Title	Leading sustainable pedagogical reform with technology for student-centred learning: A complexity perspective
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Abstract

The literature on school improvement is littered with sombre reports of how ICT-mediated innovations have failed to create impact on teaching and learning. Even when evidence-based successes are palpable, they are sporadic and rarely sustainable. Against the backdrop of the litany of such studies, this paper reports the case of a primary school in Singapore that has a decade-long experience in integrating, growing and sustaining ICT-mediated innovations. By distilling the influences underpinning its integration, the article aims to make a contribution to the theorisation of educational leadership situated in the context of technology-mediated reform for student-centred learning. Using a complexity lens, this paper looks at how school leaders, together with other autonomous actors in its ecological system, foster the favourable conditions for sustainable technology-mediated pedagogical reform. Data of the study are drawn from interviews, observations of lessons, fieldtrips and professional development meetings as well as document analysis. Based on the findings, a complexity-informed model for technology-mediated reform is devised and its implications discussed. They include the need to cultivate the following within and across the subsystems of the school: (a) ecological awareness; (b) collective reflexivity on practices and implementations, (c) creating alignment and; (d) capacity to forge ecological coherence.

Keywords:

School change, sustainable pedagogical reform, complexity perspective, ecological alignment, technology leadership, technology integration

Introduction

The literature on technology-mediated reform in schools is littered by the rhetoric that technology has largely failed to transform teaching and learning (Cuban, 2013). Many attributed this unrelenting gap between the promise and performance of technology to the fact that schools largely fail to take into account the broader ecological influences that affect the technology integration (Zucker, 2008; Toh & So, 2011). These influences are multi-faceted and can encapsulate the school's vision, mission and goals; culture; ICT planning and decision-making mechanism; governance; curriculum and instructional strategies; assessment and evaluation; student expectations; personnel and financial resources, social capital and relationships with community (Levin & Schrum, 2012). The school organisation, including its nested sub-systems and the broader socio-cultural environment it interacts with, can shape and create a constellation of conditions over time to either impede or promulgate the use of ICT for pedagogical-related innovations. Such rich interplay of influences is not prominently featured in the literature which in general either focuses on the empirical evidence related to specific interventions or piecemeal innovations, musings at the theoretical level or analysis at the sub-system level such as classroom dynamics. In addition, although educational leadership and the use of technology in education have been broadly discussed, there is little scholarly dialogue between the two areas (Albion, 2006). The lack of rich narratives often obfuscates the holistic contextual influences that have real explanatory power over the school's ability to harness, integrate and sustain the use of ICT for pedagogical reform longitudinally.

This article hopes to fill this gap by looking at the enduring conditions that school leaders can create to integrate, grow and sustain technology-mediated

innovations in schools. The concept of "ecological coherence" across the subsystems of a school's ecology will be unpacked in an attempt to dispel infantile expectations associated with technology integration. Against the backdrop of a litany of literature that reports the limited role of technology in advancing pedagogical change, the case school featured in this study provided a countervailing example where the use of technology was not only sustained, but sustained through a transformative process that was both emergent and evolutionary. Instead of relegating the role of technology to piecemeal innovations or empowering individual students just to be computer literate, technology was used as an enabler to actualise a more learner-centred pedagogy in conjunction with a systemic whole-school approach that involved re-culturing and re-structuring.

As the study is based on an exemplary school, generalisation is apparently not the aim. However, the findings can allow schools to re-think the facets of technology-mediated reform in their own school context. This can be possibly achieved by allowing schools to: 1) gain a deeper understanding about the inter-connectedness of the multi-scale interactions taking place within their school ecology; 2) have a better grip on the contextual factors that promote or impede technology integration efforts for pedagogical reforms in school and; 3) heighten their awareness on how emergent success may be sustained through purposeful re-organisation of resources and re-alignment of goals.

This paper is organised as such: Starting with explicating the theoretical underpinnings and literature review on technology-mediated reform, the article problematises technology-mediated school reform as a construct that both shapes and is shaped by the complex interplay of multiple influences. Next, the context of the study

and its research methodology are elucidated, followed by the illustration of salient conditions that foster school improvement. The article ends with the discussion on the implications of leadership for technology-mediated pedagogical reform for student-centred learning.

Literature review

Pedagogical considerations underpinning technology-mediated school reform

The discussion underlying the pedagogical considerations of using technology in education is perhaps best explored by first revisiting some of the earlier and seminal works of scholars who deliberated in great length the affordances and limitations of technology-mediated learning. Scholars who are upbeat about the use of technology often subscribe to the belief that its use in education can support constructivist practices (Creighton, 2003; Owen & Demb, 2004; Tan et al., 2006; Selwyn, 2011). Drawing explicit connections between technology and student-centred learning, Hannafin and Land (1997) as well as Bransford, Brown and Cocking (2000) expound that a technology-enhanced student-centred learning environment can promote constructivism as it requires individuals to be active in the learning process through assimilating and developing meta-knowledge for exploring, generating, simulating, reflecting and solving authentic problems afforded by augmented interactivity and networked resources – expanded opportunities brought forth by technology. Echoing this view is Hirumi (2002) who believes that constructivist design principles can inform educators in creating strategies to transform from teacher-directed into student-centred learning environment. Although the term "student-centred learning" is defined differently by scholars, much of the interpretations in the foregoing literature converge along the line

of giving students more voice, which is often accompanied by a shift in power from the teacher to the students.

However, whether technology use in a student-centred classroom is necessarily a constructivist tool is dependent on the designers' inscriptions aimed at shaping learners' behaviour (Spiro et al., 1992), the in-situ context of how it is being used in the learning ecology (Zhao & Frank, 2003); the socio-political influences that coalesced around flawed thinking of the use of technology as complicated rather than complex phenomenon (Cuban , 2013) as well as the ways schools address the "deep incompatibilities between schooling and the new technologies" (Collins & Halverson, 2010, p. 19). It is therefore not surprising that the use of technology without the creation of supporting ecology often yields lacklustre results (OECD, 2015). Although it is widely reported that technology-mediated reforms tend to perpetuate prevailing practices (Cuban, 2008; Gipson, 2003; Harris, 2005; Weston & Bain, 2010), there have also been increasing pockets of successes in integrating technology for deep reforms, which can be attributed to the holistic considerations about the pathology of school; such as the interactions between people, innovation and culture (Coppola, 2004; Dimmock, 2000; Ertmer et al., 2012; O'dwyer et al., 2004; Tondeur et al., 2008). These positive experiences give us reasons for exercising cautious optimism when expounding critically on the issue of technology-mediated school improvement.

