EDeR

Educational Design Research

Volume 2 | Issue 1 | 2018 | Article 14

Contribution Type Practice Illustration

Title **STEM Practices: A translational framework for large-scale STEM education design**

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Abstract

Underpinned by the nation-wide Early Learning STEM Australia (ELSA) project, this practice illustration presents a design framework to respond to the challenges of scaling and sustaining a large design-based research project. The framework, known as STEM Practices Framework, is informed by work within the Learning Sciences which suggests that the interplay between project innovation and the wider educational reform priorities are critical to the sustainability and scalability of projects. The ELSA project responded to this by developing processes of developmental evaluation to parallel the design based research of the project. Emerging from that process was a design proposition that the object of the project, and the entire STEM education agenda, is not simply to improve educational practice, but to shift educational purpose. Specifically, the paper argues that STEM Practices represents a qualitative shift in purpose from the content bound traditions of science, technology, engineering and mathematics education towards developing a greater capacity to use practices in diverse STEM contexts. The STEM Practices Framework described here was developed to support educators and developers to implement the project innovations built on this understanding. The framework is in two parts: (1) an adaptation of Kemmis et al.'s (2014) practice architectures approach and the practice architectures that support and constrain those practices. (2) A heuristic for working with STEM practices in large scale implementation.

Keywords design research
developmental evaluation
early years
ELSA
STEM
STEM education design
STEM practices framework

DOI dx.doi.org/10.15460/eder.2.1.1243

Citation Lowrie, T., Leonard, S. & Fitzgerald, R. (2018). STEM Practices: A translational framework for large-scale STEM education design. *EDeR - Educational Design Research, 2* (1), 1-20. http://dx.doi.org/10.15460/eder.2.1.1243

STEM Practices: A translational framework for large-scale STEM education design

Thomas Lowrie | Simon Leonard | Robert Fitzgerald

1.0 Introduction

> "As researchers, we [the Learning Sciences] have developed rich understandings of how technology can foster learning in specialized situations; we now need to develop knowledge about widespread appropriation and use of cognitively oriented technologies by school and school systems as part of real-world reform efforts" (Fishman, Marx, Blumenfeld, Krajcik, & Soloway, 2004, p. 45).

The Learning Sciences emerged as a distinct field in the 1990s, driven by a need to move learning research out of the laboratory and into "real-world" learning environments. The stock-in-trade work that quickly developed, and which still dominates the field, has been design-based research projects centred on specific educational innovations. This work has gone on under different names such as 'design experiments' (Cobb, Confrey, & diSessa, 2003) and 'educational design research' (Richter & Allert, 2017). Early in the life of the still nascent field, researchers found that despite the move into real world settings, translation and impact remained a challenge (Blumenfeld, Fishman, Krajcik, Marx, & Soloway, 2000; Coburn, 2003; Fishman et al., 2004). More than a decade on, and notwithstanding the growing diversity of interest and approaches within the field (Yoon & Hmelo-Silver, 2017), it is apparent that the challenge of translation has not been resolved and that it remains difficult to bring the innovative work within the Learning Sciences to scale, or even to sustain it at pilot sites once introductory projects are completed (Sarama & Clements, In Press; Sotiriou, Riviou, Cherouvis, Chelioti, & Bogner, 2016; Stanford et al., 2017).

Reporting from within a nation-wide design-research project called Early Learning STEM Australia (ELSA), this paper continues the discussion of the propagation and scaling of design research interventions. It does so particularly noting the importance of the interplay between innovation and wider educational reform efforts noted by Fishman et al. (2004). ELSA is an important context for this discussion as, even in pilot, the innovations within the projects are being trialled on a very large scale. At the time of writing this paper, we were working in 100 early learning centres spread across every state in Australia. The project connected with 300 educators and over 1700 children. Scale is an important component of the project because the design brief from the government required a tight alignment between the design work of the project and a wider policy agenda right from the outset. Due to its scale and deep entanglement with reform, the project demanded a translation and implementation stance from a much earlier stage than might typically be expected when undertaking design-research. In responding to this requirement, the ELSA project has strengthened the use of *developmental evaluation* (Patton, 1994) to widen its design considerations. In doing so, it demonstrates the value of drawing upon multiple methods to expand the design vision before zooming in on the core design experiment (Clements, 2008; Yoon & Hmelo-Silver, 2017).

