Digital *learning trails*: Scaling technology-facilitated curricular innovation in schools with a *rhizomatic* lens

Azilawati Jamaludin[1] · David Wei Loong Hung[1]

Abstract Technological advances in the form of ubiquitous computing has altered the learning landscape today. Contemporary modes of learning afford curricular innovations in schools. While learning journeys of decades ago entailed field trips to places of interest such as museums and zoos where students completed tasks or worksheets after each trip, the learning journeys of today are facilitated by technological tools such as smart devices and global positioning systems. Learners are moving away from being mere content consumers through technology-facilitated dialoguing and content creation (Tay and Lee 2014; Tan et al. 2011). In this paper we unpack tenets of a technology-facilitated curricular innovation (CI) through a case study analysis of the development and implementation of a Digital Learning Trails (DLT) project. Through tracing the trajectory of the DLT project, we identify factors related to the scalability and sustainability of this CI that was developed in one school and subsequently used by more than 200 schools in Singapore. We posit that scaling curricular innovations in schools can be conceptually provisioned through a rhizomatic lens where innovation is characterized by multiple trajectories, allowing for recontextualizations of CIs. We argue that, (1) the pedagogic process in the context of education and scaling is based on supporting apprentice-schools to make multiple recontextualizations; (2) the enculturation process of a school adopting and implementing a particular innovation is based on a rhizomatic rather than linear, conception of the development of expertise; and (3) the process of CI implementation is based on developing the capability to not only make multiple

✉ Azilawati Jamaludin
   azilawati.j@nie.edu.sg

   David Wei Loong Hung
   david.hung@nie.edu.sg

1 National Institute of Education, Nanyang Technological University, Singapore, Singapore

🐾 Springer

recontextualizations but also to accumulate enough capital to send out new 'roots and shoots' as it spreads.

Keywords Curricular innovations · Digital trails · Education reform · Innovation diffusion · Scale and sustainability

Introduction

In an era of exponential change in the pace and scope of economic and political developments across the globe, tandem shifts are requisite for both social and educational progress. Singapore, for instance, has always related its development to education. In the wake of economic recessions in the 1980s, an Economic Committee recommended the education of each individual to his or her maximum potential, and the development of creativity and flexible skills in order to maintain Singapore's international competitiveness (Ministry of Trade and Industry 1986). The need for creativity was reiterated by the Economic Planning Committee in the early 90s (Ministry of Trade and Industry 1991) where education institutions were called upon to engender the requisite change (Ng 2009). Consequently, education reform has been a key component in the national development strategies of Singapore (Hallinger 2010). In one OECD report, Singapore's overarching narrative of a *learning nation* toward raising educational levels to "one similar to that of many developing countries to match the best in the OECD" (OECD 2010, p. 160) was recognized. The tight interrelations between education and socio-economic developments propel the need for Singapore to restructure not only its economy into knowledge-intensive industries but so too to introduce reforms to its education system that has previously "focused on efficiency and standardization, with a premium on examination success" (Gopinathan and Mardiana 2013, p. 23).

Education reform: Curricular innovation in Singapore schools

In a bid to move from efficiency and standardization to an 'ability-driven' system, a 'Thinking Schools, Learning Nation' (TSLN) policy initiative was introduced in 1997 where the then Prime Minister of Singapore (Goh 1997) called for Singapore's education institutions to respond to the knowledge economy by using, creating, critiquing and applying knowledge rather than showing off mastery of content in examinations (Koh 2013). TSLN led to a "veritable hurricane of reform initiatives in Singapore schools (Deng and Gopinathan 2003, p. 51). In 2004, the 'Teach Less, Learn More' (TLLM) initiative was further launched, heralding Singapore's Ministry of Education (MOE) commitment "to an ambitious program of pedagogical reform in Singapore schools in anticipation of the kind of institutional challenges—particularly those in increasingly globalized labor markets—that young Singaporeans are likely to face in the coming decades" (Hogan and Gopinathan 2008, p. 369). Since TSLN and TLLM, profound changes have been introduced to the structure of Singapore education, with a view to affording flexibility, "pathways and bridges" (Ng 2009, p. 2) for students across the spectrum. The proliferation of
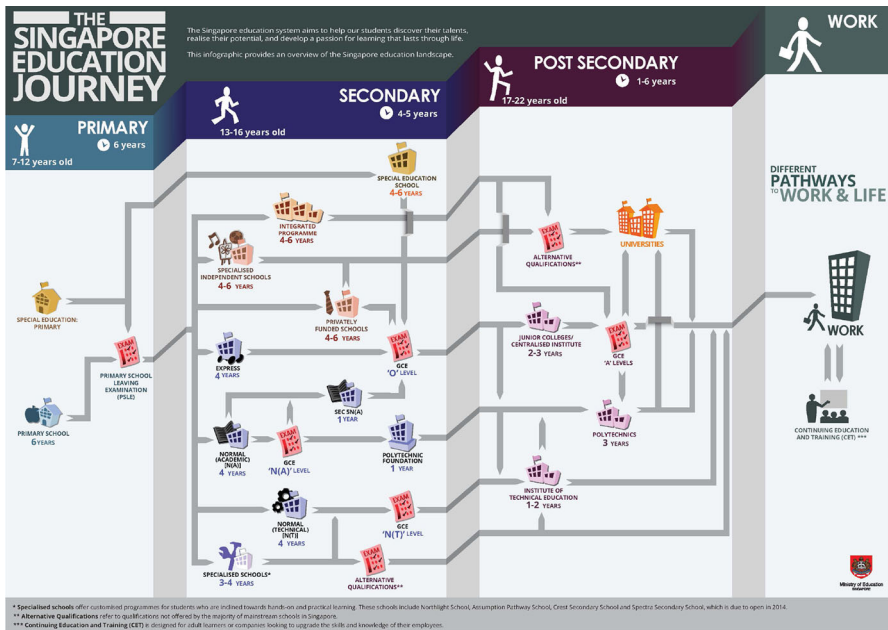
Fig. 1 The Singapore education journey: different pathways to work and life (Ministry of Education 2015)

pathways and bridges included access to tertiary education and higher levels of schooling, as well as creating different trajectories of specialized schools that focuses on niche areas such as sports, arts, or science and mathematics (Gopinathan and Mardiana 2013) (see Fig. 1).

The shift from an industrialized economy to a globalizing economy has led to education reform policies that place strong emphasis on transforming attitudes to knowledge and pedagogy (TSLN, TLLM), strengthening citizenship (National Education), and leveraging on the power of information and communications technology (IT Masterplans) to meet the desired outcomes of 21st century education.[1] Yet against these centralized thrusts of the education system, there is system flexibility at the ground level with increased autonomy given to schools to engage in decision-making 'de-centrally', in response to their own pedagogic needs. Within this vein, schools have the latitude to make curriculum adaptations within their local context as long as those approaches are aligned and consistent with the overall intent of the overarching education policies, characterizing a centralized-decentralization approach of the Singapore education system (Chua 2014). While there is centralization at the macro policy level, schools have the agency to implement and enact the policy directives in accordance to contextual nuances at the micro school level. Recognizing the need for flexibility in light of economic demands for innovative, creative, entrepreneurial and problem-solving skills, the

---

[1] Singapore's MOE 21st century education and student outcomes framework can be found at http://www.moe.gov.sg/education/21cc/.

At the end of <u>Primary</u> school, students should:	At the end of <u>Secondary</u> school, students should:	At the end of <u>Post-Secondary</u> education, students should:
be able to distinguish right from wrong	have moral integrity	have moral courage to stand up for what is right
know their strengths and areas for growth	believe in their abilities and be able to adapt to change	be resilient in the face of adversity
be able to cooperate, share and care for others	be able to work in teams and show empathy for others	be able to collaborate across cultures and be socially responsible
have a lively curiosity about things	be creative and have an inquiring mind	be innovative and enterprising
be able to think for and express themselves confidently	be able to appreciate diverse views and communicate effectively	be able to think critically and communicate persuasively
take pride in their work	take responsibility for own learning	be purposeful in pursuit of excellence
have healthy habits and an awareness of the arts	enjoy physical activities and appreciate the arts	pursue a healthy lifestyle and have an appreciation for aesthetics
know and love Singapore	believe in Singapore and understand what matters to Singapore	be proud to be Singaporeans and understand Singapore in relation to the world

Fig. 2 The desired outcomes of education at different stages (Ministry of Education 2015)

process of de-centralization, sought to achieve the desired outcomes of education (see Fig. 2).