Predominately, the scholarly discourse on technology integration and implementation are centred on individual teacher's sense-making and the trajectory of integrating technology into their teaching practices. Rarely do we see the notion of technological integration being discussed at an institutional or the broader ecological level (Wong & Li, 2008). The report, "Making Better Connections" (Downes et al.,

2002), a study funded by the Commonwealth Department of Education, Science and Training (DEST) is one explication of ICT integration from the institutional perspective. The authors categorise the nature of technology integration as follows:

> Type A: Encouraging the acquisition of ICT skills as an end themselves;
> Type B: Using ICTs to enhance students' abilities within the existing curriculum.
> Type C: Introducing ICT as an integral component of broader curricular reforms that are changing not only how learning occurs but what is learned;
> Type D: Introducing ICTs as an integral component of the reforms that alter the organisation and structure of schooling itself. (Downes et al., 2002, p. 23)

Sustaining technology-mediated school reform

In the wider literature on ICT integration for school reform, the use of technology without accompanying systemic changes in professional development and curriculum reforms, as exemplified in Type A and Type B integration, are regarded as bolt-on additions to the existing institutional frameworks and their efficacies to revolutionise how students learn and how educators teach will be limited (Burns & Dimock, 2007; Coppola, 2004; Owen & Demb, 2004). Type C integration incorporates pedagogical innovations but this provision seldom leads to transformative learning if there are no systemic changes to the institutions and such cornerstone philosophy is quintessentially embedded in type D reform. Schlechty (2009) makes similar assertions that systemic changes would be required "before the disruptive innovations might produce the effects it promises'" (p. 19). What follows from this vein of argument is that Type D integration which encompasses the introduction of curricular reforms should be viewed

as a precursor to successful integration rather than an absolute consequence of using ICT.

Whilst schools may experience initial success in integrating technology holistically to transform itself, to sustain such dynamic efforts for innovation is another set of amorphous challenge. Looi et al. (2005) contend:

> Schools either jump from one innovation to another, or that implementations failed to consider the complexity of the educational system, societal needs, policies, curriculum, pedagogy, practices, epistemic beliefs, skills and others. (p. 244)

Fullan (2002) espouses the need of alignment in terms of focusing not on the quantity of innovation, but to "innovate selectively with coherence" (p. 6). Looking more broadly at the sustainability of innovations in general, Geels and Schot (2007) argue that for innovations to transit to sustainability, the interplays between technology, policy, power, politics, economics, cultural discourse and public opinion have to be considered. Zhao and Frank (2003) use the metaphor of "ecology" to highlight the systemic relationships of factors affecting technology use in schools. Thus, there is a need to look at ICT reform in a holistic way, as opposed to adopting a compartmentalized techno-centric view.

Complexity perspective in educational leadership

Complexity theory is used as a frame of reference to understand the systemic factors underpinning technology integration in this paper. Ontologically, complexity truth is

about “inter-objectivity” where subjective and objective knowledge shape and are shaped by each other. Learning is therefore about knowing how to manage the enfolding and unfolding of individual and collective knowledge and a learner is one who is capable of igniting spontaneous change with respect to dynamic circumstances (Davis & Sumara, 2006). This tinkering process between personal knowing and collective knowledge is exemplified when it comes to the use of technology for education. Educators’ beliefs towards the efficacy of technology are evolving alongside innovations, suggesting the need for leaders to look at the mutually-constituting elements in the whole system when technological-mediated reform. This point is also reflected in recent literature which evinced the use of different levels of analysis such as organisational culture, resource management and planning, teacher readiness and school improvement conditions (Aesaert & Braak, 2014; Chang et al., 2008; Law, Yuan and Fox, 2011; Toh et al., 2014) to explore the phenomenon of ICT integration at an institutional level.

Integral to the concept of connectedness is “nestedness”. Due to the nested nature of complex system, “there are system effects that are different from their parts” (Urry, 2005, p. 5), complementing the essence of complexity perspective where the relationship amongst multiple influences is non-linear.

Bronfenbrenner’s (1993) ecological model that is originally used for human development is adapted for ICT integration to help us visualise the mutually-constituting influences. Macro-level influences are the broader contexts such as global developments, national policies, ideologies or societal norms that have bearings on the school’s technology integration plans. Examples of such include the global emphasis on 21st century skills, inquiry learning in science, national emphasis on the

competiveness of Singapore's economy, educational policies and parental expectations. Geels and Schot (2007) argue that exogenous changes at the landscape level can exert downward pressure for policymakers to change their existing structures and regulations.

An example of such exogenous change is the pervasive use of ICT in socio-cultural spheres such as work and play in many developed countries. There is a preponderance of studies which suggests that many children in the developed world have exposure to technologies, in their early years. Plowman, Stephen and McPake (2010) termed this phenomenon as "the technologization of childhood" (p33). However, these experiences are mostly coalesced around out-of-class or school settings rather than in classrooms, thus resulting in the "gulf" of learning between formal and informal contexts. It is deemed necessary to help students make meaningful connections of learning across different learning spaces as part of knowledge deepening process (Mctavish, 2009). Collins and Halverson (2009) rightfully point out that the pressure to change schools is coming externally from beyond the classroom. They advise that:

> Even those of us who don't embrace technology in our lives now must understand the possibilities of the new technologies from the inside, if we want to guide the future of education. (p. 122)

To prepare students for future career, many policymakers have now included computer literacy skills as the repertoire of skills that students should acquire. This provided the impetus for creating the edifice of integrating technology into education.

Nested within the layer of macro landscape is the exosystem, which are distal influences that do not directly involve the school as active participant but still affect the way ICT is being implemented. Here, the exosystem pertains more to organisational culture or processes implemented by professional affiliations. Examples of exo-level actors include affiliated associations, researchers, industry partners and parents that the schools may collaborate with. Subjected to the tremendous pressure that stems from the macrosystem to integrate technology, coupled with the potential affordances of technology to reform pedagogies, schools are increasingly looking at using technology as a catalyst to change intransigent teaching practices. However, integrating technology at a school-wide level is a complex endeavour that requires differential expertise, which provides a compelling reason for working with exo-level partners to collectively achieve this goal. It is noteworthy that these exo-level actors are often situated in social spaces with distinctive routinized frames that are different to schooling, which makes such partnership replete with opportunities and fraught with tensions as well.