The major contribution of this illustration of practice is the description of the *STEM Practices Framework, which has been* developed using processes of co-design (Britton, 2017) and developmental evaluation (Leonard, Fitzgerald, & Riordan, 2016) to support the translational stance of the ELSA project. The framework is being used within the ELSA project both to inform the design work and as a basis for professional learning with the hundreds of educators who are implementing learning experiences during the project. It is offered here as an example of how socio-cultural theory can support the scaling of educational innovation. The paper is offered in order to begin a discussion on the merits of using socio-cultural approaches as a means of going to scale with educational design research. At the time of writing, the utility of the approach is largely conjecture. It has made sense in our design sessions but there is a clear need for further research, and indeed for the development of research methods, both in this project and others.

The framework we offer here is an adaptation of the *practice architectures* approach of Kemmis et al. (2014). It develops from our findings in the early design process of ELSA that the major debates in the STEM Education literature around approaches such as the integration of science, technology engineering and mathematics (English, King, & Smeed, 2017) and making 'real world' connections (see for example Asunda & Mativo, 2017; Newhouse 2017) were not particularly useful for early learning design. This position was heavily informed by previous research by our group finding that even with older students (11-12 year olds) establishing meaningful realistic understandings of real world problems in group rather than individual situation is extremely challenging in practice (Lowrie, 2011). It is an attempt to find a more "useful" theoretical structure as the basis for design.

A principle on which the framework is based is that large scale interventions arrive in the middle of educational environments that are already underway and must recognize that they cannot demand a "clean" starting point. STEM Practices is a framework for engaging with the ongoing narrative of educational environments *per medias res*, or "through the middle of things". It is developed with an awareness that the environments educational designers and researchers work with have their own history and culture before the intervention and that they will carry on in complex and unpredictable ways after the project. To this end, the paper will also present the heuristic version of the framework that is intended to be adaptable in the vast variety of contexts that the ELSA project engages. Before describing the STEM practice framework or its heuristic form, however, the paper will begin with an outline the project and policy context of the design research work from which the framework emerged.

2.0 Learning through design

The STEM Practices Framework described in the later part of this paper emerged from the design process of the Early Learning STEM Australia project. It is an example of how design-based research can contribute both to questions of practice and questions of theory. This first section of the paper sets out this design-research trajectory.

2.1 Early Learning STEM Australia (ELSA)

ELSA is a design research project commissioned by the Australian Government. As described in the call for tenders, the "ELSA pilot programme is designed to specifically inspire curiosity and engagement in STEM concepts in preschool children." The project requires the development and piloting of four "highly engaging early learning apps" for digital tablet devices such as the *Apple iPad* or *Samsung Galaxy* Tab to be used in early learning centres such as preschools. The project also requires the development of a support app and professional development for educators in those settings, and for an app for families of the children.

The intention of ELSA's technological intervention is to support educators and provide them with new and enhanced ways to engage children in STEM learning. The apps are specifically *not* intended to provide stand-alone activities but rather to support play-based learning consistent with both the Australian model for early years learning (*Belonging, being and becoming: The early years learning framework for Australia,* 2009) and with the cognitively oriented designs long espoused in the Learning Sciences (Bransford, Brown, & Cocking, 1999).

Intended by Government as a national program to be used in all early learning settings across the country, ELSA is a very large project even in pilot. The pilot involves trials at 100 early learning sites spread across all of Australia's states and territories. The sampling methodology employed ensures the inclusion of metropolitan, regional and remote sites and that the sites involved cater to communities reflecting Australia's cultural and socio economic diversity. The sites selected also reflect the structural diversity found in Australia's early learning environment in which patterns of attendance and levels of staffing qualifications can vary greatly. The ELSA project has not simply moved out of the controlled environs of the laboratory, it has actively sought out virtually every source of complexity available.

The project was initially developed as a large design experiment (Cobb et al., 2003) and has established processes of iterative co-design with educational researchers, app developers and practicing early learning teachers and educators. The parameters of ELSA, however, do not allow the typical design-based research trajectory starting with a relatively small-scale proof-of-concept phase. Rather, as a condition of contract, the project must move to substantial scale in the pilot phase, and then to national adoption within a few years. Notably, ELSA is also not attempting innovation within a well-established curriculum as there has been little to no official curriculum development or tradition in

Australian early years learning. As these parameters have been engaged, the methodology of the project has evolved to draw on other established research methods such as developmental curriculum evaluation (Clements, 2007).