From a system structural perspective, the process of 'de-centralization' was initiated with nine leading schools in 1988 to have greater school autonomy in terms of pedagogic maneuverability at the school level. The move was soon followed by the creation of autonomous schools in 1994, and the creation of cluster schools in 1997, further organized into geographical zonal branches in 2000 (see Fig. 3).

Within each geographical zonal branch, schools were further organized into clusters (approximately 7–8 clusters per zone), with an average of 11–13 schools per cluster (a mix of primary, secondary, and post-secondary institutions). With a view to raising the capacity of the leadership teams and the level of performance in each school, a cluster superintendent was attached to every cluster to facilitate networking, sharing and collaboration among the member schools within the cluster (Ministry of Education 2015). Each school zonal branch further oversees the management of the schools within their purview, in terms of personnel development and facilitating projects and activities oriented towards overarching desired outcomes of education.

Singapore has a centralized education system characterized by a universal teacher-training program, and a strong focus on data-driven external accountability, yet the country also embraces localized innovation and application of technology, personalized learning, and holistic education (Hargreaves and Shirley 2012). To this end, in operationalizing the enactments of the reform policies at the school level, various research interventions and curricular innovations, such as inquiry based
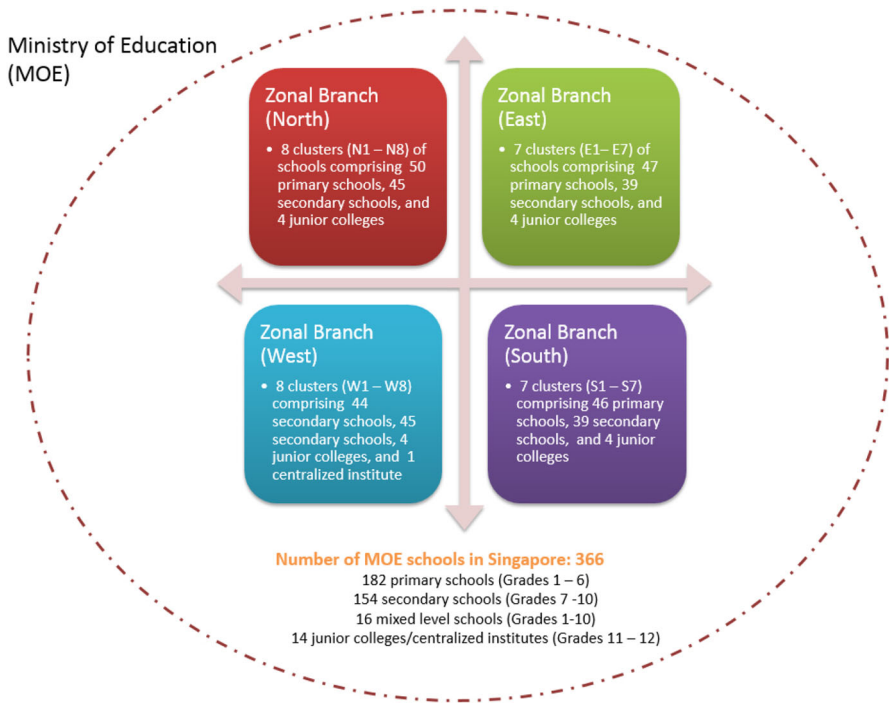
Fig. 3 Zonal and cluster organization of all Singapore schools (primary, secondary, junior colleges, institutes)

learning mediated by technologies, have been introduced in classrooms (Hung et al. 2015). An example of such an intervention is a cluster-based Digital Learning Trails (DLT) project which, within a context of the third MOE ICT Masterplan (MP3) initiative (Ministry of Education 2008), aligns its research objectives with key thrusts of MP3, particularly that of student-directed learning (SDL), collaborative learning (CoL), and authenticity in learning (AoL) facilitated by technology-enhanced mobile learning opportunities.

Cluster-based digital learning trails project

The DLT project revolved around the use of a digital learning trail toolkit developed in a secondary school in Singapore, in partnership with a software development company. While learning journeys, as place-based experiential pedagogy, has been used in many classrooms in Singapore, National Secondary School (NSS), an autonomous school[2] consisting of students aged 12–16 (equivalent to Grades 7–10),

---

[2] Autonomous Schools in Singapore were established in 1994 to provide pupils with quality education within the framework of a non-independent status but with greater autonomy devolved to the schools. Autonomous Schools are given additional funding to enable them to develop a wider and better range of programmes to stretch the capability of their pupils (Ministry of Education 2002).

mooted the move to go beyond traditional 'pen and paper' trails. Leveraging on the ubiquity of pervasive computing to develop a mobile app on mobile and handheld devices,[3] the development of digital learning trails aimed to not only harness place-based experiences traditionally designed by teachers but also entailed a component for students to design their own mobile learning experiences. While traditional learning trails entailed students' excursions or field trips to places such as the zoo or museum, and completing worksheets related to the place and topic of study, the digital learning trails programme mounted by NSS is oriented towards engaging learning at a much deeper level where not only teachers, but learners too, can create dynamic inquiry-based and problem-based learning content while being in placed-based learning environments, akin to the idea of 'bringing the classroom to the students'. Importantly, the customisable and user-friendly web-based interface of the digital learning trails application also meant that both students and teachers are no longer handicapped by the 'one-size-fits-all' fashion of teaching and learning. Rather, teachers are able to customize the learning content in accordance to their pedagogic needs while the same set of learning contents can also be easily customized to cater to each student's learning ability, pace and style (Rockmoon 2015). Shifting toward student-directed forms of learning, the introduction of the use of digital learning trails also serves as a means of harnessing elements of real-world data collection, collaborative learning, and active knowledge construction. As part of NSS' integrated curriculum initiative that was introduced in 2008, the school crafted performance tasks to complement traditional tests for a more holistical student assessment. The performance tasks require students to complete complex tasks that tapped on students' prior knowledge, what they have learnt recently, and apply relevant skills they have acquired to solve authentic issues. These tasks were mediated by the use of digital learning trails which were explored as a form of alternative assessment for students in the school. Figure 4 depicts screenshots of the digital learning trails tools via an iPad device.

The historical journey of implementing learning journeys through trails began in 2008 at NSS, as part of their holistic student assessment endeavour. In 2011, NSS worked with a technology partner to develop a digital platform for learning trails in keeping up with their status as a school-designate for leading technology-enhanced teaching and learning. Developing the learning trails platform jointly with education technology vendor, Starlight (a pseudonym), NSS identified limitations of the toolkit in terms of its portability (across platforms) and customization capabilities. In 2012, NSS attained funding from one of the education ministry's funding body (eduLab 2015) as it proposed a 'scale-up' plan of further refining the design of the learning trails toolkit while simultaneously collaborating with ten other schools within its designated cluster on the use of digital learning trails. This funded collaboration was entitled the Digital Learning Trails (DLT) project. Within this project, each of the 11 participating schools (6 primary schools and 5 secondary schools) had the autonomy to implement the use of DLT within their respective schools in response to their pedagogic needs. For example, in NSS, DLT was

