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Using a Systems Perspective to Develop Underlying Principles for Systemic Educational Reform

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Abstract: One of the enduring problems in the education system is the gap between theory and practice, where the research to improve teaching and learning is not fully realised in the classroom. This has impacted the effectiveness of education reform. We take a systems thinking approach to better understand the complexity of an education system, which involves multiple stakeholders, each with different levels of power, purposes, and perspectives about what is important. Drawing on an extensive body of research we propose a set of six foundational and five enabling principles that support systemic educational reform. These 11 principles are put forward to provide guidance for decision-makers, researchers and practitioners on how a given educational reform might be more effectively implemented.

Introduction

Effective systemic educational reform has been a historically elusive goal, with contributing factors thought to be an underuse of research evidence and political influences over educational policy (Levin, 2010). The OECD (2007) also described the education sector as one with low levels of investment in research, and weak links between policy, research, and innovation. Further, reform in educational systems has also been hampered by poor implementation processes which do not acknowledge that "(i)mprovement is necessarily a process of learning by all those involved (Levin, 2010, p.742).

Moves to strengthen the links between educational research, policy, and practice, are also evident in worldwide efforts to increase the use of research evidence in decision-making across many different sectors, including education (Boaz et al., 2019, Farley-Ripple et al., 2017; Levin, 2013). However, achievement of this outcome involves more than simply identifying appropriate research and encouraging its up-take by practitioners (Farley-Ripple et al., 2017; Levin, 2013).

Farley-Ripple et al. (2017) noted that different stakeholders value different forms of research. For example, Levin (2013) points out that political pressures lead top-down policymakers to value large scale quantitative studies, but also claimed these forms of research do not necessarily capture the lived experiences of other stakeholders. To address this, he argued that education reform needs to be considered from a more systemic perspective. Green (2021) noted this idea is not new as the eminent former educational researcher, Garth Boomer, while also acknowledging inherent constraints, recognised the importance taking a systems perspective to enact educational change.

In this paper, we also consider change or reform as occurring within an education *system*. Thus, we draw on systems research to understand the nature of an education system and education research to understand the characteristics of educational change and synthesise

learning from both fields of research. From this work we propose some first principles to underpin systemic educational reform.

Taking a Systemic Perspective

Using the language of Meadows (2014), the education sector can be described as a "complex adaptive system", defined as an interconnected set of elements that work together to achieve a specific purpose, including numerous diverse subsystems each with their own purpose and practices that can impact on the system as a whole. For Meadows (2014), whether a system is considered "simple" or "complex", is determined by how easy it is to change. Where a small shift might bring about predictable change in a simple system, in a complex system the outcomes are less predictable (Meadows, 1999).

Similarly, Chapman (2004) claims a complex system is more than the "sum of its parts" and may exhibit dynamic, goal-seeking, self-preserving, and adaptive behaviour. It involves multiple-levels, and often ambiguous processes, which makes the outcomes of any given change process uncertain. Checkland (2012) referred to organisations as "soft systems" to distinguish them from "hard" systems governed by physical laws, and to account for the unpredictability of human influences over change. Dealing with change in these complex systems, therefore involves an exploration of the interactions between and among multiple dynamic elements.

Further, change can be incremental or transformational. Meadows (1999, 2014) argued that the more impactful and fundamental a change is meant to be, the more it challenges the underlying rules and purpose of the system itself. Similarly, Kania and colleagues (2018) argued that "systems change is about 'shifting the conditions that are holding the problem in place" (p.3). They identified six conditions ranging in their degree of visibility. The most explicit conditions include the policies (e.g., rules, regulations, priorities), practices (e.g., activities, guidelines, habits) and resource flows (e.g., how money, people, knowledge, information, infrastructure are allocated and distributed). Semi-explicit conditions include relationships (e.g., connections, communications, perspectives) and power dynamics (e.g., authority, distribution of decision-making power). The least explicit conditions are the mental models (e.g., the beliefs, assumptions that influence how we think, what we do, and how we talk), out of which the system arises.

Many change initiatives tend to focus on the explicit conditions, because they are relatively easy to address. However, the less explicit are more impactful for sustained change, but also more challenging (Kania et al., 2018). Explicit conditions are associated with structural change, but transformational change must address the mental models, which are mediated through positive and negative feedback loops. These link actors, across multiple levels in a complex system, serving to change or maintain the current conditions respectively (Meadows, 1999; 2014; Senge et al., 2012).

Checkland (2012) also emphasised the importance of social interactions across the system as a key to reform by enabling the integration of multiple world views and objectives through continual adaptation. Consistent with Levin (2013), Checkland (2012) also argued that reform results from learning, in a system that aims for improvement. Thus, systemic educational reform necessitates processes that allow a degree of autonomy for experimentation, accept the potential for failure, and importantly, enable feedback and continuous learning to achieve sustained improvement efforts.

The Value of Establishing 'First' Principles

If we accept an educational system as a complex adaptive system, we may be able to identify some foundational or *first principles* which underpin how the system functions and what should be considered when attempting systemic reform.