The catalyst for this methodological evolution was the initial design challenge of supporting several hundred teachers and educators to implement the pilot phase of the project when interaction between those teachers and the project team would be very limited; [1] and when so few of those teachers and educators would have any formal training or experience in STEM beyond work in pre-numeracy. These are the challenges of translation and implementation that typically either come later in the life of projects such as this, or are simply never attempted (Stanford et al., 2017).

2.2 Designing for early translation and implementation

ELSA began with a series of design workshops that brought together experts in science, mathematics, technology and early learning; a highly accomplished app development team; practicing teachers; experts from Australia's leading science centre; and science communications professionals with backgrounds in radio and television production. This team sought to establish a design process by which to choose a set of learning activities which were appropriate for the learning environments of the pre school year, and which could be enhanced by the use of a tablet device.

The early ideation process undertaken by this group quickly produced dozens of activity ideas, largely adopted or adapted from our collective educational and communications experiences. The educational purpose and merit of these activities were immediately obvious to the experts within the room, although there was some debate about the developmental appropriateness of some activities, and the extent to which certain activities supported the "open-ended" learning that quickly emerged as a tacit objective. Two major issues emerged in this early ideation process. The first was around a need for clarity on what was "STEM", as opposed to the recycling of science and mathematics activities that was clearly occurring in the process. The second, particularly raised by the practicing teachers, was that the familiarity with the learning approaches and content quickly assumed by our expert team was probably not available in most early learning settings.

With the project's need to work at scale in mind, the issue of teacher knowledge and understanding took priority. The design team called for a research review on the support of teachers in the translation and implementation of educational innovation. The review quickly made it apparent that this is a complex task that remains a source of significant debate. Bereiter (2014), for example, has argued powerfully for the need to support the development of *principled practice knowledge* (PPK) – essentially a set of design principles to guide educational practice, giving teachers both the "know how" and the "know why". Janssen,

[1] "Educator" is used in the Australian early learning context to describe a worker who may or may not be a fully qualified teacher. They typically hold a sub-degree qualification, work under the direction of a degree-qualified teacher, and are the largest part of the early learning workforce.

Westbroek, and Doyle (2015), however, contend that Bereiter's formulation of PPK lacks the specification that professional designers and teachers require in real world settings. Their argument is that changes to practice come at a high cost in time and cognitive demand, and that teachers will only make the investment required when there are clear and discernible returns on that investment. They advocate instead for the use of "fast and frugal heuristics". In mounting this argument, Janssen et al. point to research suggesting that professionals in complex real-world settings do not make decisions by carefully weighing alternatives, but rather through heuristics or procedures that allow them to ignore a lot of available information (Gigerenzer & Gaissmaier, 2011).

The arguments put by Janssen et al. (2015) reflect the concerns of the researchers such as Fishman et al. (2004) and Kelly, Baek, Lesh, and Bannan-Ritland (2008) in their demonstrations that in recent decades, political forces have pushed teaching practice away from the cognitively rich approaches promoted by the Learning Sciences. The resulting argument for design-based *implementation research* (DBIR, Penuel, Fishman, Cheng, & Sabelli, 2011) that is, design-based research that also systematically includes a concern for the impact of systemic reform on practice, is compelling and has influenced the work of the ELSA design research team. In thinking from this perspective, however, it became apparent that the systemic reform and political processes that formed the context of the ELSA project was not only the neoliberal reforms to teacher practice that the researchers cited above were referring to and which have been well explored in other education literature (see for example Ball, 2003; Connell, 2013; Leonard & Roberts, 2016). Through design considerations of options such as PPK or fast and frugal heuristics, it became clear that the "know why" could not be left out of the support provided to teachers in the ELSA project. This was evident because of the first challenge we had identified of clearly differentiating STEM from the subjects that form its acronym.

At this stage, it was apparent that the initial approach to the project based on design experiments was not sufficient to meet the project objectives. Through tacit agreement within the group, the work had taken on the character of developmental evaluation (Leonard et al., 2016; Patton, 2015) so that approach was explicitly adopted. Developed by Patton (1994) developmental evaluation departs only slightly from the more familiar formative evaluation approach in that it starts even earlier in the life of a project. In doing so, it brings an evaluative stance to the determination of the very objectives of the project and provides frameworks for the development of joint understandings of those goals and their elaborations. While ELSA had begun with a clear and apparently straight forward objective of app development, the work of the project had, by necessity, moved into a broad consideration of the goals of STEM. Notwithstanding the above, it should be noted that the app development team were very practiced in agile methods for rapid prototyping of ideas and products and found this approach very consistent with their work practices. The team called for a widening of literature review on STEM to support the re-evaluation of the project objectives.