---

[3] More information about the digital learning trails application may be found at http://www.rockmoon.sg/products.html.
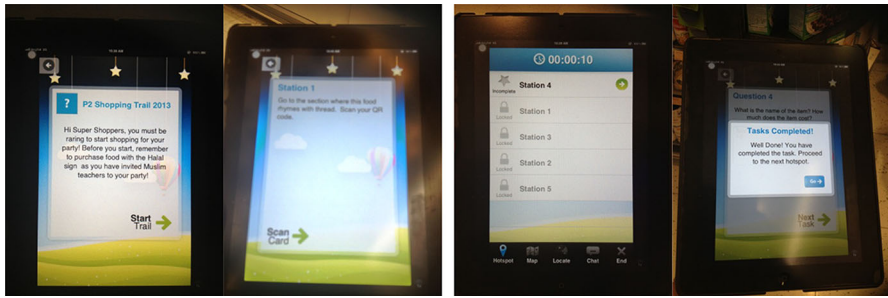
Fig. 4 Screenshots of the digital learning trails software at various stages of the trails

interwoven within the curriculum as part of their interdisciplinary learning pedagogy, while in Concorde Secondary; it was used in subjects such as Elements of Business Skills (EBS). The DLT project took place over a period of 2 years (2012–2014) and involved 68 teachers and more than 1700 students from the 11 schools, within the cluster structure. In this paper, we report on how DLT facilitated the spread of the learning trails toolkit from its use at NSS to the ten cluster schools and beyond. We analyze the related school programs and activities organized by NSS that may bear upon the scale, spread, and sustainability of the learning trails toolkit. Specifically our research addresses the following questions:

RQ1 What is the scaling model adopted by NSS for its digital learning trails (DLT) endeavour?

RQ2 What are the facilitating and/or impeding factors for the scaling up of the digital learning trails (DLT) CI?

Scaling of curricular innovations

Discourse surrounding curricular innovations typically revolves around issues of sustainability, scalability, transferability, and its relationship to the leveling up of education. Yet issues of 'scale' and 'sustainability' remain key challenges for schools, evidenced by eminent examples of withered practices found both in alternative[4] schools and in activities aimed at changing schools from within (Sannino 2010a). Conceptions of CI scale remain variedly defined Cohen and Ball (2007) characterize innovation scaling as dependent on not only the innovation but so too one's judgment of what scale means. This judgment may be in terms of mere

---

[4] An alternative school, in the US and some other parts of the world, is an institution which provides alternative education. It is an educational establishment with a curriculum and methods that are nontraditional. These schools have a special curriculum offering a more flexible program of study than a traditional school. A wide range of philosophies and teaching methods are offered by alternative schools; some have strong political, scholarly, or philosophical orientations, while others are more ad hoc assemblies of teachers and students dissatisfied with some aspect of mainstream or traditional education. In Singapore, schools which focus on a particular niche area e.g. sports, arts, science and technologies are called specialized schools.

'use' (or intended use) and 'adoption' which entail some change in practices in the schools that *adopt* the innovation. The extent of scale for CIs such as prescribed tests or learning repository systems may be assessed quantitatively by the number of schools that use it. Such a quantitative measure represents a weak proxy in assessing the extent of scale in terms of articulating the qualitative change in schools that adopt them. Engendering a CI on an inquiry-based seamless curriculum in Science requires changes in terms of not only teacher practices and student assessment. Rather, to qualify the scale of such a CI necessitates going beyond quantitative measures of the number of schools or classrooms that *adopt* it to a qualitative cognizance of how deeply such an innovation permeates teaching and learning practices.

Whilst Fuchs and Fuchs (2008) describe scalability research in education as an "effort to reproduce an effective practice in a considerable greater number of classrooms and schools" (p. 132), Buzhardt et al. (2006) posit that a critical piece to understanding CI scalability is knowledge of the tasks required to move from *no* implementation to *complete* implementation, how long it takes to get to that point, and the factors affecting the rate of achieving those tasks. Whilst the definition of *complete* implementation remains relative across contextually nuanced settings, Fishman and Krajcik (2003) unpack complete (efficacious) innovation implementation as the axial optimal intersections between usability of a curricular innovation in light of the capacity of its adopting context (see Fig. 5).

Arraying the elements of school culture, capability, and policy and management in the form of three axes originating from a common point, Fishman and Krajcik (2003) argue that any curricular (or other) innovation can be placed in the space created by these three axes, where the distance between the innovation and the origin represents the gap that exists between the capacity required to successfully enact the innovation and the current capacity of the local setting. Moving to narrow this gap therefore represent endeavors toward achieving a complete efficacious CI
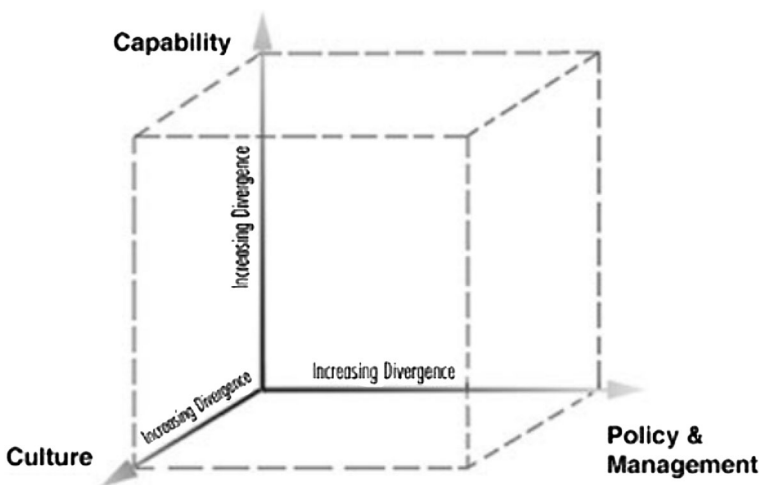

Fig. 5 Three axes of identifying usability of curricular innovations

implementation. Cohen and Ball's (2007) analysis of 'scaling up' innovations surfaces further qualitative barriers to effective innovation implementation. This include the difficulty of designing innovations that are usable for teachers who have "modest professional knowledge and few common professional standards, the difficulty of addressing weaknesses of teacher capability, and the difficulty of devising means to manage the environments and support implementation" (p. 17).

In addressing some of the qualitative difficulties, Bocconi et al. (2012) propose a framework of ICT-enabled innovation for learning which looks at five dimensions of an innovation in order to characterize possible CI diversity in terms of nature of innovation, implementation phase, access level, impact area, and target of innovation. In a recent report comparing ICT-enabled innovations for learning across Europe and Asia, Kampylis et al. (2013) mapped seven identified cases[5] of CIs, that have either been developed over a period of more than 10 years or are initiatives that have been built on system level initiatives that started 10 years ago, onto this five-dimensional framework. As shown in Fig. 6, diverse characteristics of each (minimally decade long) CI were identified based on the five postulated dimensions.

Arising from these differences, Kampylis et al. (2013) identified three conditions for ICT-enabled innovations they deem to have the most impact on learning. These are: (1) a pedagogy-first orientation that foregrounds the use of ICT to empower student learning, encouraging self-directed learning and collaborative knowledge creation, (2) strong teacher support and autonomy, and (3) an establishment of better definitions and assessment for 21st century skills. For Kampylis et al. (2013), scaling-up was identified as a "primarily a learning challenge" (p. 7). To this end, they identified four salient characteristics that facilitated the scaling up of ICT-enabled innovations across seven case studies. These characteristics include:

1. Encouraging learning that is experiential, generative and self-organizing.
2. Providing architectures (i.e. structures and mechanisms) for learning across sites and levels.
3. Propagating and consolidating learning to higher levels of the system hierarchy through changes to services and organization.
4. Leveraging on technology as an integrated infrastructure for learning at multiple levels.
   (Kampylis et al. 2013, p. 7–8)

Arising from these studies, scaling up CIs do not only entail the interplay between the affordances and requirements of technology mediating the enactment of curricular interventions, but so too necessitate a cognizance of contextual differences between district wide cultures and local classroom adaptations. There is thus a need to move away from construing scaling up as a mere focus on