One explication of abovementioned tensions is school-university-industry partnership. Thus, such protracted tensions have resulted in less than spectacular collaborative attempts that culminated in sustainable reforms. The peril, as Ball (2012) points out is that relationships are "built upon contract rather than collegiality and aimed at profit generation rather than knowledge for its own sake" (p. 24). The knowledge embedded in researchers or commercial partners can become cognitive capital which proffers new frames of learning or result in "cognitive imperialism" (Hall & Stahl, 2012) which stripped schools of the core of teaching and learning through failed negotiations and encroachment of the school's established learning spaces. Thus,

we see that nature of partnership can either close or widen expectation gaps, belief gaps and competency gaps.

The meso level interfaces between the macro and micro-level influences and pertains more to institutional culture or strategies such as capacity-building strategies employed; envisioning of school's mission and vision; buying-in strategies used; resource alignment and renewals of structures. Micro-level influences relate to individual or classroom-level influences, such as individual's motivation to use technology; epistemological, technological, pedagogical and content knowledge embodied in individuals; actual enactment of ICT lessons by individual teachers as well as micro politics and ICT implementation by individual departments.

Such micro analysis of how teachers are integrating technology in classroom can be explicated using Technological Pedagogical Content Knowledge (TPACK) - a conceptual framework for understanding how teachers synthesise the different knowledge bases when integrating technology for teaching and learning. Thompson and Mishra (2007) position TPACK as the dynamic interdependence of the three knowledge areas. Chai, Koh and Tsai (2013) suggest that the development of teachers' TPACK can only be studied more holistically by encompassing contextual factors such as the enculturation of participatory learning and tolerance for chaos and ambiguity that accompany reforms. In view that the ecological elements of leadership practices, peer support, student feedback, researcher intervention and technological-pedagogical-content knowledge frequently act in an intertwined fashion to shape classroom practices, Toh et al. (2013) propose to study TPACK by examining the discursive feedback loop which translates into boundary spanning from micro to exo level influences.

Cutting across all these dimensions is the chronosystem, which takes into account the longitudinal changes made to the system and sub-systems, paying particular attention to the historicity, currency and future of school's development trajectory that influences the use of technology.

In a rare exposition of sustainability from the complexity perspective, Lemke and Sabelli (2008) argue that complexity theory is a useful lens to understand why some features are tenacious and the conditions under which they would change. They advocate the study of "relationships among the timescales of change processes in different elements of the system and between the system and the larger socio-political-economic systems in which it is embedded and in which its functioning depends" (p. 120). As sustainability depends on the perturbations a system can absorb without detracting from its core beliefs as well as the degree to which the system is able to self-organise and build capacity for learning and adaptation along time scales (Folke, 2006), the question that this paper would like to address is: How do school leaders, together with other autonomous actors in its ecological system, foster the favourable conditions for sustainable technology-mediated pedagogical reform?

Stacey (1996) proposes that a complex system can be studied by looking at the rate of information flow through the system; the richness of connectivity between agents and in the system as well as level of diversity within and between the schemas of agents. According to Leithwood et al. (2009a), complexity science holds "promise for unpacking the nature and consequences of distributed leadership" (p. 6).

Complexity scholars such as Hazy et al. (2007) calls for formal leaders to "enact formal organizational policies and processes for emergence and self-organisation to happen" (p. 95) in a complex adaptive system" (CAS) characterised by semi-

autonomous agents having the capacities to adapt to the changing environment.. This parallels Lewin and Regine's (2000) proposition that leaders should just concentrate on creating the right conditions for reform to happen.

Figure 1 shows the conceptual framework that emerged from the literature review. The ecological influences that have bearings on the sustainability of educational reform can be mapped out using Bronfenbrenner's (1993) ecological model. The interfacing within and across the five dimensions can be studied through the lens of school as a complex adaptive system and operationalised via the three thrusts identified by Stacey (1996).

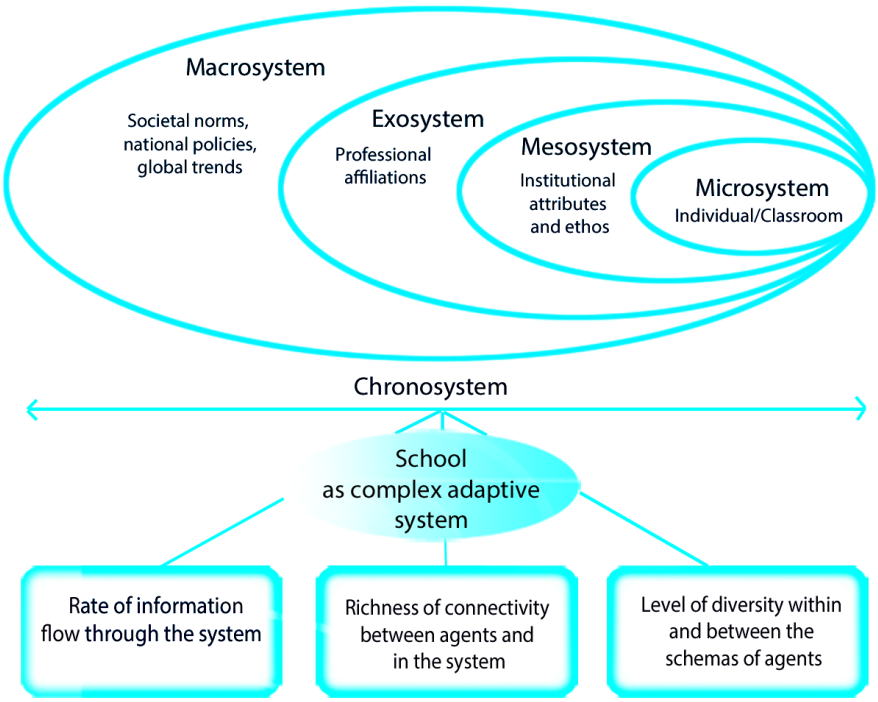

Fig. 1 Framework for studying education system as a complex adaptive system

The figure explicates that the way an organisation deciphers information can be affected by the rate of information flow through the system and the richness of connectivity between agents and in the system. In addition, whether such information can be translated into knowledge capital is dependent on the malleability of the agents' schema in interpreting new and diverse perspectives. The underpinning thrusts of the case school's ICT-mediated pedagogical reform are written up based on this conceptual anchor.