2.3 STEM as reform

"Learning by doing" has a long tradition in education in the wider sciences, and has been given a renewed impetus with the emergence of activities such as the *maker spaces* (Sheridan et al., 2014). Given our team's advocacy for an active and embodied learning design, there was a certain pleasure in the realization of our own team's learning, which arose through the design of support for teachers and educators. That learning, it must be said, came via the frustration of numerous design failures. Through reflexive analysis of these failures, we came to see STEM not simply as an object for design, but as a reform initiative. This learning from within the design process was a key step in the development of the framework described later in this paper.

While STEM is an acronym derived from four connected disciplines, in our reflexive view, the policy discourse around STEM makes it clear that it represents an agenda beyond finding pedagogic efficiencies. ELSA, for example, has been commissioned as an initiative under the Australian Government's Science and Innovation Agenda (Commonwealth of Australia - Department of the Prime Minister and Cabinet, 2015). This agenda in turn is part of a broader policy suite seeking to make Australia a

> "science nation… in which science is woven, not only into our classrooms, but also into our boardrooms, our workplaces and our living rooms, as one of the building blocks of our prosperity" (Commonwealth of Australia, 2015, p. iii).

Australia is not alone in positioning this expansive vision of science, increasingly under the banner of STEM in the educational context, as a basis for its future economic well being. Indeed, Australia has largely borrowed the policy discourse from Europe (Rocard et al., 2007) and the United States (Committee on STEM Education, 2013), as have many other nations (Marginson, Tytler, Freeman, & Roberts, 2013; OECD, 2014). However, with a historical reliance on primary production and an industry policy discourse that positions the national research ecology as high in knowledge development but low in translation and commercialization (Carter, 2017; Davidson & Potts, 2016), the idea of STEM education seems to have had particular resonance in the Australian context – although a similar resonance can be found, for example, in Canada (Science Technology and Innovation Council, 2013). It is notable that in the policy suite from which ELSA emerges, STEM is explicitly part of a policy strategy seeking to address issues such as Australia being ranked last among OECD nations for business-academia collaboration and the fact that it is slipping on the rankings in the Global Innovation Index (Commonwealth of Australia - Department of the Prime Minister and Cabinet, 2015). In other words, in the Australian policy context, STEM is not simply an approach to improving science, mathematics and technology education. Rather, it is a fundamental repositioning of the goals and objectives of formal education to better support national innovation.

Through the evaluative engagement with this scholarship, the design research team concluded that we could not support the implementation of the project across the 100 pilot sites through the deployment of simple heuristics alone. This is because the idea of STEM has emerged from economic and industry policy and has been poorly specified for education. The ELSA project brief to "inspire curiosity and engagement in STEM concepts" is itself an example of this. In Australia, STEM has not yet been included in the official curriculum apparatus, so what makes something a "STEM" concept as opposed to a science concept or a mathematics concept is not immediately clear to educators without a significant engagement beyond the tools and systems of standard practice. Even with such an investment, teachers, educators and educational designers will encounter diverse ideas and opinions on what STEM should be and look like (English, 2017).

2.4 Reforming the heuristics of STEM education

Emerging from the reflexive analysis of a developmental evaluation process, our argument and design premise is that STEM is a policy discourse from beyond the world of "education". STEM is not a continuation of science, technology, engineering and mathematics education traditions. Rather it represents a point of discontinuity, of society asking for a qualitative change in the objectives of education undertaken in the domain of the sciences. Given this policy discourse, the dominant heuristics that have emerged for educational designers and teachers – "integrate disciplinary learning" and "connect to the real world" – are insufficient. They are inadequate as they do not draw from a broadly understood or well specified curriculum. STEM, we contend, points to a different set of "fast and frugal" ideas that are specified only in the most general of terms, even within their original economic and industry policy discourse, through imprecise phrases such as "changing skills needs in the labour market" (see for example Education Council, 2015; Office of the Chief Scientist, 2014; PwC Australia, 2015). In response, the design work of the ELSA team expanded. It was recognized that to implement the project, we would need to move beyond ideas like disciplinary integration and develop a new sense of "STEM in the world" not fully available in the antecedent subjects of science, technology, engineering and mathematics with their deep content bound history.