---

[5] The seven case reports were made up of in-depth analyses of three cases of ICT-enabled innovation for learning from Europe and four cases from Asia. The cases are: (1) eTwinning (Europe), (2) 1:1 learning in Europe, (3) Hellerup School (Denmark), (4) e-learning Pilot Scheme (HongKong SAR), (5) CoREF (Japan), (6) MP3—Third Masterplan for ICT in education (Singapore), (7) Digital Textbook (South Korea).
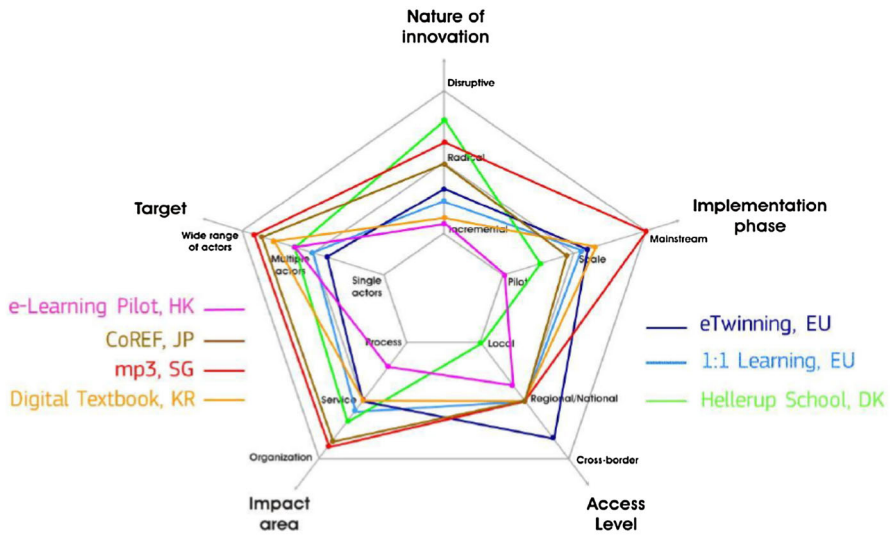
Fig. 6 Differences between seven identified decade-long ICT-enabled innovations on five dimensions (Kampylis et al. 2013, p. 6)

increasing the installed base of schools to an imperative reconceptualization of scaling as a process of effecting deep, broad, and sustained change in practice by supporting schools in fully taking ownership of implementations of CIs.

Education reform versus accommodating local adaptations: A *top-down* and *bottom up* dialectic

An increasingly globalized and networked world is having a major impact on the nature and structure of education systems—moving from an era of nation-centric in orientation to one of greater internationalism. Particularly, issues such as inward student mobility, new knowledge, advances in cognitive sciences, powerful technology platforms, changes in economically-valuable competencies, and international comparisons of student performance across systems conducted by international organizations (e.g. OECD and IEA) are leading many education systems to embark on school reform agenda by rethinking their curricula and pedagogy (Deng et al. 2013). Yet, over the past two decades, large-scale school improvement has emerged world-wide as a "primary problem of education policy and reform" (Peurach and Glazer 2011, p. 2). Characterized as organizational replication, wide-scale education reform has been criticized as a top-down driven approach for education change. Such an approach typically focuses on transformational change of the school system without taking into account localized practices. The rhetoric of education reform is underpinned by two assumptions: (1) wide-scale education reform adheres to a sequential model of CI, what education researchers have framed as RDDU: research, development, dissemination, utilization (Rowan

et al. 2004) and (2) RDDU-like replication processes enable rapid, large scale improvement by providing schools with 'research-based' and 'research-proven' programs that can be implemented quickly, effectively, and efficiently. Such a process efficiency rhetoric has fueled criticisms towards the top-down, one-size fits all strategy that are at odds with 'local control and professional autonomy' (Peurach and Glazer 2011, p. 5).

At a basal level, deep epistemological differences between rhetoric of top-down education reform and that of bottom-up locally adapted innovations exist. Whilst the former may be adopted at once by a whole educational system through linear means of prescription, the latter spread and diffuse through localized adaptations and interpersonal interactions. Extrapolating these ideological differences, we posit that contemporary discourse on scaling of CIs may be positioned within a "2-P" articulation of *process* versus *populace* modes of efficacy (see Fig. 7).

The foundational characteristics of a top-down process prescriptive view are linearity and belief in the power of explicit prescription of each relatively self-contained linear process. In contrast a populace foregroundment view emphasizes reciprocity and lateral interactions which cannot be fully prescribed. We posit that the gap between these two rhetoric of CI scale, spread, and sustainability represents a challenging contradiction which cannot be easily resolved—efficient and rational processes of top down education reform are not sustainable if there is no populace community which owns and develop them. Yet a populace community is not sustainable if there is no process efficacy in producing desired results. In this paper, we ask whether and in what ways this dichotomy may be transcended—illustrating our case through an analysis of a 'digital learning trails' CI within an education system that has embarked on change reform, in response to globalization, almost three decades ago (Gopinathan and Mardiana 2013).

Case study of the DLT project: A *rhizomatic* lens for innovation scale and sustainability

In tracing the trajectory of the DLT project, our research identifies factors related to the scalability and sustainability of this CI that has 'scaled up' from one school to more than 200 schools in Singapore, developing in tandem to technological advancements. Against a background of an education system characterized by centralized-decentralization, we posit that scaling curricular innovations in schools should be enacted through a *rhizomatic* lens where innovation spread is characterized by multiple trajectories and off shoots, allowing for new horizons and recontextualizations of CIs (Jamaludin and Hung 2013). By rhizomatic, we refer to shifts beyond mere ground up evolvements, to foreground principles of (1) heterogeneity and connectivity [just like any point or node of a rhizome can be connected to any other, so can CIs from typically dichotomized areas form connections with one another and (2) asignifying rupture (just as a rhizome may be broken, but still retains its ability to allow new roots and shoots from its nodes, CIs should necessarily be insusceptible to fissure based on its fluid boundaries and yet affording multiple forms and routes to using and harnessing the CI), in relation to
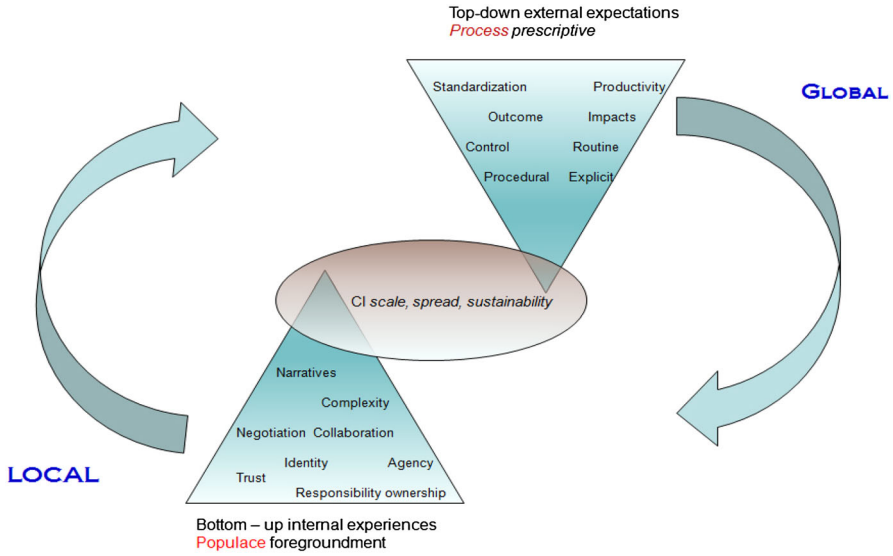
Fig. 7 The rhetoric and visible gap between *process* prescriptive view vis-a-vis *populace* view
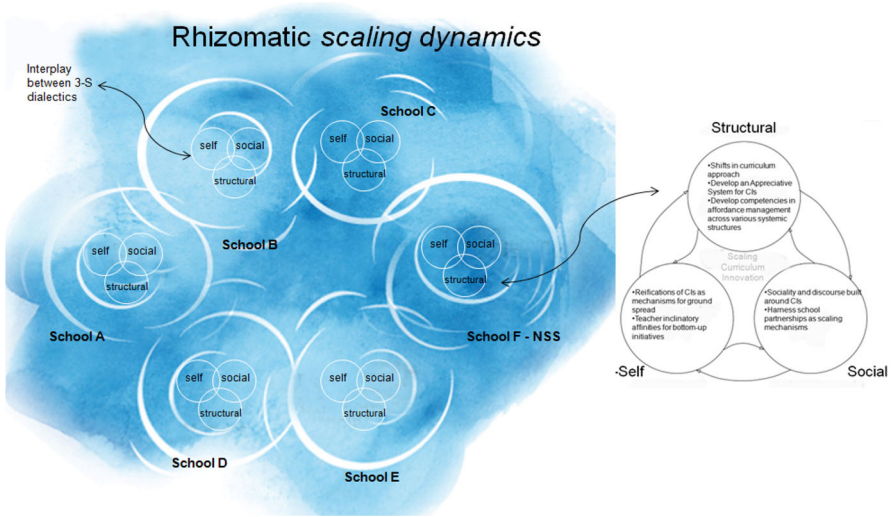