Aristotle (n.d.) proposed the idea of "first principles" as the "basis from which a thing is known." These are foundational propositions of knowledge in a given field. While a first principles approach is widely used to solve problems in science and engineering, its suitability to solving complex problems in "soft" social systems is not wide-spread, arguably due to the greater level of contestability of the knowledge in these fields. If, however, some first principles can be identified for educational reform, they would provide decision-makers with more confidence in how to approach a given change initiative, by articulating the pertinent aspects that need to be addressed to bring about change across the system.

There are several examples where educational researchers have endeavoured to articulate a set of principles related to complex educational problems. For example, principles have been proposed to improve initial teacher education (Darling-Hammond, 2006; Ingvarson et al., 2014) and to underpin the design of effective learning activities (Merrill, 2002; Tytler et al., 2013). As Green (2021) points out, Boomer also advocated some principles in relation to curriculum reform.

To our knowledge, this is the first attempt at proposing a set of principles to underpin reform across an educational system. In this endeavour, we take up the challenge by Checkland (2012, p.469), for researchers to find practical ways to ensure they engage with the "complex reality" that is an education system.

Identifying First Principles for Educational Reform

The first task in looking for principles to guide systemic educational reform is to explore what is known. This is a daunting task because the body of pertinent research covers an extensive range of different fields. To address systemic change, it will be necessary to draw on research into education policy, curriculum development and implementation, teacher change, teacher professional learning, and disciplinary-specific research around teaching and learning. Given such a broad literature base, and limited space, we choose to focus on a selection of key research in each area, without attempting to be exhaustive in any one field.

Education Policy

In a complex adaptive education system, effective reform processes need to provide a voice for a range of stakeholders. This immediately brings into focus the nature of relationships and power dynamics operating in the system (Kania et al., 2018). Too often, the education sector is forced to respond to "top-down" reform, so it is not often successful. Chapman (2004) attributes the failure of top-down approaches to their inability to account for the diversity and complexity in decision-making, leading to poor understanding of contextual considerations, unintended consequences, and ultimately less effective outcomes from a given reform. This approach fails to acknowledge that "different individuals and organisations within a problem domain will have significantly different perspectives, based on different histories, cultures and goals" (Chapman 2004, p.20). Senge and colleagues (2012) noted while that top-down educational reform initiatives may show some initial improvements, these may not last, because if, for example, teachers are not invested in the

change, they may lose interest in the reform or begin teaching to the change instead of the students.

Similar points have also been made by educational researchers. Green (2021) noted that Garth Boomer came to believe that curriculum reform, in the classroom and the educational bureaucracy, should be informed according to the principles of "explicitness, negotiation, questioning and reflection" (p.221). Similarly, Farley-Ripple et al. (2017, p.4) suggested a "bi-directional" approach to decision-making by including other stakeholders in the development of educational policy. Hargreaves and Fullan (2012) also argued for broader stakeholder input into systemic policy decisions, pointing to need to promote better coherence between the goals, implementation, and evaluation (i.e., accountability) which is often missing from the implementation plan. This notion of coherence is common to each of these researchers and consistent with the need to build a common understanding across the system: "This requires a sophisticated theory about systems and the way they work, as well as a learning theory (Boomer 1999, p.240, as cited in Green, 2021).

Expanding on these ideas, Hargreaves and Fullan (2012) called on decision-makers to "involve communities, along with professional educators and governments, in establishing goals and contributing to their attainment" (p.5). This educational research accords with systems research and highlights the link between a more inclusive input into decision-making and the notion of building coherence of the change process through feedback. Integrating the ideas in this research suggests two underlying principles:

That an effective educational system:

1. *Develops and implements policy based on sound and well-established educational research relevant to the context of all key stakeholders.*
2. *Builds coherence in policy by proactively promoting the involvement of key stakeholders in the formation of education policy and its ongoing development.*

Coherence Through Feedback: Accountability as Feedback

In a system, feedback loops serve as the mechanisms to monitor how well a system is functioning. As accountability mechanisms, negative feedback loops, act like "thermostats" to maintain a certain temperature in the room, or to maintain a steady state. Applied to the education system in a generative way, these processes can ensure the perspectives of different stakeholders are better understood and the policy is kept on track. To ensure policy coherence and address issues in a timely way, there is a need to focus is on what policy might look like at different levels in the system and gather evidence to inform policy. Here, an earlier point, that different stakeholders may value different forms of evidence (Farley-Ripple et al., 2017; Levin, 2013) becomes relevant. Key decision-makers need to include evidence pertinent to other stakeholders. Green (2021) noted Boomer's awareness of these constraints and how they must be understood and negotiated between the stakeholders to effect change. These ideas inevitably link to the notion of power in an educational system (Kania et al., 2018).

Given the importance of the role played by teachers, Hargreaves and Fullan (2014), along with Darling-Hammond et al. (2014) called on decision-makers to be especially careful that the accountability mechanisms put in place support teachers' work in classrooms. This point is also emphasised by the OECD (2007, p.25), who pointed out that: "In every national context and every kind of system, education reform is, ultimately, only as good as what actually takes place in the classrooms."