Research context

Systemic imperative for using technology in Singapore's educational landscape

The Singapore government's longstanding efforts to systemically integrate ICT into education can be distilled from the evolvement of its ICT Masterplans over the years. The narrative for change is centred on the imperative to equip students with 21st century competencies. The cornerstone of MP3 is to transform the learning environment so that students can become self-directed learners capable of engaging in deep learning independently as well as collaboratively anytime, anywhere. The Ministry of Education (MOE) advocates that technology be integrated throughout the educational process of planning, designing, enacting and assessing – a forward-looking policy that recognises the limitations of piecemeal technology integration plans. During this phase, schools enjoyed more autonomy as school leaders can exercise professional discretion to customise their ICT plans further, formulate directions and create conditions to harness ICT for teaching and learning (MOE, 2008).

Context of the school

Founded in the 1940s by a Chinese clan association to provide basic education for the children of immigrants from China, Genesis Primary School (pseudonym), or GPS in short, receives partial funding from the government and supplementary funding from private sources. GPS is a performing primary school that consistently achieves better results than the national average standards in high stake national examinations. The school started tinkering with technology in 2001 and established itself as a school with a niche in 1:1 computing from year 2005. It joined the rank to become one of the eight ICT prototype schools in 2011. Besides a string of accolades awarded by MOE for its purposive, prevalent and sustainable use of technology for enhancing student-centred learning across all levels, it has also received global recognition for its forward-looking curriculum. These are attestations of the school's persistent efforts to embed technology into their learning ecology, instead of using technology to propagate piecemeal innovations. These innovations can be bottom-up teacher-initiated efforts, or top-down leader-suggested initiatives that entail longer-term collaboration with university researchers. In a nutshell, GPS is a "Type D" school that has integrated the use of technology in many aspects such as curriculum design, professional development and profiling of teachers. It has also sustained the use of technology despite leadership change. Thus, GPS can be considered as an 'intrinsic' (Stake, 1995) case study where the technology integration has accompanied pedagogical reforms.

Data Collection Methods

As argued above, the nature of the topic of technology leadership for technology integration is descriptive, exploratory and laden with intangible constructs, thus the qualitative method of data collection is favoured. Complexity theory suggests that the unit of analysis should transcend individuals, institutions, communities and systems. These entities should merge to become a web or ecosystem, and it is this web that would constitute the unit of analysis (Cohen et al., 2007; Lemke, 2001) where the global nature of the institution is viewed in totality for holistic case study (Yin, 2014). The main methods of data collection for this study include interview, observation, documentary research as well as information gathered from serendipitous events collected over the four years (2009-2012) while collaborating with GPS as a university researcher.

Altogether, 17 people across the hierarchy were interviewed. They were identified based on the position they held, the roles they played in relation to an array of ICT-related projects, teaching experience, recommendations from the school and resident researchers, preliminary classroom observations and their ICT profile. Lessons observations were also conducted for six technology-using teachers with different profiles (based on teaching experience and proficiency of technology integration) to examine how technology integration unfolded within the classroom in a naturalistic setting. The researcher also acted as a participant-observer during professional development sessions and the notes that arose from the meetings served as data triangulation tool to the interviews. Document analysis also played a part in connecting the "past and present on the one hand, and between public and private on the other" (McCulloch, 2004, p. 28). Examples of documents analysed include meeting minutes,

lesson plans, emails, presentations, publications, ICT policy paper, photos and publicity material.

A longitudinal approach is employed as changes in a complex system cannot be understudied or explained just by examining synchronic snapshots. Such an approach allows us to examine "within-unit change", "growth trajectories" and "inter-unit differences in change" (Ployhart & Vandenberg, 2010, p. 97). For holistic analysis of change, a "contextualist" and "processual" (Pettigrew, 1990, p. 269) orientation are necessary to see the interconnection of changes happening at different levels across time. With Stacey's (1996) three complexity constructs of "rate of information", "connectivity" and "diversity" in mind, data is then coded according to these three broad themes. As with most qualitative studies, open codes formed are subsumed under categories that are "mutually exclusive", "sensitising" and "conceptually congruent" (Merriam, 1998, p. 184). Data that are in congruence across the different data collection methods adds credibility to findings. Data that are in conflict were studied in detail, triangulated with more participants such as resident researchers as well as followed up during the member-checking phase for greater clarity. "Inferential glue" (Miles & Huberman, 1994, p. 261) is then applied to link categories and themes together so that a proposition can be drawn up.

Findings

In this section, the writing of the findings is organised using the three thrusts of complex adaptive systems as expounded by Stacey (1996). Congruent to the three themes identified by Stacey is that at the leadership level, the school leaders can foster favourable conditions for technology integration to happen within and across different sub-systems of the ecology.

1. The rate of information flow through the system

The rate of information flow is vital as it is the premise on which organisations act and respond to perturbations in the systems. 'Micro-structuring for interaction' (Goldspink, 2007, p. 42) and systematic levelling up of innovations are elements that can affect the rate of information flow through the system. The former serves to increase the flow of information while the latter aims to slow down the rate in order to translate information into knowledge.

(i) Micro-structuring for interaction

To ensure information that stemmed from complex and dynamic cross-scale interactions could reach locally interacting heterogeneous agents, GPS adopted the "all-channel" (Morrison, 2002, p. 145) model of communication where interactions can be vertical between individuals and upper management through weekly contact time; lateral between individuals and departmental colleagues through departmental meetings; converging between individuals and project team members through time-tabled time (one and a half hour of discussion time instituted into curriculum time) and self-organised between individuals and like-minded colleagues linked by common interests. The all-channel dialogues facilitated discussion and information flow as there were many opportunities, including through informal alliances or relational affinities, to share macro and micro-level issues related to technology integration. It also encouraged reflexivity on the interplay of influences. Such musings allowed actors at the micro level to be attuned to making adaptations and collectively made decisions on technology integration.

The collective feedback and adaptations were able to reach the management for further action. As an example, some of these re-structuring efforts in GPS were top-down responses *[meso]* to bottom-up *[micro]* suggestions. Notably, teachers reflected the pressing need to structure a common and longer block of time within the curriculum timetable for project members to discuss matters pertaining to their innovation as well as to enact student-centred lessons. Teachers also suggested that the professional development sessions could be more personalized and implemented in the format of small-group peer coaching. These measures increased efficiency as more time was freed up for constructive discussion rather than coordinating logistical demands.