The proposition that the design heuristics of integration and real-world connection are inadequate finds support in the literature on educational designs in STEM. These twin heuristics make intuitive sense, but it is not clear that they are leading to powerful, sustainable and scalable designs. The arguments that the integrated approach is leading to a reduction in disciplinary strength (English, 2017; Honey, Pearson, & Schweingruber, 2014) for example, poses significant challenges for the viability of the entire STEM project. As we have noted, STEM education design does not occur in a vacuum. In Australia, as in most places, it takes place within a schooling system that valorises content bound disciplinary knowledge through instruments such as exam systems and university entrance procedures. Educational approaches that seem to erode the knowledge forms which are so richly rewarded within the formal education system are not likely to be implemented in a sustainable fashion.

Resulting from the need to maintain strong discipline-based content, STEM is largely being implemented as an additional activity alongside continuing classes in at least science and mathematics. Reviews of these additional activities find that mathematics and engineering are often and increasingly neglected in "integrated" designs, largely in favour of technology (English, 2016). That is, the object of curriculum design has become the use of a particular technology such as robotics or 3D printing, with a tacit assumption, based more on hope than design, that the engagement will improve learning across all areas of STEM. There is evidence to suggest that this hope is misplaced with relevant studies showing, at best, mixed results (see for example Selcen Guzey, Harwell, Moreno, Peralta, & Moore, 2017).

The weak design outcomes built on the integration heuristic are not surprising, as successful integration across subject and discipline traditions can be shown to require extensive time and resources (Becker & Kyungsuk, 2011; Shernoff, Sinha, Bressler, & Ginsburg, 2017) and, critically, depend heavily on the understandings of integration of the teachers and school leaders involved (Becker & Kyungsuk, 2011; Clark & Ernst, 2009). It is apparent that strong integrated design requires the development of a strategic approach to implementation (Kelley & Knowles, 2016) and a strong, shared understanding of the goals of the integration. The framework proposed in this paper is providing the basis for a more strategic implementation within the ELSA project.

The other "go to" heuristic of STEM – the principle that learning should connect to the "real world" – also needs a rethink in how it is realized in implementation. The ELSA design team agree with, and strongly advocate for, the basic principle of authentic learning, but our contention is that the poorly theorized understandings of what makes educational activity authentic has led to very thin learning designs. We note, for example, the findings of Aydeniz, Baksa, and Skinner (2011) whose study of a scientific "apprenticeship" program for high school students did develop the participants competency in experimental methods, but had limited impact on their deeper understanding of the nature and value of science. This study is typical of a common interpretation of the real-world heuristic as "the real-world practice of scientists/engineers" (see for example Costa, 2017; Newhouse, 2017). In this case, the students will indeed use mathematics and technology in their scientific inquiries just as real scientists do, and their attention may be drawn to this. However, the design has an implicit assumption that the purpose of the activity is to instil the disciplinary practices of science and does not bring about the discontinuity sought by STEM.

Another common realization of the real-world heuristic is an aphoristic call on new labour market skills. Writing in a professional school leadership journal, Costa (2017) for example, points to labour market forecasts suggesting that "almost all of the 30 fastest growing occupations in the next decade will require some background in STEM" (p. 32) as the primary rationale for her claim that robotics is the "coveted E-ticket" to prosperity. Yet the link between robotic coding and the technology entangled jobs of the future is not as self-evident as it might appear. We note, for example, more complete analysis of the skills requirements being listed in job advertisements shows instead, a growing demand for apparently non-STEM skills like communication within STEM aligned occupations (The Foundation for Young Australians, 2017). We note also the limitations of assuming that any new technology, or even any growing labour market trend, however well substantiated, will have universal appeal. Our argument is for a more nuanced conceptualization of real-world connections. Even as the STEM policy discourse is driven primarily by a perceived need for different forms of human capital within the labour market, there is a need for far richer understandings of what that capital is. STEM calls not simply for more people to be trained to fill the occupations we can perceive or use the nascent technologies that may or may not dominate our futures, it calls for the development of greater capacity for more people in our society to use the powerful tools and forms of reasoning that have emerged in the STEM fields since the enlightenment.