Other researchers have expanded on this through the notion of "reciprocal accountability" (Darling-Hammond et al., 2014; Farley-Ripple et al., 2017; Hargreaves and Fullan, 2012). Darling-Hammond et al., (2014, p.5) based their thinking on the three pillars of meaningful learning, professional capacity, and resource accountability, so "each level of the system is held accountable for the contributions it must make to produce an effective system". The intention of reciprocal accountability is to ensure the coherence of educational policy-making and improve the working relationships between the levels in the system. Educationally, the intention is to create conditions that enable teachers to do their work well (e.g., support students' learning). It goes further, however, by emphasising that decision-makers must also be accountable for providing adequate resourcing, pointing to the resource flows within the system. This is particularly important for supporting and sustaining the implementation of transformational reform initiatives.

A coherent educational policy environment is one where the curriculum is clear about, relevant to and supportive of any "new vision for learning" and aligned to "systemic changes implied by that goal" (Darling-Hammond et al. 2014, p.4). This level of coherence is particularly salient for the work of teachers. To illustrate this, Hargreaves and Fullan (2012) reported on the comparative performance of educational systems, and noted that, in lower performing systems, the emphasis of policymakers was on the performance of schools and teachers through "standardization, external accountability, high-stakes testing, and market driven competition" (p.82). By contrast, higher performing systems emphasised building teachers' capability as, "individuals and groups…[who] willingly take on personal, professional and collective responsibility for continuous improvement and success for all students" (Fullan et al., 2015, p.4).

While both forms of feedback intend to hold teachers accountable and inform decision-makers on the progress, they reveal fundamentally different power dynamics and relationships operating within the system. Where the former is punitive in nature and places restrictions on teacher autonomy and professionalism, the latter actively encourages their involvement and development of their professional capacity. The latter is more in tune with change as learning in a complex system, and the need to support individual and organisational practices such as experimentation and continuous learning (Checkland, 2012).

Other researchers have noted that the extensive use of standarised tests as an accountability measure to gauge systemic improvements and teacher performance is not coherent with calls for 21st Century learning (Darling-Hammond et al., 2014; Farley-Ripple et al., 2017; Fullan, et al., 2015). Fullan et al. (2015) argued that there is little evidence that external accountability approaches lead to "lasting and sustained improvements in student and school performance" in contrast to the "solid and mounting evidence on the fundamental impact" of more intrinsic accountability approaches (p.6). In other words, thinking systemically, the accountability measures need to extend beyond a narrow focus on achievement scores, to include broader and multiple measures of success to avoid unintended consequences (Chapman, 2004).

Thus, in terms of the inherent power dynamics, Hargreaves and Fullan (2012) argued strongly that an effective educational system must be based on developing a professional teaching workforce. As a foundational and costly systemic issue, it is clearly a matter for policymakers to enable and adequately resource this outcome. However, they claimed an effective educational system is one where "policy-makers … place their emphasis on the development of the collective capacity of the profession and its responsibility for continuous improvement and for the success of all students" (Hargreaves & Fullan, 2012, p.83). They added that a professional teaching workforce will be more open to, and capable of, innovation and effective reform, if accountability processes, enable feedback, are coherent with policy and support the work of teachers. This research suggests two further principles.

That the educational system will be more effective when it:

3. *Recognises and values the centrality of teacher professional expertise as a foundation of an effective and adaptive educational system.*
4. *Designs accountability processes that align with education goals within curriculum policy, as a way to support and guide teachers in their work.*

Promoting the Professional Role for Teachers

The contention that an effective educational system should be based on a capable and professional teaching workforce (Hargreaves & Fullan, 2012), is consistent with calls for experimentation and continuous learning to support adaptive change (Chapman, 2004; Meadows, 1999; Senge, 2012). But what does it look like in reality?

Green (2021) claims that educational improvement needs classroom teachers operating as practitioner scholars; that is, experts researching their own practice and theorising the curriculum (p.222). Hargreaves and Fullan (2012) called for researchers to "delve into teaching" to understand the nature of teaching, because "to change anything, we must first know what it is we are changing" (p.23). In searching for relevant principles, here, we turned to the body of research on teacher expertise and professional learning.

When Lee Schulman (1986, p.9) posed the question: "What are the domains and categories of content knowledge in the minds of teachers?", the notion of *teacher knowledge* was little understood. His aim was to develop a more coherent theoretical framework to understand teachers' work. Schulman (1986) argued that, historically, teaching is the highest form of understanding, where "the ultimate test of understanding rests on the ability to transform one's knowledge into teaching. Those who can do. Those who understand teach" (p.14). He explored the connection between subject matter content and the related pedagogical practices teachers use to try to distinguish professional teachers from others who did not teach. Much has changed since he first proposed the notion of Pedagogical Content Knowledge (PCK).