However, it appears that for such free flow of information to happen, at the micro level, the various social networks have to build collegial people-oriented relationships so as to facilitate self-organisation. Consensual outcomes can then be reached alongside with the prompt re-configuration of the system only when there is rapport and trust. This was observed during one of the meetings of Arts department (department name concealed) where teachers deliberated about the enactment of their ICT-mediated lessons. They had no qualms revealing their 'incompetence'. There was veracity in teachers' views as they shared about their apprehensions and aspirations, which in turn, encouraged deeper tinkering and critical reflections. These articulations became feedback loops where positive narratives were amplified in other classes and problems nipped in time as teachers collectively responded and prevented the replications of the problems in other classrooms.

The extraordinary collegiality, higher rate of information flow and prompt self-organisation within the particular department could be attributed to: a) geographical proximity; b) more reflection time together; c) cognisance of the common need to inject

new lease of life into the teaching and learning of the subject matter which is traditionally given less emphasis in Singapore's context; d) longstanding tradition of resource-sharing and camaraderie; e) flat hierarchy as Heads of Departments (HODs) worked alongside the teachers and adopted a very spirited stance and f) presence of key ICT champions whose enthusiasm was contagious. These favourable conditions enabled synergies or misalignments to surface and allowed actors in the system to respond to them in-situ.

(ii) Systematic levelling-up of innovations

The school's emphasis on having proof-of-concepts before levelling up the innovation was another example of harnessing feedback loops. Although the process of reform can be "messy", clear lines of communication need to be established and information interpreted to expose and act on weaker links timely. GPS adopted a judicious attitude when spreading innovations in the school. Systematic pacing was consistently highlighted throughout GPS' decade-long history of experimenting with technology. Instead of levelling-up innovations to the whole level from the onset, they were diffused gradually over time. The first principal explained the rationale:

> ICT cannot be rushed. If you want to do it then you must give yourself the time to grow many things. You may not know exactly what is it that your school can do and what you want to do. So you got to give it some time.

This was akin to "sense-making" where effort was spent critically reviewing the value that technology adds to teaching and learning, the alignment of affordances with pedagogical principles and its compatibility with the school's ecology before making

bigger-scale investments. The development of proof-of-concept was one of the important building blocks to motivate teachers to come on board voluntarily. It also served as a basis of judgement for departmental heads to decide whether to incorporate the innovations into the department's scheme of work, which is in congruence to Leithwood's (2011) observation that high performing schools use evidence-based data to inform school's decisions and to solve problems. Gabriel highlighted that instead of fleeting from one innovation to the other, promising innovations in GPS would undergo iterative cycles of reviews to improve its design and implementation. Carl, the first principal of GPS explicated:

> You don't want to move abruptly to something new and change everything altogether. Then you cannot tap on the experience of that growing. Move in a very logical manner so that the growing makes sense to people.

Although the rate of information flow may be slowed down due to the iterative discussions, they are necessary as it allows GPS to become more purposive in resource channelling and avoid incoherent endeavours that dispersed their innovation efforts.

2. Richness of connectivity between agents and in the system

Inter-connectedness is one of the hallmark characteristics of a complex adaptive system and such couplings can manifest in the form of policy, social and temporal connectivity, as seen from GPS' case.

(i) Policy connectivity through shared accountability within and across subsystem

The learning climate in GPS is generally an inclusive one. This can be seen from the participatory dialogues that the principal facilitated when crafting the cornerstone of the school's teaching and learning framework. The principal was also inclined towards using lexicons such as "a project that we all like to do", "all of us will play a role" (observation of contact time), "this is not my school, this is our school". This instilled a sense of collective ownership. Such efforts to create shared visions and new directions through dialogues were important means to maintain coherency in ICT integration.

In addition, distributed leadership can also be observed across a spectrum of activities. In terms of curriculum innovation, the school espoused a whole-school approach which witnessed the synergy of bottom-up initiatives and top-down support. The former include empowering teachers to provide instructional leadership, enact curriculum innovation and improve teaching practices. The latter culminated into leaders providing visionary and strategic leadership, curriculum framework and translation of effective programs. Gabriel, the ex ICT-HOD explains the importance of bottom-up initiatives:

> (In 2009) ICT innovations are run by the ICT department, I guess our creative juices will run out sooner or later. So in terms of sustainability and ownership, [the principal] wants it to come from bottom-up……

In the past, the ICT department was also tasked to level up successful pilot projects across the whole level but the school was quick to realise the inherent weakness in this reform model. Experiencing difficulty in sustaining momentum as more and more projects were propagated in the school, the principal decided to emphasise shared

accountability between the ICT department and the instructional leaders of the respective subject departments. The ex-ICT HOD pointed out the merits of such arrangement:

> Because of all these structures [the principal] put in place, the ICT department can focus on what we do best, which is to explore and to bring in ICT pedagogy.

Converging along the same argument, Nigel, the current ICT HOD felt that such an approach allowed the school to "see more synergy and integration".

Apart from the departmental synergy between the subject and ICT departments, shared accountability can also be observed via the cross pollination of ideas and shared decisions made on curricular matters across different departments. The most prominent example being the co-designing of mobilised learning journeys where different departments provided inputs across all aspects of programme – trail design, data collection and logistical coordinating. The benefits of cross-departmental interactions are aplenty, as according to Nigel:

> The discussion is very much richer, because it comes from multiple perspectives…..With regard to the school's planning, we do not want a situation where the departments work in silos, where they are just concerned about what they are currently doing for their department.

By having such cross-departmental interactions, organisational goals and expertise complementariness can be heightened.

Shared accountability also enhanced the credibility of the decisions made. The key personnel of all departments collectively reviewed the curriculum innovations and decided their future direction. The principal explicated that such a decision-making mechanism buttressed his confidence in decisions made as he was leveraging on collective intelligence. Using a metaphorical description, Nigel described this as casting a wider net so that the decision-makers were not "localised to only a few". This constituted an integral part of the buy-in process of innovations, which had bearings on the sustainability of ICT programmes. This is in line with O'Day's (2002) argument about the concomitant emphasis of whole-school administrative and professional accountability to create meaningful and lasting reforms.