Ultimately, a major limitation of design heuristics as they are used to implement innovation on scale is that they are interpreted through the lens of existing methods and traditions. They are, in effect, "avatars" inserted into a social ecosystem (Abbott, 2005) that are then subject to the competitive pressures of that environment. Educational environments are so complex that it is unrealistic that all of the pressures can be anticipated and responses to them specified in a design. It is essential, therefore, to create "hinges" to connect the ecosystems of implementation with those of designers and the policy discourses they represent. To develop such a hinge, ELSA sought a stronger theoretical foundation for thinking about the real-world context of STEM and found it in *practice theory*.

3.0 The STEM Practices Framework

In the previous section, we sought to describe the design research thinking on how to implement the nation-wide Early Learning STEM Australia project pilot at scale. The scale of the project, and its setting within a policy discourse that comes from outside of education, present particular challenges for sustainable and scalable implementation. A key response has been to design ways in which to support educators who, ultimately, will be responsible for implementing the project without the benefit of significant access to [or contact with] the ELSA design research team. The approach taken has been to induct the educators into the design process. To support them as co-designers, the STEM Practices Framework was developed and is presented in this second half of the paper.

3.1 Practice theory and practice architectures

Practice theory is far from unified and might be thought of as a broad approach used by diverse social theorists to find an explanatory balance between individual human agency and the influence of social structures (see for example Bourdieu, 1977; Giddens, 1979; Schatzki, 1996). In adopting this theoretical set, our conjecture is that the explanatory modes offered by practice theory also offer a productive way to think about and design with the real world connections of STEM learning. Our framework is particularly influenced by the educational application of practice theory through the *practice architectures* approach of Kemmis et al. (2014). Noting the tendency of our times to understand education as a technical process for producing "learning outcomes" from the raw materials of students themselves, this work instead brings the agency of students back into educational thinking. It argues that education, which is perhaps distinct from schooling, is about initiating students into *practices*, and fostering desired *practice architectures*.

In the model of Kemmis et al. (2014) practices are socially established forms of human activity. They are enabled and constrained by practice architectures, which are characteristic arrangements of actions and activities (doings). These 'doings' are comprehensible in terms of similarly characteristic arrangements of ideas and discourses (sayings), and through the arrangement of people and objects (relationships) (Mahon, Kemmis, Francisco, & Lloyd, 2016). That is, practices do not simply happen in "context" but are both influenced by and creative of the architecture of the language, activity and social structures in and through which they occur.

In developing the STEM Practices framework, we have adapted the model of Kemmis at al. (2014), highlighting, though, the importance of non-verbal *representation* and reasoning within STEM. The STEM disciplines have long used symbolic and graphical representations as important forms of meaning making and, as Lowrie (2014) has argued, specialized language is likely to be overshadowed by other forms of representation in the future. As such, our addition of representation to the practice architectures model serves only to highlight the diversity of semiotic practice within STEM. STEM reasoning has been harder to position.

Within the literature, reasoning is often discussed in association with language use (see for example Norenes & Ludvigsen, 2016; Selling, 2016) and so might also be a *saying*. Elsewhere, however reasoning is understood in terms of tool use (see for example Cobb, 2002; Nevile, Haddington, Heinemann, & Rauniomaa, 2014) and so might be seen to take place within the medium of activity and work. For this project, we have positioned reasoning alongside *sayings*. We suspect, however, that there would be value in exploring further how forms of STEM reasoning such as spatial or computational thinking might be understood within a design framework as an emergent property of activity involving both semiotic and physical space (see for example Abrahamson & Sánchez-García, 2016; Engeström, 2006). Many of our design team have come to refer to such forms of reasoning as a 'meta-practice' emerging from the interactions of sayings, doings and relatings.

As set out in Table 1, the practices framework supports educational designers to see the connections between the "sayings" of individuals and the social world of ideas or discourse; the "doings" of people and the social arrangement of material-economics; and the "relatings" of individual and the socio-political arrangements of people. This is a framework for the "why" of learning, and one that provides a series of tangible contact points for design. As such, it has the capacity to provide a foundation for both principled practice knowledge and heuristics.

