives beyond a loose call for a 'return' to a romanticised vision of the a bygone era. It is difficult to imagine the circumstances in which unstructured conversation, no matter how scholarly it may end up being, will be seen as a 'quality' design for mass education. Coordinated diversity, however, may offer an alternative to mass standardisation.

To respond to Johnson's questions, we will recount the nature of the conversations that occurred through our application of the conjecture mapping technique to a specific project within our work of translating museum practice designs to formal education. This project was on the use of 3D printing for educational activities with teenagers.

3.1 A case study of 3D printing

This paper is not intended as a full illustration of practice, but in order to ground our consideration of the resultant conversations, it is necessary to provide some context through a description of the sorts of design work we were engaged in.

From printing body parts to specialized equipment for the battlefield, there is little doubt that 3D printing is the new digital blacksmithing. Some commentators go so far as to suggest that the economic impact of 3D printing may be greater than the internet (Sedghi & Hall, 2015). In 2015 Questacon implemented a new 'virtual excursion' built around a 3D printing design challenge in which schools in Western Australia, Victoria and the

Australian Capital Territory (ACT) simultaneously participated. In keeping with all Questacon virtual excursions the major design conjecture, that is the hypothesis of the mediating activity the design will elicit, is that the participants will take on the intellectual and physical activity of a scientist/engineer. That is, the default design principle is 'learning by doing'. In this case, the challenge was designed to produce the specific behaviours and thought processes of an engineer including iterative problem solving and collaboration. The design focused the behaviours on the use of computer-aided design (CAD) and computer-aided manufacture (CAM or 3D printing), and scaffolded the behaviours through a number of learning activities, regular videoconferencing and through providing guidance to the supporting teacher within each participating school.

The enabling technology in the challenge, 3D printing, though relatively new, has already been used in diverse ways from printing viruses, to medical bionics to emailing a spanner to the international space station. In schools, 3D printing can obviously be used for fabrication in technology classrooms. In this virtual excursion, though, the Questacon design team used the affordances of 3D printing and CAD for a different educational purpose.

In the Questacon design student teams from participating schools were asked to collaboratively design body parts for an imaginary creature, with each school focussing on a different body part. In itself, the product being designed is relatively trivial and is not an important part of the design conjecture. The design hypothesis held by the Questacon team was that the participating students will use CAD/CAM technology to collaborate in a design process. Collaboration is an important real-world skill in science and technology and a strong theme in the Australian science curriculum, but can be difficult to authentically replicate in the school setting with its strong focus on individuals 'covering' the (standardised) curriculum. The design conjecture embodied in the Questacon activity is that a specific but open-ended challenge can create a more conducive environment for collaboration. This hypothesis has been at the heart of many science activities from Murder Under the Microscope, an Australian interactive environmental investigation game played by teams representing their school, to solar car challenges. A significant variation here, though, is the emphasis on collaboration across multiple school sites. This provides students with a greater sense of contemporary collaboration in research and industry, and reflects the strong emphasis on trans-national collaboration found in recent revisions to the Australian science curriculum.

The importance of the design conjecture in this project should not be under-estimated. For all its hype, the 'digital education revolution' has been dominated by digital content delivery (Cuban, 2003). At times the multi-media capacity of this delivery has added to what teachers can achieve, but in terms of the mediating processes that are elicited digital content is often not that different from a text book. Revolutionary educational designs, it might be argued, should be leading to new types of mediating process. The use of CAD/CAM technologies to support collaboration between students across geographic locations creates a qualitatively different mediating process when compared with much that has gone before. Even in the world of online learning the use of technology to support collaboration has largely been limited to discussion through asynchronous forums and possibly video conferencing. This Questacon design, however, uses technology to support collaboration requiring higher order thinking skills in collaborative design and problem solving.

3.2 A conversation among educational designers from different contexts

Prompted by Johnson, the remaining authors have considered how our conversation around this project progressed through the aid of the conjecture-mapping framework. The matter of the 'legitimacy' of the questions that arose particularly interested us. Noting that two of us (Leonard and Fitzgerald) have a school teaching background and have spent most of our careers in university-based teacher education, while the other (Kohlhagen) has spent a career in science communication at Questacon, we think that the conversation that arose was legitimate in the sense meant by Johnson. The conversations we had began with the question of 'what can those in formal education take away from this learning design from the museum context'? We were well aware that this conversation could and would quickly leap to 'known' answers relating to 'student centered'-ness and 'hands-on' learning, but we also knew that teachers from formal education settings have fundamentally different conceptions of what those things mean compared to educators informal settings like museums. So we were clearly working into a problem space with legitimate questions with unknown answers.