(ii) Social connectivity in the system

Shared accountability at the meso level mentioned above can be hampered by inter-department dynamics and social affinities at the micro level. For example, during the period from year 2009-2010, the ICT department and one of the Sciences departments (department name not disclosed) experienced disjuncture in their joint technological integration efforts. The reasons were: a) lack of shared imperative revolving the essential use of ICT to improve student outcomes; b) the resultant effect of Sciences HOD working at "arms-length" with the IT department and researchers and c) absence of proactive ICT champions. As there was no total buy-in, the middle manager became the sole conduit between ground-level actors, administrative leaders and researchers. The two-year dead lock was resolved when the new ICT HOD whom was promoted

from within the school came on board. The middle manager of Sciences department whom supported the use of ICT for teaching and learning later became the new Sciences HOD after the former head left the school to assume a more senior role in another school. The duo had more affinity and worked closely during the scaling phases of innovation. Propositions can be drawn up based on the micro-meso dynamics exhibited by the two departments: a) informal alliances or relational affinities such as friendship have more power than formal authority; b) self-organisation is more apparent only when there is collegiality and self-referential properties revolving around core identity.

(iii) Temporal connectivity within and across the chronosystem

Information that flows through the system comprises not only forward-looking changes that are taking place in the broader socio-political landscape, but also the historical perspective which the school is embedded in. As Cilliers (1998) points out:

> Any analysis of a complex system that ignores the dimension of time is incomplete, or at most a synchronic snapshot of a diachronic process. (p. 4)

Leveraging on institutional memory, GPS managed to achieve depth in its innovations by making deliberate choices to advance student-centred learning through 1:1 computing over the decade. As such, there is continuity in the school's philosophical underpinnings on ICT usage even in the face of new stewardship. The self-referential identity of GPS as a 1:1 learning school enabled the whole fraternity to remain focused on the core innovations, reject peripheral ICT involvements, expand and later

streamline its coalition as well as structure its school operations for student-centred learning.

The sustainability of innovations in GPS constituted another building block towards its success. Because of the school's efforts to sustain and scale up successful pilot projects, there were opportunities for institutional memory to become embodied tacit knowledge which was deepened over time. The tacit knowledge was subsequently transformed into knowledge capital that attracted more social and financial capital to sustain the innovations.

Environmental scanning is an integral mechanism for GPS to respond intelligently to changes. Mason (2008) explains:

> Successfully adaptive institutions will continually rearrange their constituent networks according to the future that is anticipated by internal modelling based on prediction and environmental feedback. (p. 40)

In GPS, there is on-going scanning of macro policies, pedagogical developments, technological environment and social networks. The scanning of environment had enabled GPS to set the strategic directions for its ICT development. Connecting to experts, understanding socio-political trends, making systemic evaluations regarding technology, assessing contextual readiness all add to create a better sense of mission in the usage of technology. In this sense, being cognisant of institutional memory and co-scanning the external environment can help the school understand its bounded context and develop its potential over time, thus connecting its past, present and future more coherently.

3. Level of diversity within and between the schemas of agents

The level of diversity within and between the schemas of agents can affect how issues have been deliberated in an institution. According to Davis and Sumara (2006), the mental models of individuals will be enfolded in nested layers of subjective understanding, classroom collectivity, curriculum structures and objective knowledge. Such enfolding process of schema development can be shaped by capacity building efforts, mitigation of tensions among actors in the system, presence of psychological safety for diversity and the system's ability to find convergence amid diversity.

(i) Multi-pronged capacity building efforts

Schools that are able to renew themselves to change the mental models of teaching fraternity invest in capacity building efforts. In GPS, the school emphasises on building the capacity of teachers so that they can become teacher-researchers. To see this to fruition, the school established an in-house research centre where teachers can work along with resident researchers to augment their research skills – a precedent for local primary schools. Such a move also ensures that successful projects will not be episodic in nature. Building on the strong fundamentals of viable projects, more teachers will be trained and a critical mass of champion established through social apprenticeship. Through apprenticeship with researchers *[meso]* and social learning with peers *[micro]*, teachers experienced pedagogical change and gained professional capacity to re-design curriculum. These changes were further moderated by students' performance *[micro]* and parental expectations *[exo]*. A stark contrast to ad-hoc professional learning sessions, the handholding by researchers took place on a weekly basis which

promulgated the internationalization of new schemas that emerged from the social interaction.

(ii) Mitigating systemic tensions amongst stakeholders

Technology-mediated reform involves social-cultural reconfiguration and the social act of mitigating systemic tensions among actors of the system. Lichtenstein et al. (2006) posit that perturbations from social actors and the resulting feedback loops will result in the re-alignment of individuals' mental models about teaching and learning. In complexity terms, this is "co-evolution". The rate of information flow which was mentioned in the preceding segment is one of the enabling conditions that accelerate the realignment of cognitive maps among agents. In GPS, co-evolution can emanate from tensions between policy (macro), research (exo), industry (exo) and practice (micro).

At the macro level, policymakers provide a protected environment with extra resources for ICT prototype schools (known as FutureSchools) to experiment with radical or disruptive innovations. They were also given the mandate to build up the innovation capacity of other schools in the area of ICT integration through the proliferations of their innovations via networked effects. GPS, being one of the FutureSchools, has to lead the reform efforts in its school zone in a fashion that is aligned with the thrusts of the third ICT Masterplan - to promote collaborative and self-directed learning. Thus these top-down accountability measures constitute an exogenous force for GPS to leverage on system structures such as MOE grants to diffuse innovations to more collaborating schools.

However, diffusing innovations to other schools is not an easy feat as it involves intensive mobilisation of resources from within the FutureSchools. To resolve this predicament, GPS puts in a sustainable plan that allows and encourages the selected champion teachers and support staff to move beyond their comfort zone to enter new spaces of teaching and learning. The school effected structural reforms for resource orchestration, offloading teachers and providing time for reflexivity so that they can be enculturated with new skills of re-contextualising innovations at new sites. This process requires working with partners from the academia and industry over time. Thus, at the macro landscape, there is a need to avoid falling into the belief trap of "technology determinism". The interplay of technology, political-economy and socio-cultural factors are to be considered in totality.

One example of socio-cultural tensions that comes with working with multiple partners is the research-practice gap *[exo-meso-micro]*, discernible from mismatched expectations between researchers and practitioners. This could be attributed to inadequate communications of research protocols such as the need to use control groups to benchmark against the learning gains of intervention. Such requests from researchers were often misconstrued by non-experimental teachers who were wary that their teaching practices may be portrayed as inferior when compared to the invention class which had been receiving intensive support from the researchers.

