Front. Digit. Educ., 2024, 1(2): 121–131
https://doi.org/10.1007/s44366-024-0002-2

REVIEW ARTICLE

Transcending the Dualities in Digital Education: A Case Study of Singapore

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Abstract This study explores the complex dualities in digital education, focusing on the case study of Singapore. It highlights the ethical issues surrounding the integration of information and communication technology (ICT), especially artificial intelligence, in the education sector. The paper presents a theoretical framework to explore these dualities, examining how they have been navigated in Singapore's policy reforms to enhance digital education. These dualities include centralisation vs. decentralisation of resource orientation; customisation vs. standardisation of curriculum, formal vs. informal learning with respect to pedagogical approaches; human agency vs. technological automation for data interpretation; and peaks of excellence vs. equity in achievement outcomes. These aspects significantly impact the outcomes of ICT-enabled reforms. The study draws upon Singapore's longitudinal trajectory of integrating ICT in education, illustrating its efforts in reconciling these dualities. The findings underscore the importance of careful consideration and balance in integrating ICT in education, emphasising the need to transcend these dualities to build a more inclusive digital learning environment.

Keywords artificial intelligence (AI), integration of information and communication technology (ICT), digital education in Singapore

1 Introduction

Time and time again, advances in technology have prompted educators to rethink, reimagine and redesign their teaching practices to harness the affordances as well as avoid the pitfalls of emerging technologies. The current prevalence of artificial intelligence (AI) further compels us to question assumptions, challenge existing norms and set healthy boundaries while critically examine ways to capitalise AI to improve teaching and learning outcomes. This paper fleshes out a range of ethical issues surrounding the integration of information and communication technology (ICT), particularly AI and devise a theoretical framework for exploring the dualities in shaping the integration of technology in education. Grounded in socio-technical systems theory and the concept of analytical dualism, the authors contextualise the framework and apply it to the case of Singapore, underscoring the policy nuances behind each wave of technology-mediated reform and explicating how these dualities manifest in practice and offers insights into strategies for navigating these complex tensions.

Received May 6, 2024; accepted June 17, 2024

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2 Understanding the Dualities Shaping the Integration of ICT in Education

The new era brought forth by AI has prompted many educators to rethink about their roles, beliefs, and practices as they evaluate the affordances and pitfalls of the emerging trend. As expounded by socio-technical studies, technological change can be "influenced by a multiplicity of actors, political and economic interests, and contextual conditions" (Ahlborg et al., 2019). Such dynamic and dialectical interplays between the social processes and development of technology shape and are shaped by social interactions, power relations, and cultural practices. The consequences of which can be both empowering and alienating (Ropohl, 1999). In the thought-provoking paper written by Dieterle et al. (2024), the authors enumerated five divides that can gravely undermine the benefits of integrating technology, in particular, AI in education. They are

namely, 1) *access divide*, where not all learners and educators have access to the hardware, software, and connectivity necessary to engage with digital tools and learning platforms; 2) *representation divide*, where the lack of learner and educator access exacerbates their ability to contribute to data generation, subsequently underrepresenting their voices; 3) *algorithmic divide*, where unfettered social datasets can amplify systemic bias that favour certain groups over others; 4) *interpretation divide*, where educators' variegated knowhow and subjective confirmation bias can result in the misinterpretation of data; and 5) *citizenship divide*, where structural stigmas may be perpetuated due to asymmetrical digital participation rate and the ability of disadvantaged groups to accumulate social capital for leapfrogging over time.

Inspired by Dieterle et al. (2024), this study extrapolates how the five divides will have bearings on resource orientation, curriculum and learning approaches, data interpretation, and outcomes of ICT-enabled reforms—dimensions that not only correspond to the five divides but are also critical determinants of technology-enabled reforms. The choice of focusing on resource orientation, curriculum design, lesson enactment, and outcomes of ICT-enabled reforms in this study is deeply rooted in both theoretical and practical considerations. From a theoretical perspective, these four aspects represent critical dimensions of educational practice and policy that are significantly impacted by the integration of ICT. The framework draws inspiration from the above-mentioned socio-technical systems theory, which emphasises the interplay between social and technical aspects of organisations, prompting us to examine the elements of the system where interactions with the environment are most visible, as well as the strengths and weaknesses of the mediating effects between technology and these elements (Appelbaum, 1997).