Fig. 8 A rhizomatic conceptualization of scaling curricular innovations

putative issues of CI scale and sustainability. We further posit that rhizomatic trajectories of CI spread are in turn characterised by dialectics of school-self, social, and structural constituents within its particular context (see Fig. 8), an interplay we unpack in the DLT case study.

Method and data collection

A mixed approach was employed to ensure that our research team had a range of direct experiences with the learning trail CI, in attempts to analyse and understand the scale, spread, and sustainability of the CI from varied perspectives (Teddlie and Tashakkori 2003). Key leadership personnel, participating teachers, and teacher-aides were interviewed. In addition, the research team participated in the out-of-classroom learning trails that were designed by teachers and students themselves to attain the experiential perspective of learning through this mode. Figure 9 illustrates the of out-of-classroom learning mediated by DLT. Field notes were taken and observation insights were corroborated. As researchers participated in the experiential learning trails, conversational data with participants of the trails were also recorded to form a more coherent analysis of the analytical case study. Interview data that were audio-recorded were transcribed verbatim and salient themes were distilled for the analysis. In addition, apart from data collection at NSS, we also sought to compare and corroborate analytical data with two of NSS' cluster member schools.

Findings and discussion

Leveraging structural affordances for CI scale

Within its own school, NSS had already put in place a three-tiered staff professional development model to emphasize on the 'whole-school approach' commitment to innovative pedagogies, emphasizing on leaner-centeredness and interactive forms of learning. At the first tier, all teachers were inducted into technology-oriented programs to standardize the basic technological skills necessary to concretize and enact the school's vision. The second tier involves looking into the needs of each department within the school and to work collaboratively with the departments heads in planning their department's Information and Communication Technologies (ICT) trajectory. This includes customising workshops based on the department's

Fig. 9 Screenshots of the digital learning trails enacted in out-of-classroom learning

ICT plan wherein ICT coaches will mentor identified teachers (based on needs) in the department. The third and topmost tier is oriented towards specialized training that is meant to 'stretch' NSS' ICT expertise. The ICT head, ICT directors (those who work with department heads), and ICT coaches (those who mentor identified teachers) will attend special training, present at relevant conferences, or to lead in ICT projects such as the DLT. We noted that at an overarching level, NSS has developed a well-established *appreciative system* for CIs within the school. This is evidenced through cultural manifestations of the school's commitment to harnessing on ICT for teaching and learning for both teachers and students that underpin the spread of CIs within the school. In addition, given their rich culture on leveraging on ICT learning approaches and outcomes for students that are relevant to the digital age, NSS also took the lead in establishing an NSS academy for digital age learning. The purpose of such an academy was to implement programmes that will help like-minded schools in their journey towards digital age learning.

Against this culture of a 3-tiered professional development model in NSS, we a similar tiered approach was taken by NSS' in its relationship with the cluster member schools. Figure 10 illustrates an extrapolated social ecology of the DLT project. On one level, there is the interplay of social interactions between the ICT leaders and key personnel within each respective cluster member school. These occurred through collaborative dialogs wherein each school's ICT lead was involved in one of the four-tiered approach to ensure planning and effective implementation of the project based on a common shared vision of 'exploring technology-enhanced on-the-go learning opportunities'. The four-tiered panel approach (advisory, steering, organizing, and working panels) was further broken down into four stages of implementation (stage 1: planning; stage 2: implementation; stage 3: review and reflect; stage 4: share and celebrate).

NSS worked on promoting a normative commitment among the respective ICT leads, from the ten other schools within the cluster, to DLT's goal of 'self-directed, collaborative, and authentic learning' for all students. This goal was in turn aligned to the overarching national agenda of self-directedness, collaboration, and
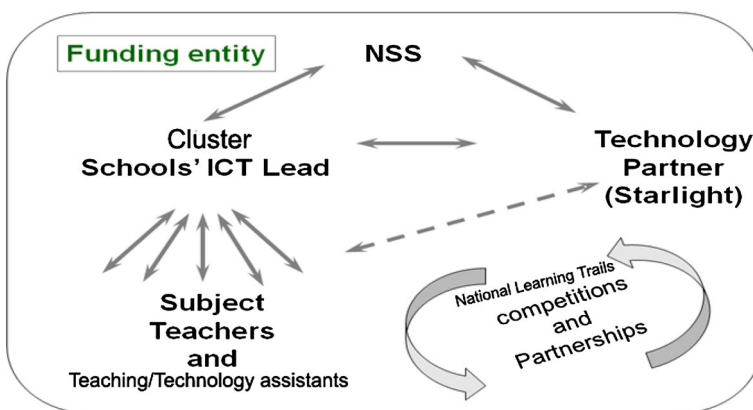

Fig. 10 Social ecology of NSS and the DLT cluster-schools project

authenticity in learning as communicated in the third ICT Masterplan for learning (Ng, 2008). On a second level, these leaders in turn worked with their respective subject teachers on their plans in the implementation of the CI within their school. Enacting the operationalizations mechanics of the DLT project proceeded on a *process* efficacy approach wherein well-defined guidelines to be realized within specific time limits were put in place. Each cluster member school is mandated to share their learning experiences at cluster level meeting, and through presentations either at an international or locally organized conference. Each school was expected to produce a learning package on their enacted learning trail that is oriented for "scaling across schools", in terms of developing first level utilization of the CI prototype. Educational technology officers (ETOs) from the funding entity also worked closely with both NSS and the DLT cluster schools, assisting in matters of school implementation. Specifically, the ETOs were instrumental in facilitating innovation related processes such as teacher development and design and implementation of the CI both within classrooms and out of classroom learning.

In a recourse to our *process prescriptive* vis-a-vis *populace* perspective, we observed that, whilst the project emerged from a bottom-up collaboration amidst proximal schools leveraging on the cluster mechanism, certain top-down external expectations and structures, akin to the *process* efficiency rhetoric discussed in Fig. 7, were put in place within this bottom-up initiative. Each cluster member school was given "measurement results" in the form of specific deliverables and expected *process* outcomes pertaining to DLT as a CI adopted within their respective institutions. Yet these top down expectations were tempered by a *populace*-oriented move in that each school had the agency to contextualize the adoption of the learning trails toolkit based on the needs and limitations of their particular institutionalized context. In a sense, although DLT was *process* oriented in terms of delineating specific deliverables and outcomes, yet it remained non-prescriptive in nature. The CI was not targeted at particular school subjects for improvement, nor did it provide teachers with explicit guidance about curriculum objectives or teaching strategies. Rather, teachers were facilitated through modelling of a systematic process of organizational development to design unique paths toward powerful learning for its learners, while affording adaptations of locally-appropriate forms of pedagogical practices consistent with this approach.

As articulated by the ICT head in Concorde Secondary, one of the cluster member schools,

> "…although NSS initiated the project, their role…I would say their role is more administrative…as a school we decided how we wanted to use and implement the learning trails; which subject, which level…so I would say we are quite independent, on our own in this sense…"—Lara, ICT head, Concorde Secondary

We observed that teachers within Lara's school preserved agency and ownership towards the kinds of CIs implemented within their institutions whilst a whole-school approach towards *curriculum shifts* was undertaken. In Lara's school, the shifts in curriculum approach resonated with the overarching objectives of the DLT project

that is, moving away from didactic modes of teaching towards self-directed learning, collaborative learning, and authentic learning.