It is in entering such a problem space where we are putting forward the conjecture mapping process in response to Euler's (2017) open question on ways to make design principles concrete. We are well aware that a design principle such as 'make the activity student-led' is far from concrete as it lacks the specification to meaningfully bridge between contexts. This is the problem space we described at the outset of this paper, we know teachers in formal education will take away the specific activity as specified but, when exposed to a learning design such as this 3D challenge, they rarely re-work their conceptual understanding of the learning processes. In using the conjecture mapping process, we also confirmed that the theoretical conjecture offered by the designers from the museum context was poorly specified and was reported at the aphoristic level of 'learn through collaboration'.

These legitimate questions, we contend, highlight Euler's point that design principles must contribute to knowledge, even if that knowledge has only a limited generalisation range. Through our conversations, it became obvious that a deeper level of knowledge was needed to transfer the full sense of the design from one context to another. This need led to the researchers in the conversation preparing briefs such as in the next section intended to flesh out ideas such as ‘hands-on learning’.

3.3 Expanding knowledge on embodied Learning

This section is an artefact from the author’s co-design work. It is one of a number of briefs prepared by the researchers in the project to expand upon the practice-knowledge that was being applied within designs being generated by the museum such as the 3D printing challenge.

Western thought and science has tended to emphasise the place of principles, laws and the logic (the essence) over the being (the existence). Such emphasis has tended to develop disembodied and context-free views of human thinking and learning, often discounting or ignoring the role of practical human activity. Even in the west, however, the links between cognition and sensorimotor processing have been long understood by psychologists. Piaget (1952/1936) for example, noted that sensorimotor activity aids in constructing knowledge and that bodily actions are not separate from, nor solely downstream from, the mind. Some of the more powerful research and more complete theoretical frameworks for this relationship between mind, body and context, however, comes from the Soviet psychologists Vygotsky (1978), Luria (1971) and Leont’ev (1978). Luria made this point well when he wrote:

> Cognitive processes (such as perception and memory, abstraction and generalization, reasoning and problem-solving) are not independent and unchanging ‘abilities’ or ‘functions’ of human consciousness; they are processes occurring in concrete, practical activities and are formed within the limits of this activity (Luria, 1971, p. 266).

These understandings are increasingly supported by research in a number of domains including neuro-psychology, which is producing relevant evidence from fMRI experiments. Among this evidence is the demonstration that simply reading words related to action leads to a somatotopic activation – that is it makes the part of the brain that is connected to that particular movement “light up” even though there has been no actual movement (Pulvermüller & Fadiga, 2010). For example, reading the word “lick” activates areas of the brain that control the mouth, whereas reading the word “pick” activates areas that control the hand. This evidence is being used to argue that even the most abstract of thought is derived from physical embodiment. In related work, through careful observation of students engaged in mathematical problem solving, our colleagues at the University of Canberra have shown the importance of hand and body gesture in improving mathematical thinking (Logan, Lowrie, & Diezmann, 2014).

Work on creativity and innovation is also showing that the human brain is fundamentally set up for action. Here we find evidence that working through problems improves when our brains are able to connect the thinking they are doing with relevant action and, importantly, also with our feelings and emotions (Hutchins, 2010). The importance and potential of using ‘cognitive tools' in this way has been known for at least a couple of decades (Egan, 1997) but, despite calls from some researchers to place imagination at the centre of any reconceptualization of education (Haralambous, 2010), it remains an uncommon feature of school learning.

Most STEM educators will find the concept of embodiment makes intuitive sense. Hands-on activity has been at the heart of science education for a long time now. A better description of embodiment, though, might be 'hands-on/minds-on'. The object of learning designs that support embodied learning is not simply to create hands-on activity. Rather it is to acknowledge the connections our brains make between thought, feeling and action. This is an essential part of the design principles being applied by Questacon' design teams.

4.0 An 'interjection' on design science

In an early form, this paper concluded here with the neat observation that the use of the conjecture mapping had led to a design-research conversation leading to a more useful and 'concrete' specification of design principles. Johnson, however, had much more to ask, and we'll use his comments here to instead point to directions for further research.