By focusing on these four areas, the study aims to capture a comprehensive picture of the educational landscape, acknowledging the multifaceted nature of schooling that encompasses resource allocation, pedagogical strategies, instructional practices, and student outcomes. Each of these dimensions provides a unique lens through which the complexities and dualities of digital education can be examined, thereby offering a holistic understanding of how ICT reforms are implemented and experienced in educational settings.

Practically, these four aspects are selected based on their relevance to ongoing educational reforms and their potential to illuminate critical issues in the integration of digital technologies. Resource orientation examines how resources are distributed and utilised, which is crucial for understanding equity and access in digital education. Curriculum design addresses the content and structure of what is taught, highlighting the tension between customisation and standardisation in educational materials. Lesson enactment focuses on the actual delivery of instruction, revealing the practical challenges and innovations in teaching practices. Finally, outcomes of ICT-enabled reforms assess the impact of these changes on student learning and achievement, providing a measure of the effectiveness of these reforms. By exploring these specific aspects, the study aims to provide actionable insights that can inform policy and practice, ultimately contributing to more effective and equitable digital education initiatives.

In addition to socio-technical systems theory, the authors also employ the concept of analytical dualism in our analysis. Analytical dualism, as proposed by Archer (2000), allows for the differentiation and interaction of various social phenomena. It exerts separate but interactive influences on the social realm, each possessing unique properties and capabilities. While they can be distinguished analytically, their effects can only be fully understood when considered together (Archer, 2000; Woods et al., 2004). It allows for a more nuanced interpretation of social processes and outcomes by recognising that they result from the interaction of multiple factors, rather than being solely determined by one aspect alone. The five analytical dualism applied in the study are namely: centralisation vs. decentralisation of resource orientation; customisation vs. standardisation; formal vs. informal learning with respect to curriculum and learning approaches; human agency vs. technological automation with respect to data interpretation; peaks of excellence vs. equity in terms of achievement outcomes.

Centralisation vs. decentralisation in resource orientation addresses how resources are managed and distributed across different levels of the educational system. This duality is crucial for understanding the balance between top-down directives and local autonomy in deploying ICT resources, which directly impacts the accessibility and effectiveness of digital tools in various educational contexts. Similarly, customisation vs. standardisation in curriculum design reflects the tension between adapting educational content to meet diverse learner needs and maintaining consistent standards across the system. This duality is pivotal for developing curricula that are both inclusive and rigorous, ensuring that all students benefit from ICT-enabled learning opportunities.

In terms of lesson enactment, the duality of formal vs. informal learning captures the dynamic interplay between structured classroom activities and more flexible, student-driven learning experiences facilitated by digital technologies. This duality is significant for understanding how ICT can support diverse pedagogical approaches that cater to different learning styles and preferences. Finally, the human

agency vs. technological automation duality in data interpretation highlights the balance between leveraging AI and other technologies to process educational data and the critical role of educators in making informed decisions based on that data. This duality is essential for ensuring that technology enhances rather than diminishes the professional judgment and expertise of educators, ultimately leading to better educational outcomes.

By applying these theoretical and analytical lenses, the framework captures the complex interactions between policy, practice, and technology in educational settings. Each dimension of the framework is carefully chosen to reflect critical areas where ICT integration can have significant impacts. We now turn our attention back to the five divides (access, representation, algorithmic, interpretation, and citizenship) and provide a series of guiding questions for educators to examine how they can possibly transcend the various dualities associated with these divides, providing new frames of references to build a more inclusive environment for digital learning.

At the upstream effects of ethical decisions, the *access divide* underscores the concern of accessibility to both tangible and intangible resources related to the use of technology in education by stakeholders. This begs the question of how policies should be coordinated to mitigate such tensions, leading us to explore the first duality in policy orientation. Should technology-enabled reform be diffused in a centralised or decentralised manner to give technological innovations the best chance to take root and subsequently take flight in a sustained manner when resources become dissipated over time? How are such decisions being made? What are the feedback mechanisms available? How can partnership with organisations and stakeholders be leveraged to bridge the digital divide and provide equitable access to resources?