Delving further, we analysed that DLT's goals for curricular change were generic in nature—aiming at broad strokes of reform across the board rather than targeting specific curriculum areas for change. Moreover, the kinds of changes teachers were expected to make were not formally specified, and instead, each school (and teachers within the school) was directed to 'discover' it's most relevant and efficacious means to producing authentic learning within its own contextual space. Construed this way, schools and teachers were given autonomy in their DLT trajectory, and as a result, there was minimal focus on implementation fidelity. Structurally, the governance mechanism of the DLT project is a microcosm reflection of the aforementioned dialectics inherent in the education system.

School-teacher-self mechanisms

In light of these *process-populace* dialectics, it is not surprising that a particular pattern of CI implementation emerged in DLT schools. First, as evidenced through our field notes and face-to-face interviews, ICT leaders and teachers reported that they saw the DLT trajectory as centered more on collaborative investigation of the CI rather than on specific curricular goals and objectives, with the *digital learning trails* functioning as a toolkit for their CI implementation. In such a trajectory, teachers in DLT cluster schools were trusted and encouraged to make innovative adaptations in their classrooms as they saw fit, so long as these innovations were consistent with the normative ideal of enhanced learning.

At the teacher level, we observed that in making the CI adaptations to their classroom, teachers went through a process of exploring the potential value of the CI. As they did so, they evaluated the 'results' of their exploration in terms of its 'impact' (e.g. recognition from reporting officers, students' manifestation of 21st CC etc.). This exploratory-evaluative process does not only inform teachers' subsequent course of action, determining how they proceed next with the CI but it also seeds the development of an *appreciative system* for the CI. As teachers go about exploring–evaluating the CI in their classrooms, it entails a process of recognizing the value of the CI through 'appreciating' the response from the structural and social environment. Such a self-socio-structural interplay afforded by the *appreciative system* promoted high levels of motivation and CI impetuses— what we describe as *agentic enaction*.

In an interview with Mr. Chan, a subject teacher in Concorde Secondary, he shared how, he attempted to explore the use of learning trails in other non-academic disciplines such as leadership,

> "…we really wanted to see how the students can benefit from this new thing…I actually tried it on non academic disciplines like, for example, during a leadership camp. So we use different hot spots around the island. So we had to use it to navigate around the island and all. So a bit of leadership skills. How a leader could lead the rest of the group to find the different locations and overcome obstacles along the way…and I think [Mr. Eng] also did…character

education, character education trail, heritage trail…"—Mr. Chan, subject teacher

Recontextualizing the use of learning trails from specific subject domains to leadership and character education represents a step forward towards the adoptive spread of the CI. Rather than being adopted at once by a whole educational system, a populace-oriented view affords the spread, albeit small scale, through social and interpersonal experiences. Teacher Eng, through his experience and development of an *appreciative system* for the CI, tries to recontextualize digital learning trails for his own local agenda, that is, his organized leadership camps. These small-scale, bottom-up initiatives—dependent on the commitment and involvement of the teachers themselves—are more likely to attain sustainability, not necessarily in terms of complete appropriation of the initial CI or through system-wide reform, but through the transformation of local practices driven by the agentic enaction of the teachers.

Within this vein, we further observed such agentic enactions are dialectically driven by teachers' *inclinatory affinities*. To illustrate an example, in another cluster member school, Gracefields Primary, a strong collaboration was observed between the ICT subject head (Mr. Teo) and the subject teacher who was involved in implementing learning trails in her classroom. The latter, Ms. Gan, had volunteered in implementing the CI in her classroom. When asked what drove her to volunteer to be part of the DLT project, Ms. Gan shared that she believes in the need to move away from traditional learning practices for her students. Interestingly, we observed that Ms. Gan had an academic disposition, in that she enjoys reading and writing journal papers related to her field in education. Such a disposition inherently equipped her with a certain level of cognizance of the current trends in education research. Ms. Gan was also involved in the curriculum planning for implementing DLT at a whole level approach. In a sense, Ms. Gan's role may be characterized as a 'champion teacher' possessing the propensity to innovate. Her leadership had a large bearing on DLT as a CI to attain scale and sustainability within Gracefields Primary—in 2012, the CI was implemented within the school for P6 classes; in 2013, it spread to include the entire P2 level and encompasses interdisciplinary subjects such as english, mathematics, health education, and social studies. Ms Gan was instrumental in writing up the journey of her school's use of the CI and even presented, together with Mr. Teo, at an international conference. Through this conference, Mr. Teo and Ms. Gan shared that their work related to the use of DLT in Gracefields Primary had generated interest during the conference presentation and that some of the attendees will visit Gracefields Primary to observe the process of enacting DLT in classrooms, with the possibility of henceforth using DLT in *their* classrooms. In a sense, reification of the CI's (usually abstracted) process merits through concrete modes such as the research findings and conference presentation by Mr. Teo and Ms. Gan served as a mechanism for generating discourse related to the CI, seeding innovation spread at the ground level. These reifications in turn, evolved from interactions afforded by an affinity space between the practitioners based on their shared inclinations and strong interest towards the CI.

Social mechanisms

Teacher *inclinatory affinities* for bottom up-initiatives were similarly observed in Concorde Secondary. Subject teacher Mr. Chan articulated that there were indeed "roadblocks" in the uptake of CIs in schools when the teachers were "uninclined" towards the CI. Mr. Chan juxtaposed these "roadblocks" with how he and his colleague Mr. Eng were the "excited ones" who went further with the learning trail CIs. We postulated that aligned interests and inclination towards the CI had seeded an affinity space for Mr. Chan and Mr. Eng to share knowledge and informally learn together. This is to say that, because members are interested in a common belief practice/activity (of the CI), they have common ground and motivation together to intrinsically scale the CI based on their recontextualizations of the CI through other modes of implementation (e.g. in Mr. Chan's case, through leadership camps). Articulated by Gee (2005) who posited the construct of affinity spaces as a more fluid interactional space for people of similar evolving inclinations, vexatious issues typically associated with COPs' membership (e.g. only Mathematics teachers) and participation (e.g. only Mathematics teachers who use or are keen to use DLT)-such as *which* people are in and *which* are out of the community, *how* far they are in or out and *when* they are in or out—are mitigated. Instead, the emergence and evolvement of the interactional space for the CI-inclined teachers are more, what we characterize as, *rhizomatic* in nature.

The following excerpt from the transcript provides an insight into the generation of *rhizomatic* 'spaces' through which regulative discourse about CIs are afforded amongst teachers sharing the same inclinations:

> Researcher (R):…are there any plans or are you aware of any plans to scale DLT to other streams or other levels?
> Mr. Chan (MC): I think it's actually feasible but I'm not sure whether the other departments would be keen to take up this project.
> R: What do you think are some of the reasons they may not be keen to take up the project?
> MC:…probably the hassle of having to design something because I would say it's quite time consuming having to find out certain things, design and then try it out and whether it works. And then refining it again before implementing it. So it's a relatively long process which I'm not sure all teachers would be keen to take up on top of the current work load.
> R:…but what are some of the factors that may encourage the spread of this learning trails?
> MC:…I think they just need probably someone to do up something and show them that oh this is relevant, how it's relevant to the course of studies for the students…something that they could implement and probably to show them that it's actually not that difficult because some teachers are probably a bit wary of new technology…so I think if someone could actually do up a sample and show them…this actually took me like a short time to do it, it's actually not that difficult and this is applicable for this particular chapter and it's actually more fun for the kids to do it and learn rather than being in the

classroom. Probably in time to come, they might just take it up…because I don't think it's easy to get people to be interested in something that is alien, very alien to them…whereas for me, I was introduced by Mr. Eng and then he was very excited about it and he got me very excited. So we are just exploring all the different ways…the different functions such as the QR code. So we talked about it and we implemented it…it was quite exciting actually…

R:…that's interesting. So you talked about it and then implemented together?