	The initiation into practices of the individual	**Medium**	**The fostering of desired practice architectures**	
	Sayings, Representation and Reasoning	Semiotic space, language, symbols	Individual and collective self-expression, discourse	
Individual world	Doings	Physical space, activity and work	A sustainable economy, activity for self and community development	The world we share
	Relatings	Social space	Self-determination, democratic society	

Table 1: Adaption of Kemmis's Practice Architectures framework

3.2 A foundation in STEM Practices

The practice architecture approach has offered a productive way for our educational designers and educators to think about the nature of STEM learning. We have used this approach to provide a more substantial, robust design framework that is more sensitive to what is known about learning than simple heuristics like "real world learning". As set out in Table 2, we have identified a set of practices we see as core to STEM, and then asked our designers and educators to think about how those practices play out through semiotic, physical and social space in the practice architectures that are available to their children. This brings attention specifically to the real world of the child and the practice architectures with which they actually engage. An outcome of this in the app design has been a dance activity that highlights the STEM practice of identifying and using patterns.

<table>
<tr><th></th><th>The initiation into practices of the individual</th><th>Medium</th><th>The fostering of desired practice architectures</th><th></th></tr>
<tr><td rowspan="3">Individual world</td><td>Ideas
Problem finding
Finding and validating evidence
Questioning
Proposing
Designing and building
Exploring and challenging</td><td>Thinking, communicating</td><td>Understanding how the world works, Finding ways to make the world better</td><td rowspan="3">The world we share</td></tr>
<tr><td>Methods
Generating ideas
Processing information
Encoding and decoding information
Using appropriate language and vocabulary
Using tools to produce artefacts
Thinking critically</td><td>Designing, building, experimenting, modelling</td><td>A sustainable economy, community development, enjoying the world</td></tr>
<tr><td>Values
Curiosity
Integrity
Imagination
Creativity
Teamwork
Persistence</td><td>Working with others</td><td>Participation in democracy, custodianship of nature, innovation and improving human lives</td></tr>
</table>

Table 2: STEM Practices

Notably this approach is not content-bound. This is not common in the wider discourse on STEM as can be seen in the various calls to broaden the acronym to include, for example, STEM(-Medicine), STE(Arts)M, or ST(Reading)EAM, which all suggest a continuing focus on discipline content. We would argue, in fact, that it is actually detrimental to the intent of STEM engagement to align STEM curriculum design with content domains such as science, technology, engineering or mathematics. The goal of enacting STEM Practices, in contrast, provides a way to think of diverse engagement with STEM without recourse to content. As such it supports thinking about STEM engagement by artists, doctors, and any other field that field or activity that makes use of STEM Practices. STEM connects to the real world not on the basis of disciplinary content, but through the diverse use of the sayings, doings and relatings of STEM practice (Kemmis et al., 2014).

We appreciate that a philosophy of moving away from a content base works particularly well in the early years context of ELSA where learning is associated with play-based engagement and intentional teaching rather than discipline content and curriculum syllabi. As Becker and Kyungsuk (2011) argued, an integrated approach to teaching STEM in the younger years appears easier since higher year levels are more confined by standardized assessments, structural limitations in schools, and issues of collaboration among teachers (Shernoff et al., 2017). However, we contend that an approach through STEM Practices has wider application. Most schools and education systems will continue to be overwhelmed by the challenge of integrating discipline content into a STEM program if subjects within the acronym continue to drive initiatives.

The STEM Practices approach also appears more productive than the rather hit-and-miss approach of finding "contexts" that are relevant or engaging to the students. The contexts approach is a fraught endeavour that has too often been driven by unfounded assumptions like "girls will be engaged through the study of cosmetics". In contrast, this framework seeks to engage students in the use of STEM reasoning through the enactment of practices they can perceive to be authentic, even if those practices are not fun or entertaining. As such, the framework offers a very different way to conceptualize what real-world connections in STEM are.

3.3 A new heuristic: Experience, represent, apply

The STEM Practice Framework operates as principled practice knowledge (Bereiter, 2014). We recognize, however, that while most of the teachers and educators we work with understand what STEM practices are about, it remains difficult for them to jump from those big concepts to practical action within their individual and child-driven learning environments. To address this, the framework also offers a heuristic as suggested by Janssen et al. (2015). The heuristic of "experience, represent, apply" (ERA) has been adopted from a pedagogical model first proposed by Lowrie and Patahuddin (2015) which described a way of designing learning opportunities in a manner aligned to how concepts are developed. The ERA model was developed to assist educators to focus on engaging students in the use of STEM practices through the enactment of practices they can perceive to be authentic.