Around the globe, calls for 21st Century Learning have increased the expectations of teachers (Ananiadou & Claro, 2009). Professional standards for teachers have been developed to articulate in detail knowledge and skills teachers need. Some examples include those presented by the Australian Institute for Teaching and School Leadership (AITSL, 2022), and other education jurisdictions such as Canada and New Zealand (British Columbia Teacher's Council, 2019; Education Council of New Zealand, 2019). Typically, these standards outline key components of teacher expertise, including a deep understanding of subject matter and how to teach it; an understanding of how to plan and assess for effective learning; an understanding of the curriculum; and an understanding of how students learn.

The growing use of standards also overlaps with the issue of appropriate accountability for teachers. While Hargreaves and Fullan (2012) supported the use of standards "to screen candidates for the profession, support and sort beginning teachers, and help drive development through helping to increase expertise", they warned against their use to determine the performance of individual teachers (Fullan, et al., 2015, p.13).

Similarly, Schulman (1986) claimed that appropriate tasks for assessing teachers should resemble those used for assessing the capacities of other professionals. These go beyond the application of techniques and propositional knowledge and "tap into the unique knowledge bases of teaching" (p.13). Indeed, some jurisdictions provide a graduated series of

expectations outlining what teachers should be able to demonstrate as they move through their careers from novice to expert teachers (AITSL, 2022; Reid & Kleinhenz, 2015).

Expertise Versus Experience

In a seminal paper on teacher expertise, Berliner (1986) claimed that expert teachers were better at recognising patterns, and categorising and adapting to problems in context. These ideas are consistent with those proposed by the Australian National Research Council (2000), who define an expert as one who can think effectively about problems in their specialist area. An expert can draw on deep knowledge organised into big ideas or principles, that are highly integrated and contextual.

Hattie (2014) also distinguished between expert and experienced teachers by the nature of the challenges they set for their students. Experts tended to offer learning activities that are "more integrated, more coherent, and at a higher level of abstraction and understanding achieved" (p.30). By contrast,

Ericsson and colleagues (2018) described a process to explain how expertise develops over time. Because a novice has limited background knowledge and experience to draw on, they tend to rely on trial and error or heuristic approaches (i.e., use of approximate solutions) to solve problems (Jiang & Braatz, 2016). Ericsson and colleagues (2018) claim that, through experience, novices naturally progress to an acceptable level, but further development is unpredictable and "continued improvements (changes) in performance are not automatic consequences of experience" (p.14). They argued practitioners must actively seek to become experts in their field.

Similarly, Hargreaves and Fullan (2012) claimed that teachers need to build "professional capital", which refers to both a professional ethos and expertise, to become excellent at teaching. Professional capital assumes a commitment to continually develop as a professional and work collaboratively with colleagues to improve the profession as a whole. They claim that "effective teaching has to be prepared for fully, and practiced repeatedly, but it will take years to perfect until you reach the heights of your proficiency" (p.79). Hargreaves and Fullan (2012) further argued that, rather than focus on recruiting and rewarding better *individual* teachers, the "only solutions that will work on any scale are those that mobilize the teaching force as a whole" (p.21-22). From a systemic perspective, this has implications for policymakers to invest in the development teacher expertise.

In summary, Hargreaves and Fullan (2012) argued that an effective education system supports the professionalism of teachers and would empower them "to make discretionary judgements" (p.93) and develop their expertise through the process of reflection on their experience on the job: a process recognised as "central to professional practice" (p.98). These ideas are consistent with Checkland's (2012) view of the importance of learning through action in context. This contextual nature of the development of teacher expertise was also recognised by Schulman (1986) and will be explored more deeply in the next section.

The above research suggests that, while developing expertise in teaching is associated with experience, it is not a consequence of it. In a high performing educational system, teachers should be encouraged to innovate or experiment (Checkland, 2012), strive to improve their own performance and that of their colleagues, and actively pursue professional development that leads to better practice (Hargreaves & Fullan, 2012; Schleicher, 2018). This implies considerable trust in educator's professionalism and discretionary decision-making power over pedagogical matters.

This research suggests two more foundational principles: that an educational system will be more effective and open to reform when it:

5. *Resources the professionalism of teachers and actively supports growth in their expertise throughout their careers from novice to expert.*
6. *Empowers teachers to interpret educational policy and influence its development through feedback based on their experiences in context.*

A brief reflection on the systems approach

These first six principles describe the underlying foundational conditions for an effective educational system. We argue that these principles enable the conditions for innovative and adaptative approaches through more inclusive decision-making, and ensure coherence between intended outcomes, appropriate resourcing, and accountability processes.

In terms of shifting the conditions for systemic change, these six principles speak to the areas of policy, practice, and resource flows (e.g., goals, accountability, continuous learning), as well as the nature of relationships and power dynamics, which are ostensibly more challenging to address (Kania et al, 2018). With these foundational conditions in place, a given educational reform is more likely to be successful (Darling Hammond et al., 2014; Hargreaves & Fullan, 2012).