MC: Yah. So he's like come, let me show you this thing, it's really cool. Then we went 'oh okay what's that'. Then he would show me and how it can be done. Okay I want to try too…so after that I tried….then he was like why not we do this for EBS, we could use this for EBS trail and it just happened…so I think it takes two or more 'crazy' people, so to speak…

Analysed from the transcript and field observations, there exists a high degree of teachers' need to 'see' the implementation of the CI, prior to their 'buy-in'. We posit that the facilitating factors of CI scale and spread is located not only within the sociality and discourse built around the CIs which stimulate the emergence of critical moments for driving the recontextualizations of the CI, but also in reifications of the CI which functioned as ground spread mechanisms as the CI is foregrounded and made visible. However we note that these reifications of CI do not exist in isolation. Rather, reifications without its accompanying sociality and discourse will only remain static.

In NSS' case, educators were able to harness partnerships with other bodies such as the National Heritage Board to organize nationwide competitions on learning trails which required participants to make use of the CI to design their own learning trails. Aside from prizes that were sponsored by the partnering agencies, this national competition, and the engagement of external community functioned as another bottom-up strategy in generating social discourse pertaining to the DLT CI. The fact that more than 200 schools participated in the competition and used the innovation, with imminent uptake of DLT within some of these schools, showed vast utility spread of the CI. In addition, in keeping up with contemporary technologies, NSS went a step further to make available and accessible the designed trails to the general public through freely downloadable apps on smart phones. These shifts towards an inclusive, participatory culture, in getting students to be designers of their own trails and in generating an authentic audience platform for the designed trails, further seeded the widespread adoption of the trails. We note that as a funded project, DLT had the resource leverage to not only customize the learning trails innovation in tandem with contemporary shifts in culture but so too the capacity to test out the use of DLT in broader scale classrooms trials. Additionally, the funding mechanism provides resources for not only evaluating the feasibility and acceptability of the DLT CI in classrooms, but also functioned as a support structure necessary as a pre-requisite to a larger-scale implementation (see again Fig. 10). At an overarching level, NSS' ability to create alignments and mitigate tensions between top-down policy demands and on-the-ground teachers' needs, to competently affordance manage across various systemic structures (i.e. attain

funding, harness partnerships with prominent bodies, creating an inclusive-participatory culture for the digital learning trails) were also key facilitating factors in the scaling up of the innovation. Figure 11 provides a graphical encapsulation of the dialectical interactions surfaced from our findings.

A *rhizomatic* lens for curricular innovation scale and sustainability

In this paper, we analyzed the scaling model adopted by NSS in its DLT endeavour. We found that the scaling dynamics within each analyzed contextual space had not been predetermined or orchestrated via any single entity (e.g. from top down Ministry level or from a single teacher/school). Instead, as schools, teachers and students engaged with each other, they resembled a sea of 'middles' in that they formed and reformed affinities based on expected outcomes, ownership, negotiation, collaboration, interests, and inclinations. Unlike the design of traditional school reform models (Sannino 2010a) typified by vertical hierarchical structures of top-down and/or bottom-up scaling approaches, we observed a rhizomatic scaling model based on each school functioning as a nodal point within its own scaling trajectory, as it orients itself horizontally within the DLT cluster. These trajectories are in turn
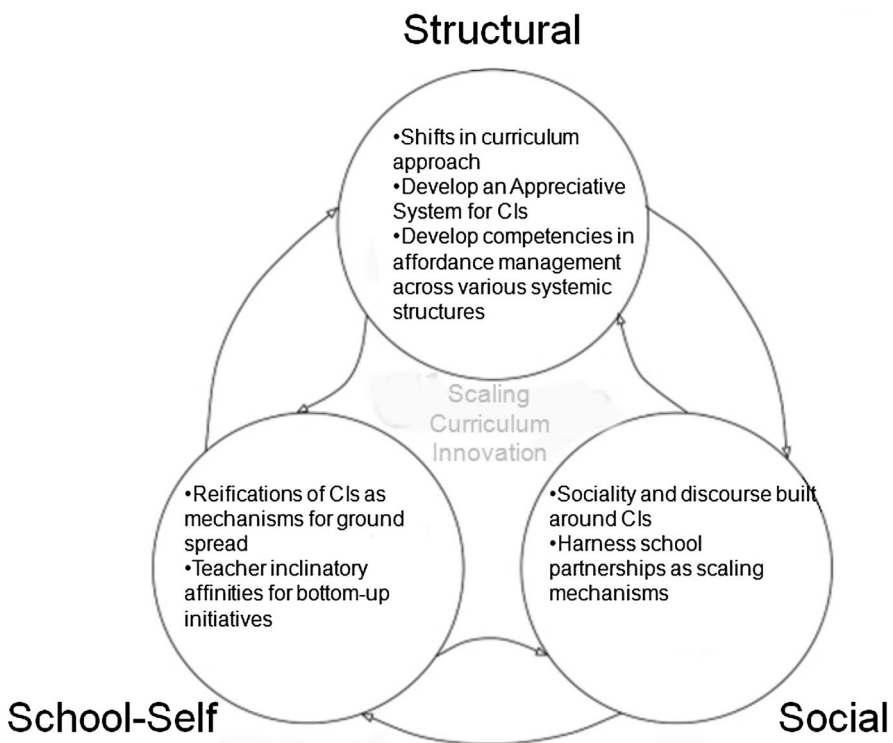

Structural

- Shifts in curriculum approach
- Develop an Appreciative System for CIs
- Develop competencies in affordance management across various systemic structures

Scaling Curriculum Innovation

- Reifications of CIs as mechanisms for ground spread
- Teacher inclinatory affinities for bottom-up initiatives

- Sociality and discourse built around CIs
- Harness school partnerships as scaling mechanisms

School-Self   **Social**

Fig. 11 Identified self, structural and social dialectics for scaling curricular innovations

characterised by a dialectical interplay between its school-self, social, and structural constituents within its particular context (see again Fig. 8).

In seeing scaling through a rhizomatic lens, the process towards CI implementation resembles the tangle of nodal growth and propagation, both broken and whole. The key lies in seeing the scaling process not as isolated, but interacting and interfering with one another. Our analysis of the DLT scaling lead us to interpret the scaling 'challenge' in terms of cycles of rhizomatic learning. Scaling of CIs through a rhizomatic lens may be conceptualized as cyclic interplay between the school and teacher self enactments, inclinatory affinities, and identities, the affordances of social structures for developing and sharing knowledge and the management of structural affordances to effect scaling efficacy. Emphasizing process as opposed to linearity and deterministic outcomes, such a rhizomatic framing of scaling focuses on teachers as agentic participants, not as mechanistic subparts of CI implementation. There is no single or best route to CI scaling; rather multiple pathways exist to innovate and scale wherein each pathway will have its own constraints and conditions for success and sustainability. As rhizomatic scaling orients itself horizontally rather than vertically, it will beget a shift towards valuing tacit knowledge that is co-constructed as schools and teachers undertake embodied experimentations and inquiry into a complete and efficacious CI implementation.

At a basal level, the notion of 'rhizomatic' scaling is to acknowledge that schools come from different contexts and that they need different things for different innovations to paths. We postulate that first, against CI reifications and visibilities of thinking, of doing-performance, and of collective sharing, the pedagogic process, in the context of education and scaling, is based on rhizomatically apprenticizing nodal schools to make multiple recontextualisations, rather than innovation-specific applications, of knowledge, skills, and judgement. Secondly, the enculturation process of a school adopting and implementing a particular innovation is based on a distributed, rhizomatic conception of the development of expertise and identity. Thirdly, the process of a nodal scale-up school maturation is based on developing the capability to not only make multiple recontextualizations but also to accumulate enough capital to rhizomatically send out new 'roots and shoots' as it spreads and forms new *connections* with other nodes. 'Rhizomatic' *scaling* is a move away from foundational notions of sequentiality—of the research, development, dissemination, utilization (RDDU) schema of education change to a cognizance of the complexity of education improvement reform agenda that begets not only change on *all levels of the system* but so too, change that foregrounds *heterogeneity and connectivity*. As Confucius aptly states, *they must often change, who would be constant in happiness or wisdom.*

References

Bocconi, S., Kampylis, P., & Punie, Y. (2012). Innovating teaching and learning practices: Key elements for developing creative classrooms in Europe. *eLearning Papers, 30*, 1–13.