The ERA heuristic asks designers and educators to create learning activities that use or enact forms of STEM practice in the context of real-world practice architectures. The three stages of the design are cyclic in nature, with the intent of each phase as follows and expressed in term of ELSA's app-based activity:

Experience. This is what children already know. Children's lived experiences are used as the foundation for concept development through social engagement and language. Children will participate in a range of play-based, off-app experiences that provide opportunities for them to use language in ways that connect personal experiences with new understandings.

Represent. Children will play a variety of games on the apps to engage with, and represent, STEM concepts. These representations will include creating images, interpreting pictures, visualizing and using symbols. Children have opportunities to create their own representations to use within the apps via the microphone and camera tools.

Applications. Children will build on their learning from the on-app activities through a range of off-app activities, guided by their educators and their families. Engagement with the visual and symbolic representatives on the app will also promote new child-centred play based experiences.

Using this model, children are provided opportunities to *experience* a concept first. This concept is then represented on the app in a game format. This engagement can then be followed with opportunities to *apply* the idea to their own environment. By way of example, children can experience copying a pattern in a story read by the educator about patterns in nature. They represent this on the tablet by copying the pattern generated by one of the characters within the ELSA app. They then apply this by putting down the tablet and copying a pattern one of their friends has made using blocks. This application then feeds back into the next ERA cycle as children experience extending a pattern based on a new story.

Active engagement with the app is restricted to the "represent" component of the learning design. The "experience' activities are intended to scaffold student understanding, as well as encourage play-based curiosity to use the apps. In early year's settings, play and engagement are child-centred—consequently, the practices that pertain to the context (the saying, doings and relatings) need to be both acknowledged and valued. The "apply" component of STEM Practices are similarly important, since the children are likely to disengaged with the digital resources at any time, of their own choosing.

3.4 'Jamming' with the ERA heuristic

The STEM Practices Framework and the ERA heuristic have now been used extensively in both app design and piloting in the first year of the nation-wide ELSA project. The design phase for the ELSA apps themselves has been carried out by the expert team described earlier in this paper. This team included a number of early learning educators, but it did not engage all 100 early learning sites in the pilot. The implementation into those pilot sites, however, has taken the form of a second iteration of the design process, with the educators from those sites being regarded and engaged as co-designers of the activity around the apps. In this sense, the professional development offered to educators from the pilot sites has tended to take the form of a design "jam", with the educators being asked to design learning activities for their context using the STEM Practice framework and the ERA heuristic. The app is provided as a resource offering a partial opportunity to "represent" STEM practices.

An analysis of the products of these educator design jams has shown that the model provides sufficient conceptual and pedagogic structure for educators to design complex and effective learning activities despite often limited content knowledge. It has allowed the ELSA project an alternative to teaching the "content" first – an approach that would simply not work at scale. Instead, the project has progressed through design discussions around the two parts of the model. The first ELSA app, for example, is associated with engagement with patterns and relationships. The STEM Practices Framework has provided ways to discuss the practices associated with patterns and so move the object of teacher attention. These practices include matching (one-to-one correspondence), sorting, comparing and ordering. Educators in the design jams have responded to this well. It is evident that they recognize these practices, and they can project them into their learning spaces without needing to develop the associated mathematical content knowledge.

A central feature of the first app is a game in which the children build a dance sequence. To engage the educators in the design process, this concept is introduced to them before they see the app. They are asked to design an activity for themselves that uses dance as an opportunity to learn about patterns. An example of the thinking from this process can be seen in Figure 1. Here we see that educators are quickly able to see the possibility for different dance moves to be used to form simple and complex patterns.

The educators were then able to use the STEM Practices Framework and ERA heuristic to generate a design-architecture to take the activity further. Figures 2 and 3 summarize the typical outcomes of this design work. The value of the concept of practice architectures is also seen here in the way it shifts the focus from simple patterns, as seen in the early design, to a consideration of how STEM practices are in play in different contexts.

4.0 Conclusion

In describing the development and use of the STEM Practices Framework, this paper has provided an illustration of how socio-cultural theory might provide a useful foundation for large-scale design in STEM. Further research, however is needed in ELSA and in other projects. So far, our educators have been able to use the framework to follow the design logic and to understand that STEM practices have utility in practice architectures as diverse as research science, industry skills and the dance of a child. Yet to be seen, however, is the utility of the framework in supporting educators to develop their own learning designs beyond the ELSA project.

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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
info.hup@sub.uni-hamburg.de
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