Enabling principles for reform in a complex system: contextual considerations for education

As discussed above, in a complex adaptive system, decisions made at the top level can have a direct, but difficult to predict, impact on the schools, communities and classrooms in which teachers work and can result in unintended consequences. From a systems perspective, to minimise this, attention must be paid to the nature of the relationships and interactions between the different stakeholders. "Transforming a system is really about transforming the relationships between people who make up the system" (Kania et al., 2018, p.7). The remainder of this paper, therefore, focusses on contextual factors related to a given educational reform and on ways to facilitate these interactions.

Partnerships as a Way to Improve Relationships and Coherence of a Reform

One way of enabling stakeholder interactions and improving power relationships is through the establishment of genuine partnerships. Partnerships between universities and external bodies have been long advocated for improved learning outcomes. In professional and technical programs, the integration of learning with practical experiences in the field is widely advocated and highly valued by students, practitioners and employers, as an authentic means to link theory and practice (Cain, 2019; Darling-Hammond & McLaughlin 2011; Ingvarson et al. 2014; Jones et al., 2016).

Effective partnerships link to systemic change because they rely on recognising the mutual benefits and establishing and maintaining communication between the partners. They are based on developing trust and mutual understanding between stakeholders (Cain, 2019; Darling-Hammond & McLaughlin 2011; Ingvarson et al. 2014; Jones et al., 2016; Kruger et al. 2009; Patrick et al., 2009; McKenzie, 2014). By their nature, partnerships facilitate stakeholder interaction and necessitate negotiation on goal setting, planning, implementation and evaluation of the program. This ensures better coherence through common understanding

and facilitating feedback to quickly address problems. Partnerships promote better alignment between the formal learning situation and needs of external partners (Jones et al. 2016; Patrick et al., 2009).

In education, partnerships between schools and universities have also been widely advocated as a way to improve Initial Teacher Education (ITE) (Darling-Hammond 2006; Darling-Hammond & McLaughlin, 2011; Ingvarson et al., 2014; TEMAG, 2014). As in other professions, this cooperation provides opportunities for mentorship and supervision of novices by more experienced colleagues. Ingvarson et al. (2009, p.45) claim beginning teachers need more time in schools to make "strong connections between theory and practical experiences, and where schools and universities share an understanding of the purpose of professional experience for students" (p.20). Despite this, in teacher education there has historically there has been little real integration of school-based experiences within formal university learning programs in teacher education (Jones et al. 2016; Ingvarson et al., 2014).

Darling-Hammond (2006) also argued that strong school-university based partnerships would promote coherence, facilitate learning in context of practice, deepen understanding of learning approaches and pedagogy. Partnerships help students inquire into their own assumptions and acknowledge different perspectives through analysis of real problems of practice and develop their "adaptive expertise" (Ingvarson et al., 2014, p.12).

Campbell et al. (2018) describe a range of models of partnerships for initial teacher education from work in the Science Teacher Education Partnerships in Schools (STEPS) Project, which were developed independently at six universities to address this gap. Jones et al. (2016) described the development of an Interpretive Framework by the STEPS Project team, which can inform the development of partnership approaches in other disciplines and indeed other sectors.

This research suggests partnerships can build coherence in educational policy and develop the professional expertise of novice teachers. However, the development of teachers' expertise beyond their initial training is more problematic. Cain (2019) claims that practising teachers also need to become more aware of educational research and to be able to evaluate its implications for their own practice. To do this, he suggests strengthening opportunities for collaboration between teachers and researchers, through formal professional learning programs, participation in joint research projects, and/or post-graduate study: "First, partnership agreements should enable teachers to engage both in and with research, so that, whatever activities the partnership engages in, research-based ideas can be critically scrutinised, systematically trialled, and rigorously evaluated by teachers in schools" (Cain, 2019, p.12).

Kostoulas et al. (2019) argued that teachers value research that is relevant to their classrooms, but the impact of research on classroom practice will be more effective when their educational leaders support the approach (Darling-Hammond et al., 2017). Thus, teachers are not simply as receivers of information but are professional practitioners who can provide valuable feedback based on their experiences in classrooms, which can inform the research and improve the educational reform itself (Cain, 2019; Farley-Ripple et al., 2017). Just as importantly, partnerships can also facilitate training of mentors and opportunities for feedback from other stakeholders, such as principals, parents and students. Ongoing feedback across the system provides important information to adapt and refine policy development (McKenzie, 2014).

This research addresses relationships, and the participants' mental models which are crucial conditions for transformational systemic change (Kania et al., 2018). It suggests two principles to enable a given educational reform: that improved outcomes will result when the reform process:

7. *Facilitates the formation of collaborative partnerships between universities and schools to build the expertise of both novice and in-service teachers with a given educational reform.*
8. *Facilitates processes that enable feedback from educational leaders, teachers, and other stakeholders to inform the ongoing development of the reform based on their experiences.*

Supporting Teachers to Develop Their Expertise Through Ongoing Professional Learning

Teachers' expertise is developed in the context of their work and must be deliberately pursued through ongoing Professional Learning (PL) (Hargreaves & Fullan, 2012; Schulman 1987). Therefore, the implementation of a given educational reform needs to consider how to support teachers to develop their expertise as it relates to the reform, and through their experiences with it in their classrooms. This fits with the professional model of teaching and is also consistent with the requirements for action-based learning for change in a complex system (Checkland, 2012).