Buzhardt, J., Greenwood, C. R., Abbott, M., & Tapia, Y. (2006). Research on scaling up evidence-based instructional practice: Developing a sensitive measure of the rate of implementation. *Educational Technology Research and Development, 54*(5), 467–492.

Chua, P. (2014). Centralized-decentralization emerging in Singapore. Retrieved March 15, 2015 from http://internationalednews.com/2014/03/25/centralized-decentralization-emerging-in-singapore/.

Cohen, D. K., & Ball, D. L. (2007). Educational innovation and the problem of scale. In B. Schneider & S. McDonald (Eds.), *Scale-up in education*. Lanham, MD: Rowman and Littlefield.

Deng, Z., & Gopinathan, S. (2003). Continuity and change in conceptual orientations for teacher preparation in Singapore: Challenging teacher preparation as training. *Asia-Pacific Journal of Teacher Education, 31*(1), 51–65.

Deng, Z., Gopinathan, S., & Lee, C. K. E. (Eds.). (2013). *Globalization and the Singapore curriculum: From policy to classroom*. Singapore: Springer Education Innovation Book Series.

eduLab. (2015). eduLab funding programme. Retrieved April 9, 2015 from http://www.nie.edu.sg/edulab-funding-programme.

Fishman, B., & Krajcik, J. (2003). What does it mean to create sustainable science curriculum innovations? *Science Education, 87*(4), 564–573.

Fuchs, L. S., & Fuchs, D. (2008). The role of assessment within the RTI framework. In D. Fuchs, L. S. Fuchs, & S. Vaughn (Eds.), *Response to intervention: A framework for reading educators* (pp. 27–49). Newark, DE: International Reading Association.

Gee, J. P. (2005). Semiotic social spaces and affinity spaces: From the age of mythology to today's schools. In D. Barton & K. Tusting (Eds.), *Beyond communities of practice: Language, power and social context* (pp. 214–232). Cambridge: Cambridge University Press.

Goh, C. T. (1997). *Shaping our future: Thinking schools, learning nation*. In *Speech by Prime Minister Goh Chok Tong at the opening of the 7th International Conference on Thinking*, Singapore.

Gopinathan, S., & Mardiana, A. B. (2013). Globalization, the state and curricular reform. In Z. Deng, S. Gopinathan, & C. K. E. Lee (Eds.), *Globalization and the Singapore curriculum: From policy to classroom* (pp. 15–32). Singapore: Springer Education Innovation Book Series.

Hallinger, P. (2010). Making education reform happen: Is there an 'Asian' way? *School Leadership and Management, 30*(5), 401–419.

Hargreaves, A., & Shirley, D. (2012). *The global fourth way: The quest for educational excellence*. Thousand Oaks, CA: Corwin Press.

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

Hung, D., Jamaludin, A., & Toh, Y. (2015). Apprenticeship, epistemic learning, and diffusion of innovations in education. *Educational Technology, 55*(4), 20–26.

Jamaludin, A., & Hung, W. L. D. (2013). Rhizomatic experiencing: Game play and 21st century competencies. *Paper presented at the international symposium on education, psychology, and social sciences (ISEPSS), Kuala Lumpur, Malaysia*.

Kampylis, P., Law, N., & Punie, Y. (Eds.). (2013). *ICT-enabled innovation for learning in Europe and Asia: Exploring conditions for sustainability, scalability and impact at system level*. Luxembourg: Publications Office of the European Union.

Koh, A. (2013). A vision of schooling for the 21st century: Thinking schools learning nation. In Z. Deng, S. Gopinathan, & C. K. E. Lee (Eds.), *Globalization and the Singapore curriculum: From policy to classroom* (pp. 49–63). Singapore: Springer Education Innovation Book Series.

McLaughlin, M., & Mitra, D. L. (2001). Theory-based change and change-based theory: Going deeper, going broader. *Journal of Educational Change, 3*(1), 301–323.

Ministry of Education. (2008). MOE launches third Masterplan for ICT (MP3) in education. Retrieved January 10, 2015 from http://www.moe.gov.sg/media/press/2008/08/moe-launches-third-masterplan.php.

Ministry of Education. (2015). Schools division. Retrieved February 20, 2015 from http://www.moe.gov.sg/about/org-structure/sd/.

Ministry of Trade and Industry. (1986). Report of the Economic Committee of the Singapore Economy: New directions. Retrieved March 25, 2015 from https://www.mti.gov.sg/ResearchRoom/Documents/app.mti.gov.sg/data/pages/885/doc/econ.pdf.

Ministry of Trade and Industry. (1991). The strategic economic plan: Towards a developed nation. Retrieved March 25, 2015 from https://www.mti.gov.sg/ResearchRoom/Pages/The%20Strategic%20Economic%20Plan%20-%20Towards%20a%20Developed%20Nation%20(1991).aspx.

Ministry of Education. (2002). New Autonomous School. Retrieved 28 July, 2016 from https://www.moe.gov.sg/media/press/2002/pr30072002.htm

Ng, E. H. (2008). Opening address at the international conference on teaching and learning with technology (iCTLT). Suntec: Singapore.

Ng, E. H. (2009). Seizing opportunities to build a world class education system. Financial year 2009 Committee Supply Debate: 1st reply by Dr Ng Eng Hen, Minister of Education.

OECD. (2010). Singapore: Rapid improvement followed by strong performance. Retrieved June 30, 2016 from https://www.oecd.org/countries/singapore/46581101.pdf

Peurach, D. J., & Glazer, J. L. (2011). Reconsidering replication: New perspectives on large-scale school improvement. *Journal of Educational Change, 13*(2), 155–190.

Rockmoon, P. L. (2015). Trail shuttle: Location-based mlearning. Retrieved December 31, 2015 from http://www.rockmoon.sg/products.html.

Rowan, B., Camburn, E., & Barnes, C. (2004). Benefiting from comprehensive school reform: A review of research on CSR implementation. In C. Cross (Ed.), *Putting the pieces together: Lessons from comprehensive school reform research* (pp. 1–52). Washington, DC: National Clearinghouse for Comprehensive School Reform.

Sannino, A. (2010a). The predictable failure of sustainable innovations in school? From warrants to actions and back to the future. In K. Yamazumi (Ed.), *Activity theory and fostering learning: Developmental interventions in education and work* (pp. 61–85). Osaka: Kansai University Press.

Sannino, A. (2010b). Breaking out of professional abstraction: The pupil as materialized object for teacher trainees. In V. Ellis, A. Edwards, & P. Smagorinsky (Eds.), *Cultural-historical perspectives on teacher education and development: Learning teaching*. London: Routledge.

Saranson, S. B. (1990). *The predictable failure of educational reform. Can we change course before it's too late?*. San Francisco: Jossey-Bass.

Tan, Y. H., Tan, T. Y., & Lim, E. (2011). Digital learning trails: Harnessing ICT to facilitate inquiry-based learning. *Paper presented at the eLearing Forum Asia, Singapore*.

Tay, G. P. L., & Lee, T. T. K. (2014). Designing of authentic learning mediated by mobile technology for primary school learners. *Journal of the International Society for Teacher Education, 18*(1), 42–52.

Teddlie, C., & Tashakkori, A. (2003). Major issues and controversies in the use of mixed methods in the social and behavioral sciences. In A. Tashakkori & C. Teddlie (Eds.), *Handbook of mixed methods in social and behavioral research* (pp. 3–50). Thousand Oaks, CA: Sage.