The *representation and algorithmic divides* speak to the tenacious predicament faced by the underrepresented population. Big Data tends to amplify the voices of learners who can be connected to digital learning while marginalising those who have difficulties overcoming the barriers of participation. In a broader sense, it can also favour educational systems that are already relatively privileged (WEF, 2024). How should educators address this pivotal issue so that they do not perpetuate a biased system and subsequently widen the learning disparities over time? This brings us to the discussion on the second duality: How can educators reconcile the needs for flexibility with standardisation in curriculum design to accommodate diverse participation methods, particularly for learners lacking access to technology? Additionally, how should educators balance formal and informal learning, as well as personalised and collaborative approaches to ensure that these varied learning avenues mitigate rather than exacerbate the representation divide? Furthermore, educators may consider: How can culturally responsive teaching strategies be integrated to better address the needs of underrepresented learners?

Related to the above, educators inevitably experience variance in enactment when implementing technologies in education. Stemming from the *divide in interpretation of data,* educators can potentially empower or disenfranchise learners based on the ways they leverage human intellect and AI to engage and evaluate learners. As what Looi (2024) allude to, even as educators enjoy the benefits of automated educational services afforded by AI, there is still a need to exercise human agency to enable meaningful teacher–student interactions and individualised support. Educators must address an observed disparity: Proficient students demonstrate a propensity to utilise technology for advanced skills, while less proficient students often rely on technologies in a routine manner, lacking substantial enhancement to their grasp of content or processes. To bridge potential gaps in the learning outcomes, educators must guide learners in developing metacognitive abilities to critically evaluate their use of technology in facilitating their own learning. Central to the facilitation of learning experiences, educators have to invest discernible efforts to harmonise the humanistic and technological aspects to build synergistic relationships between learners and machines (Holstein & Olsen, 2023). Such delineation of "AI capabilities" and "distinctive human skills" can prompt educators to orchestrate and further locate teaching and learning goals that move up the cognitive value chain, as lucidly captured by Oregon State University's revision of Bloom's Taxonomy (See Figure 1).

The authors put forth the questions coalescing around this third duality: How can educators leverage human agency, pedagogical autonomy, and technological autonomation to facilitate learning experiences that emphasise higher order thinking skills and reflexivity in the use of technology? How can educators elevate their capability and capacity to understand data so as to make evidence-informed decisions to improve learning outcomes? How can educators avoid the pitfall of confirmation bias leading them to only adopt viewpoints and strategies that are aligned with their own worldviews and epistemological stance?

Lastly, the *citizenship divide* evinces that the preceding divides can accumulate and adversely influence behaviours, and, over time, skills, culture, economic, health, and civic outcomes. This leads us to think about how to facilitate peaks of excellence without compromising the equity of outcomes. It involves balancing the pursuit of excellence with the goal of providing equal opportunities for all learners. This

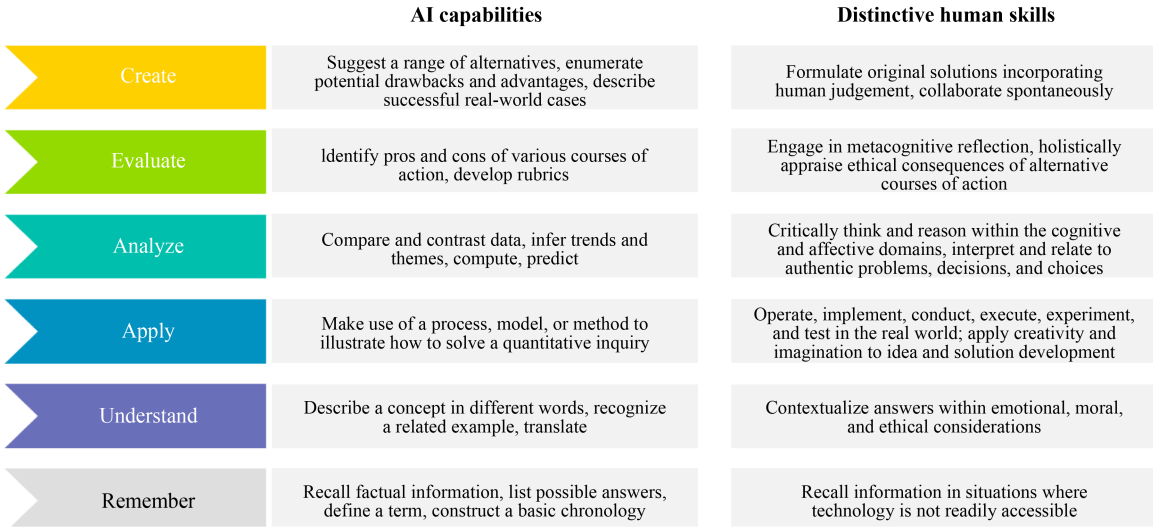

Figure 1 Moving up the cognitive value chain. Adapted from Oregon State University's recent articulation on Bloom's Taxonomy (Oregon State University, 2024).