Darling-Hammond and McLaughlin (2011) argue that teachers learn in similar ways to their students: doing, reading, reflecting, collaborating, and sharing. There is general agreement on the characteristics of high-quality teacher PL: that it needs to involve concrete tasks of teaching that focus on learning and development; be grounded in inquiry, reflection, and experimentation; be collaborative and supportive of communities of practice; be situated, sustained, and supported by modeling/coaching; and connect to other aspects of school improvement (Darling-Hammond et al. 2017; Garet et al., 2001; Hawley & Valli, 1999; 2000). Other researchers provide similar characterisations of effective teacher PL (Brand & Moore, 2011; Garet et al., 2001; Hawley & Valli, 2000; Jensen et al. 2016; Luft et al. 2015; Reid & Kleinhenz, 2015). In addition, effective PL must occur over an extended time period and in conjunction with the provision of good resources. Such approaches have been found to assist teachers to improve classroom practice and student outcomes (Appleton, 2003; Cooper et al., 2012; Darling-Hammond et al. 2017; Fitzgerald et al., 2019; Hackling & Prain, 2005; Luft et al. 2015).

Effective PL seems to be a fundamental component of effective educational reform. From a systems perspective, the provision of PL and its funding relate to the explicit conditions of 'practice' and, given the ongoing need of high-quality PL, requires considerable resources (Garet et al., 2001). Without it, there is an increased risk that a given reform will not be implemented effectively (Fitzgerald et al., 2019; Garet et al., 2001; Reid & Klienhenz, 2015). While this may save money in the short term, it will restrict the capacity of teachers to develop their expertise to implement the reform in their classrooms. Indeed, there seems little point in conducting PL that does not aim to extend or challenge teachers to change. From this research we therefore propose another enabling principle: that an educational reform program will be more effective when it:

9. *Specifically builds teachers' expertise with the reform, through extended, reflective collaborative professional learning activities (e.g., school-based action learning, mentoring), along with associated support materials.*

Contextual Factors Related to Developing Teachers' Expertise with a Given Reform

Given that teachers develop and enact their expertise when able to reflect on their experiences within a context close to their practice, it follows that different groups of teachers will have different needs to support their implementation of a given reform. For individual teachers, contexts may differ in terms of discipline, workplace, and the stage of their career. This adds another layer of complexity to considerations of building teachers' expertise with a given educational reform. We will briefly consider each in turn.

Disciplinary Context

To better understand how a given reform may be applied in the context of a discipline, we draw on a case study of reform in Science, Mathematics, Engineering and Technology (STEM) education. We do this for two reasons: firstly, because STEM educational reform has been high on the change agenda in many countries; and secondly, because this is our own area of disciplinary expertise. We recognise, however, that the emerging principles will need to be adaptable to other disciplinary contexts.

For over 30 years, many countries have reported students' disengagement in STEM subjects, leading to concerns that their future workforce will lack skills relevant to economic development in the 21st Century, placing them at a competitive disadvantage (Breimer et al., 2012; Colucci-Gray et al., 2017; DeCoito, 2016; Marginson et al., 2013; Kennedy et al., 2014; Sharma & Yarlagadda, 2019; Timms et al., 2018). The key aim of STEM educational reform has been to engage more students in STEM subjects in school and encourage them to pursue careers in STEM. This is also closely linked with employer demands for students to be 'work-ready' for the knowledge economy. Despite a concerted effort by many governments, and significant resourcing to fund many initiatives, there is no increase in students' interest in STEM, in Australia (Marginson et al., 2013), India (Sharma & Yarlagadda, 2018), and Canada (DeCoito, 2016; Parkin & Urban, 2019). This suggests that while resource flows for STEM may have been sufficient, other conditions for systemic change may not have been adequately addressed.

From a pedagogical perspective, the situation in Australia reflects much of what has happened in other countries. There is no clear link of STEM to the National Curriculum, where Science, Technology and Mathematics appear as distinct disciplinary domains and Engineering does not appear at all.

Further, STEM education reform proposes that teachers should adopt student-centred teaching practices to re-engage students through problem solving, inquiry-based approaches, critical thinking and creativity, and other methods designed to increase student learning and engagement with science and mathematics (Marginson et al., 2013, p.23). However, there is a lack of consensus on how to approach reform. For example, Marginson et al. (2013 recommended STEM should be approached from a strong commitment to disciplinary knowledge. In contrast, Timms et al. (2018, p.13) suggested the need to shift the emphasis from disciplinary knowledge to disciplinary practices.

One seemingly obvious problem is the STEM approach assumes teachers have, or can develop, expertise in up to four distinct disciplines along with the ability to integrate student-centred learning across these disciplines. Further, the development of teachers' expertise in STEM (as for other disciplines) is complicated by an increasing number of teachers, lacking appropriate disciplinary qualifications and being required to teach these subjects "out of field" in many countries (Hobbs & Törner, 2019).