> It seems that design science (rather like action research), as you suggest in your brief, sees the boundary between knowing and doing much closer to the doing bit than the knowing bit. Indeed, there is a question about whether there is a boundary there at all – but we are here at the division between ontology and epistemology. I rather like Roy Bhaskar's concept of this relationship as being one where epistemology is enfolded in ontology.
>
> In what way is design science a corrective to prevailing conceptions of being and knowing? To what extent is the notion of design here inseparable to that of social coordination, steering, conversation (and indeed, teaching)? (In this sense, design science is inseparable from the way cybernetics sees itself as design).
>
> It may be that central to 'designing' is another verb – 'listening. Maybe the more people are listened to, the better – that's not the traditional approach of education. Museums, on the other hand, could be great ears (M.W. Johson, personal communication, February, 2017)!

In reflecting on these questions in our context at the intersection of what is often termed 'formal' and 'informal' learning, the work of Naeve and colleagues (2008) on knowledge-transmitting versus knowledge-creating learning processes is informative, and specifies some of the particular challenges in moving between contexts. In Naeve's model, formal learning is typified by knowledge transmission, or pushing of the pre-specified curriculum. This leads to imitative learning processes where learners are rewarded for figuring out the right answers. In informal learning, on the other hand, knowledge and curriculum may only be created as the learning process is executed. Academic research is actually an example of a knowledge-generating learning process and, as we know, it rewards the finding of fruitful questions.

Our sense, from our position at this intersection of 'formal' and 'informal' learning, is that design science and educational design research does indeed offer an alternative to prevailing conceptions of being and knowing. In translating that alternative to an existing learning ecology such as a school or a university, however, there is a need to more fully understand the tensions in such things as the reward system. The work of another Chicago School sociologist, Abbott (2005) may provide further direction here. In his linked ecologies model, Abbott suggests that when agents in one ecology – in our case science museums – seeks to influence a linked ecology – such as schools – the incursions into the other ecology are fundamentally unknowable until they occur. It is simply not possible to fully predict how those incursions, which he refers to as avatars, will 'evolve' within the competitive rules of the new ecosystem – just as we could not have known how the introduction of the rabbit would transform the Australian landscape.

Following Bhaskar's (Scott & Bhaskar, 2015), we suggest that in addition to finding ways to 'move beyond the individual case', as Euler suggests, educational design research also needs to find ways to 'enfold' design principles within their context. That is, we need to find ways to bring the salient features of the individual case forward. In bridging between museum and school contexts for example, the work we have done in more fully specifying 'hands on learning' through articulating a more complete concept of embodied learning does not adequately take into account the different reward systems in play.

A further question from Johnson pointing to a need for further research is:

> Does conjecture mapping lend itself to diagrammatic thinking (as opposed to text) (M.W. Johnson, personal communication, March, 2017)?

This is another fascinating question of design thinking approaches in general. Diagrammatic tools are ubiquitous in most examples of design thinking. This may simply be a hand-down from the roots of design science in disciplines such as architecture, but we are also aware of the mounting evidence that visual and textual thinking are neurologically different activities (Dehaene, 2009). So we see here an important question for science of learning researchers: does the engagement of visual learning processes in teacher professional learning assist in removing the assumptions of one's normal work context?

5.0 Conclusion

Design-based research is emerging in a world where the gaps between scientific knowledge production and practice design, and even between different sites of practice design, seem to becoming wider. As Euler (2017) describes, we currently have many incentives to work in monocultures despite the clear value of work across sites of science and practice for progressing both. As argued by both Euler and ourselves, and elsewhere in different formulations (Bereiter, 2014), design principles seem a productive way to progress renewed bridge-building work across these gaps and growing monocultures. The current paper has progressed this discussion by picking up Euler's open question on concrete ways of formulating design principles within educational design research. It has argued that Sandoval's conjecture mapping expands the ways in which we can think about design principles as it assists fully articulating the purpose of, and decision-making within, an educational design, and by delineating 'design conjecture' and 'theoretical conjecture'. In doing so it has opened up new research questions in relation to how the contingent nature of design principles might be communicated, and how we might use the learning sciences to design professional learning that better spans contexts.

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Journal Details

EDeR – Educational Design Research
An International Journal for Design-Based Research in Education
ISSN: 2511-0667
uhh.de/EDeR
#EDeRJournal (our hashtag on social media services)

Published by

Hamburg Center for University Teaching and Learning (HUL)
University of Hamburg
Schlüterstraße 51
20146 Hamburg
Germany
+49 40 42838-9640
+49 40 42838-9650 (fax)
EDeR.HUL@uni-hamburg.de
hul.uni-hamburg.de

In collaboration with

Hamburg University Press
Verlag der Staats- und Universitätsbibliothek Hamburg –
Landesbetrieb
Von-Melle-Park 3
20146 Hamburg
Germany
+49 40 42838 7146
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