Fault lines that ran through the debates of whether technology should be used as an essential tool in the classroom also affected how such tools were used in various contexts. One of the department heads was sceptical about the positioning of technology as an essential tool for learning and preferred a more critical discussion on whether the add-on approach to ICT integration would pose less structural demands to

the time-tabling schedule and allow more time for the completion of mandatory worksheets. School-research-industry tensions were also evident from the recurring problem of vendors escalating the development cost of applications when they had to respond to emergent pedagogically-driven changes.

These abovementioned tensions bespoke the fact that schools, universities and industries have different ecologies and thus the conflation of interests does not come effortlessly. Nuanced and patient negotiations had to be conducted with stakeholders frequently to mete out differences, which eventuated into new mental models for actors involved. Notably, the teachers are now more receptive to the concept of using control groups, the school more judicious when selecting commercial partners and the culture of relying predominantly on drilling worksheets transformed.

At a *meso-micro* level of analysis, tensions were also palpable when experimental teachers experienced pedagogical and cognitive dissonances, especially during the "teething" stage of innovation. One example relates to the integration of school-wide pedagogy - Teaching for Understanding (TfU) framework which was mooted by the Harvard University as a model of teaching. The use of instructional framework is the school's attempt in coherence-making but inadvertently created frustrations in the process. The need to marry the TfU framework with mobilized ICT curriculum added more complexity to instructional planning, especially Mathematics, which was predominantly taught in drill-and-practice way which "did not require students to articulate their understanding through words but more needing to know the steps" (middle manager Hannah). The rigidity of national examination format also called for the need to design a generic but validated instrument for evaluating students' competency across levels and subjects. The school eventually placed less emphasis on

TfU as a school-wide pedagogy and re-configured its narrative for teaching and learning.

Another experimental teacher recounted her difficulties of enacting constructivist practices as she was unsure how to navigate between providing closures to inquiries and providing space for students to explore:

> (In the beginning), I don't conclude. ……I was lost…… You know, supply information or don't supply? So it's only after that, I go and think about it, then I reassure the students……you go ahead and look for the information that you think is right or wrong. I will tell you the answer later. Maybe this motivated them to really go and experience the activities.

As a beginning teacher, the teacher's dominant pedagogical strategy was didactic instruction and the shift of emphasis to constructivist practices posed challenge to her as well as the students. She recalled the divided responses from the students during the transition – enthusiastic students enjoyed the freedom of searching information on the web while passive students felt insecure without the immediate validation of "right" answers. To manage the diverse expectations, the class finally converged along the line that a "closure" would be provided towards the end of topic. Thus, the use of technology in the classroom had explicitly created a "culture shock" for the teacher as well as supported her transition to new pedagogic approaches. The challenge to her personal knowledge base resulted in changes to her practice, belief and theory. Her cognitive maps were constantly re-shaped by what had emerged in the classroom.

These vignettes show that actors within and beyond the school organisation interact to fulfil intertwining roles. Changes can happen as a result of longitudinal neighbour interactions among all actors as they influence, clarify and shape one another's roles, mindsets and practices.

(iii) Creating psychological safety for diversity

To facilitate heterogeneous perspectives, the school leaders have to build a psychological safety net for the voices of dissidents to be heard. Says Gabriel, the ex-ICT HOD:

> If everybody buys in, you will be very worried if you make the transition properly or not. If you are serious about change, you have to embrace them. …they are like your checks and balances.

In this sense, changes taking place in the school was more evolutionary than revolutionary. To encourage more "willing converts", the school created more avenues for dialogues, leveraging on soft persuasion and demonstration of positive narratives. As for teachers who were ambivalent towards the use of technology, the school provided them with breathing space by assigning lower primary classes to them. As these students do not use technology intensively in their early years of schooling, it provided teachers with a much needed buffer time to get acquainted with technology – a process which Amelia, the school's ICT project coordinator aptly described as "simmering". That is, the school "replace(s) polarisation with integration" (Hargreaves & Fullan, 2012, p. 154) and this encouraged re-alignment of mental models as

discussed above. The school also nurtured a favourable environment for innovations by embracing "messiness" at a more macro level and sending strong signals that it is "alright to fail" as long as they were able to understand the reasons that led to the divergence from espoused practices. This ethos ensued even after a change in stewardship of the school in 2008, which suggested a consistent, patient and tolerant culture for seeding and growing innovations.

(iv)Creating convergence amid diversity

In GPS, there is a culture of respectful sharing. As collegiality grows, so is the plethora of views that the community gets to hear. Although a high level of diversity and healthy tensions are desirable, these diversities have to be bounded by "strange attractors" – which are elements that would "hold our behaviour within a boundary and keep us from wandering into formlessness" (Wheatley, 2006, p. 132). In GPS' case, the school's overarching framework on teaching and learning is the strange attractor which the system keeps going back to. The narratives of collectivism that the principal used constituted another means to create order out of the chaotic diversity.

The school was also mindful about situating their projects in the broader socio-cultural context of the school when spreading their innovations. Projects that were led by researchers were further reviewed and customised based on the needs of teachers and students, which had bearings on sustainability. Says Gabriel:

> Sustainability…the way I look at it, what you all (researchers) did is the research component, so you all come into school with a model and are helping us to determine way of doing, learning value and whether there is outcome. But

> for us, if we want sustainability, we have to spend time to translate it back into the school's way of doing it.

Such negotiations showed that the school was aware of the pitfalls of supplanting technological integration plans without considering the unique ethos and demographics of the school.

Implications

Figure 2 is an attempt to elaborate the complexity-informed technological integration framework which arose from the reflections on GPS' case. The core ring depicts diverse and autonomous agents being bounded by common parameters which then became a self-referential norm that GPS can identify with. Together with collective reflexivity, the whole organisation became more aware about the systemic influences at play. These three outcomes form a virtuous learning loop: collective sense-making and knowledge co-production can help a system as a whole respond to the environment more intelligently; such knowledge augments the system's capacity for learning and injects buoyant energy for self-renewals and adaptations, as seen from GPS' attempts at re-structuring and re-culturing the school for promulgating pedagogical innovations.