The fact that significant resources have been invested world-wide in STEM education reform, with little progress toward its stated aims, suggests a lack of coherence in its implementation. We argue, given the earlier discussion, that the implementation of STEM has proceeded without sufficient attention being paid by policymakers and/or researchers to supporting teachers to gain the expertise needed to meet the significant pedagogical challenges it presents.

Marginson et al. (2013) argued that developing pedagogical expertise in STEM is best done within the context of a discipline. Because this is consistent with Schulman's ideas on teacher expertise, we also adopt this stance and propose to advance the discussion further by narrowing the lens of our case study to a single discipline, more specifically, science education. We will later attempt to generalise this argument to cover other disciplines in framing the language of the principles.

Building Teachers' Expertise within a Discipline: The Case of Science Education

There is a long history of reform in science education, with several "pendulum swings" regarding student participation over the past 100 years (Abd-El-Khalick et al., 2015, p. 513). Following Piaget (1952), many science education researchers advocated a shift to more constructivist, student-centred learning approaches in science, in which students actively make links between their pre-existing knowledge and new knowledge and draw on their personal experience to build understanding. This idea was extended by Vygotsky (1978) who incorporated socio-cultural perspectives using language and other symbolic tools for joint meaning making, as well as supporting students' potential development through the guidance of more knowledgeable others.

Constructivist learning led to "conceptual change" approaches which aimed to shift students' naïve conceptions of how the world works, to views more consistent with a scientific view. The research indicates, however, this resulted in little change in classroom practice or students' understanding of science concepts (Duit & Treagust, 2012; Tytler & Prain, 2013). Further, there is little evidence that teachers have adopted more student-centered, inquiry-based learning approaches (Fitzgerald et al. 2019), and the lack of student engagement with science, which prompted STEM reform programs, persists (Kennedy et al. 2014; DeCoito, 2016).

Schulman (1986) claimed teachers' content knowledge in a given subject needs to include understanding how "the basic concepts and principles of the discipline are organized" (p.9), and its "syntactic structure", or how knowledge is validated. It is now widely recognised that students also need to see the relevance of science, and experience the "nature of science", that is, how knowledge is developed within the discipline (Duit & Treagust, 2012; Duschl & Grandy, 2013; Osborne, 2014; Tytler et al., 2018).

As one response, science education researchers have turned to cognitive and socio-semiotic theories in an effort to make the epistemic practices of science more accessible to students and move away from learning science being perceived as a content driven exercise. These approaches require teachers to extend their repertoire to provide authentic experiences of science to engage students, including through their use of communication tools, such as argumentation and visualisation, to develop students' understanding of science in ways that emulate how scientific knowledge is developed (Duschl & Osborne, 2002; Gilbert, 2005; Klein, 2006; Tytler & Prain, 2013).

What is also being recognised is that the interactive nature of these pedagogies demands a lot of teachers (Kenny & Cirkony, 2018; Sherin et al., 2005; Tytler et al., 2013). These forms of science teaching require extensive mediation of the proscribed curriculum by

the teacher, their ability to design meaningful tasks and facilitate open-ended dialogue around the students' representations and to build on each student's conceptual understanding. This necessitates ongoing assessment of students' developing understanding and ongoing adjustments to the learning activities (Cirkony & Kenny, 2018; Tytler et al., 2013).

Building Teachers' Expertise in Their Practice Context: Challenges Faced by Primary and Secondary Teachers of Science

The other aspect to be considered when building teacher expertise is in relation to their workplace or practice context. As generalist teachers, primary teachers face different challenges teaching any given discipline, compared to their secondary counterparts, who generally have some disciplinary specialty. In science education, given most primary teachers have minimal science background, they tend to have limited understanding of, or background in, the proposed disciplinary-specific knowledge, particularly as it pertains to linking activities with conceptual principles. This leads to a general lack of confidence in or experience with teaching science (Harlen, 2015, p.47). Thus, primary teachers will often focus on more superficial activities at the expense of facilitating guided inquiry approaches that lead to deeper understanding of the concepts (Harlen, 2015, p.48).

However, PL designed to improve their science content knowledge is not necessarily the solution, given, for example, that many secondary teachers, who have sound knowledge of their specialist science discipline, are unlikely to possess deep disciplinary knowledge of other areas of science (Harlen, 2015). A biology major, for example, may lack deep understanding of physics and vice versa. Further, Harlen (2015) points out, for most secondary teachers, their practical experiences during their own studies in science were often confirmatory lab exercises, as opposed to genuine inquiry. So, they may "lack of first-hand experience of scientific activity that would give confidence in teaching ideas about science" (p.48). They also may find inquiry-based teaching approaches challenging, especially given an overcrowded curriculum. This suggests that developing the expertise of teachers of science to use inquiry-based approaches requires specific PL. To be confident to teach this way, all teachers need first to experience inquiry as learners, either in their initial teacher education program, and/or as part of their ongoing PL (Brand & Moore, 2015; Darling-Hammond et al. 2017; Darling-Hammond & McLaughlin, 2011).

Echoing the earlier comments, Harlen (2015) also highlights the lack of coherence between the espoused educational goals of science learning in the 21st Century and the narrow forms of approaches used to assess student learning:

> *Since what is assessed and reported is assumed to reflect what it is important to learn, it is essential that this is not limited to what can be readily tested. A range of methods should be used to gather and interpret evidence of learning so that students are able to show what they can do in relation to all types of goals (Harlen, 2015, p.9).*

In summary, the STEM case study presents an example of an educational reform largely driven by a national policy agenda that lacks coherence from both a curricula and pedagogical point of view. STEM reform suffers not from a lack of resources, but from a lack of coherence and systemic thinking in its implementation. We contend the effectiveness of STEM education reform would be considerably enhanced if policymakers had more awareness of, for example, the complex nature of teaching a multi-disciplinary construct, the needs of teachers with varying backgrounds in these domains, and the development of suitably qualified future teachers.

The case study demonstrates that when a given reform is intended to change classroom practice, more attention needs to be paid to supporting the teachers to build their expertise with the reform, implement it in their classrooms, and provide feedback to shape the reform. The accountabilities in place, such as assessment practices, need to be coherent with the aims of the initiative. From a systems perspective, there is a strong disconnect with the policy (i.e., STEM), the resource flows (e.g., funding, qualified STEM teachers), and the classroom practices (e.g., curriculum, pedagogy, assessment)

Although our argument in this final section has been developed using STEM reform as a case study, we propose two final enabling principles to underpin what effective educational reform might look like more generally. The language used in these principles is framed to be applicable to a range of disciplines and work contexts.

In supporting the development of teachers' expertise with a given reform, its implementation plan should:

10. *Aim to build students' conceptual understanding by engaging students in authentic inquiry experiences that link to relevant real-world issues and are based on epistemic practices of the relevant disciplines.*
11. *Support teachers to design and implement appropriate learning activities in their contexts and use of a range of assessment practices that align with the learning outcomes advocated in the reform.*

Conclusions

In the belief that many attempts at education reform may not have paid sufficient attention to the complexities of the education system, we took a systems perspective in researching and writing this paper. We have proposed the 11 principles (see Appendix A) needed to underpin effective systemic educational reform. These eleven principles are substantiated by an extensive body of research, and incorporate the six conditions for systemic change, including those that may previously have been given little attention due to their less explicit nature, such as the power, relationships, and mental models (Kania et al. 2018).

If, indeed, these are accepted as *first principles* for systemic educational reform, then the omission of any one of them will, by definition, reduce the effectiveness of a given reform. As first principles, they are based on what we know and outline what needs to be done to enact effective and sustained education reform. The six foundational principles will ensure the conditions exist for the system to function effectively be more responsive to a reform agenda. The five enabling principles ensure the right conditions are in place to support the effective implementation of the reform.

Linking the principles in this way illustrates that effective education reform requires addressing more than one condition to support sustained change. As the STEM case study exemplifies, despite substantial resourcing, when top-down policy lacks coherence and provides for limited feedback, there is little opportunity to develop understanding of the demands of the reform, especially on teachers in classrooms and the support they need for its implementation to be effective. The principles emphasise the need to support the foundational conditions and contextual considerations for change initiatives. Our hope is that these principles will prompt discussions amongst policymakers, research colleagues and teachers on how they may be enacted to support more successful and sustained reform initiatives in education.

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Appendix A: Principles for Effective Systemic Educational Reform.

Foundational Principles: An effective educational system is one that creates the conditions for educational excellence and innovation by:

1. *Developing and implementing policy based on sound and well-established educational research relevant to the context of all key stakeholders.*
2. *Building coherence in policy by proactively promoting the involvement of key stakeholders in the formation of education policy and its ongoing development.*
3. *Recognising and valuing the centrality of teacher professional expertise as a foundation of an effective and adaptive educational system.*
4. *Designing accountability processes that align with education goals within curriculum policy, to support and guide teachers in their work.*
5. *Resourcing the professionalism of teachers by supporting growth in their expertise throughout their careers from novice to expert.*
6. *Empowering teachers to interpret educational policy and influence its development through feedback based on their experiences in context.*

Enabling Principles: The effectiveness of a given educational reform will be increased by:

7. *Facilitating the formation of collaborative partnerships between universities and schools to build the expertise of both novice and in-service teachers with the educational reform.*
8. *Facilitating processes that enable feedback from educational leaders, teachers, and other stakeholders to inform the ongoing development of the reform based on their experiences.*
9. *Specifically building teachers' expertise with the given reform, through extended, reflective collaborative school-based action learning, mentoring, along with associated support materials.*
10. *Aiming to build students' conceptual understanding by engaging students in authentic inquiry experiences that link to relevant real-world issues and are based on epistemic practices of the relevant disciplines.*
11. *Supporting teachers to design and implement appropriate learning activities in their contexts that are coherent and use of a range of assessment practices that align with the learning outcomes advocated in the reform.*