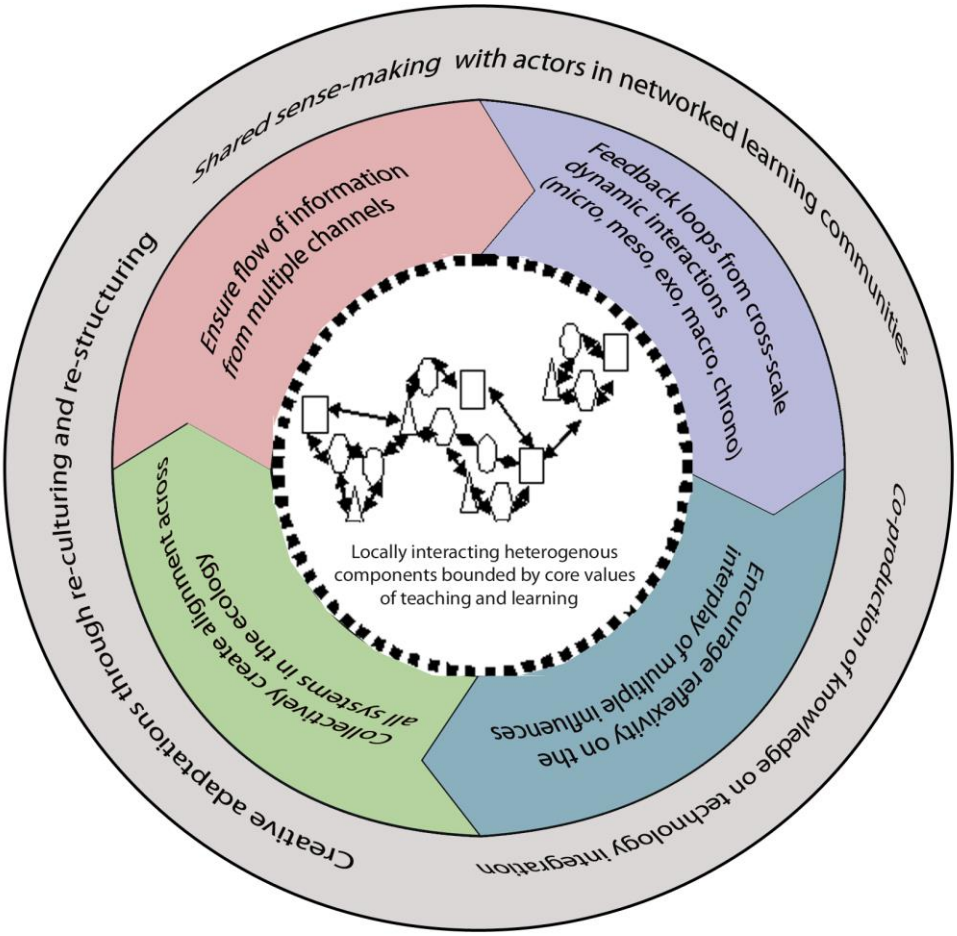

Fig. 2 Complexity-informed leadership framework for school improvement

With this mechanism in place, the tacit knowledge would potentially be transformed into knowledge capital that attracted more social and financial capital to sustain the innovations. Here, we see the formation of a virtuous cycle that had spun off from the school's early successes, attesting to the fact that complex adaptive systems are "sensitive to initial conditions". These strategies lead to the sustained technology-integration in the school.

The implications of this framework are multi-fold:

1) Policymakers and school leaders should strive to ensure ecological awareness related to technology integration rests not only within the upper echelons of hierarchy. Information that stems from the complex and dynamic cross-scale ecological interactions should reach locally interacting heterogeneous agents and this requires the building of collegial people-oriented relationship;
2) Reflexivity on the interplay of influences should be encouraged so that actors at the micro level can also be attuned to making decisions based on systemic considerations, which is aligned with Goldspink's (2007) argument to leverage on collective intelligence to "develop viable responses to the more perennially difficult aspects of administration" (p. 46). This decentralised and distributed decision-making model promotes self-organisation at the ground level;
3) The abovementioned reflexivity should culminate into efforts to create alignment through healthy feedback mechanism and encouraging heterogeneous voices at multiple levels of the systems so that the dynamic needs at the individual, organisational, professional, national and global levels can be met;
4) Piecemeal technology adoption efforts seldom result in deep changes. For integration to happen and thereafter be sustainable, the actors in the system must foster "ecological coherence". However, such coherence or alignment is transient as the conditions coalescing around technology, pedagogy and policies are constantly evolving.

Overall, the transformative journey is a result of collective intelligence, distributed across time and space. There is no "fixed" plan in the beginning but one common thing that runs through the whole trajectory is that technology should not supersede teaching

and learning. However, the growth trajectory is not completely serendipitous either. One implication of the diminishing coupling effect of Bronfenbrenner's (1993) ecological model is that it is still important for leaders to foster ecological coherence; even though actors at the micro scale can self-organise. This is so as leaders have more access to information emanating from higher levels of sub-systems and thus can play a role in providing the right conditions for effective feedback mechanisms to occur as well as for innovation and reflective culture to be established, leading to school improvement.

Conclusion

The article elucidates GPS' longitudinal response to technology integration for student-centred learning. Despite the ephemeral nature of technology development, the use of technology in the school has not exhibited signs of languish over the decade - a result of the school's persistent effort to build cumulative and critical ecological connections. The story of GPS underscores the importance of adopting a "holistic, connectionist and integrationist view" of reform and the "spontaneous reorganisation emerging from the interaction of elements" (Morrison, 2002, p. 7).

To reiterate, GPS did not achieve whole-school improvement when technology was firstly introduced. Instead, school improvement in terms of student and teacher change was the result of iterative innovations and reflections amongst all actors - an attestation to how the school became a learning organisation through distributing leadership and enhancing collectivism at all levels of social interactions.

As for future research, since this study is based on one longitudinal study of a case school in Singapore which focused on the use of 1:1 computing, researchers who wish to explore the robustness of complexity theory in understanding change processes

and technology integration can look broader beyond the setting of 1:1 computing to distil the salient essence of technology-mediated reforms. At the macro level, it would also be useful to track whether and how an exemplar school's in-depth knowledge on sustainable reform management can be diffused to other schools in the system despite the variegated contexts and challenges. For exo level, studies can be conducted on how the marketization of education can affect the relationships among the actors partaking in reform efforts, especially for technology-mediated reforms that involve a myriad of stakeholders. At the meso level, more can be done to look into how organizational attributes that are favourable for reform may be impacted by a change in leadership. At the micro level, it is vital to understand how teacher change can be sustained when both external and internal influences change. Complexity theory, despite its putative nascency, could be one of the useful lenses to study the changes that occur within or across the abovementioned sub-systems.

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