means creating an environment where high-performing schools and high-achieving students are encouraged to reach their fullest potential while also ensuring that resources and support are available to help all schools and learners, regardless of their starting point, achieve success. It involves implementing strategies that foster excellence without widening the gap between high and low achievers. To situate the ramifications of this divide within the school ecology, we posit that educators could think about: How can educators, including policymakers and school leaders, respect differential peaks of excellence across the system while avowing equity in the desirable outcomes of education? Ultimately, the aim is to create a system where excellence and equity are not mutually exclusive but rather mutually reinforcing, with opportunities for excellence available to all students, regardless of their background or circumstances.

Surmising from the above, Table 1 encapsulates the dualities influencing the complex and multifaceted nature of integrating ICT in education, highlighting the need for careful consideration and balance to maximise its benefits while addressing potential challenges.

3 Overview of Singapore's Educational Technology Journey

To contextualise our theoretical investigative framework, the authors employ the researchers' perspective

Table 1 Theoretical framework for exploring the dualities in shaping the integration of technology in education

Dimension	Duality	Guiding questions
Resource orientation	Centralisation vs. decentralisation (in response to access divide)	• Should technology-enabled reform be diffused in a centralised or decentralised manner to give technological innovations the best chance to take root and subsequently take flight in a sustained manner when resources become dissipated over time? • How are such decisions being made? What are the feedback mechanisms available? • How can partnership with organisations and stakeholders be leveraged to bridge the digital divide and provide equitable access to resources?
Curriculum and pedagogical approaches	Customisation vs. standardisation; formal vs. informal learning (in response to representation and algorithmic divide)	• How can educators reconcile the needs for flexibility with standardisation in curriculum design to accommodate diverse participation methods, particularly for learners lacking access to technology? • How should educators balance formal and informal learning, as well as personalised and collaborative approaches to ensure that these varied learning avenues mitigate rather than exacerbate the representation divide? • How can culturally responsive teaching strategies be integrated to better address the needs of underrepresented learners?
Interpretation acumen	Human agency vs. technological automation (in response to interpretation divide)	• How can educators leverage human agency and technological autonomation to facilitate learning experiences that emphasise higher order thinking skills and reflexivity in the use of technology? • How can educators elevate their capability and capacity to understand data so as to make evidence-informed decisions to improve learning outcomes? • How can educators avoid the pitfall of confirmation bias leading them to only adopt viewpoints and strategies that are aligned with their own worldviews and epistemological stance?
Achievement outcomes	Peaks of excellence vs. equity in outcomes (in response to citizenship divide)	• How can educators, including policymakers and school leaders, respect differential peaks of excellence across the system while avowing equity in the desirable outcomes of education?

to tap on the duality lens to retrospectively examine how Singapore has responded to the various wicked problems confronting its educational technology journey. The qualitative case study involves an in-depth examination of policy documents, educational reforms, and relevant literature to understand the multifaceted nature of digital education in Singapore. The case study method allows for a comprehensive exploration of the contextual factors and policy nuances that shape ICT-enabled educational reforms. Singapore serves as an intrinsic case study due to its extensive history of systemically integrating ICT into education, a journey spanning almost three decades (MOE, Singapore, 2023d). It also ranks first in digital inclusiveness globally, based on the Roland Berger's Digital Inclusion Index 2020 (Low et al., 2021). Delineating the guiding principles behind every key milestone of Singapore's ICT journey, the authors consider the practical considerations encompassing resource, pedagogy, curriculum, professional development, capacity building, research and development, as well as infrastructure and support.

Broadly speaking, Singapore's educational policies are closely aligned with national goals, ensuring coherence in policy development and execution. The inaugural ICT Masterplan for Education (MP1) spanned from 1997 to 2002. At that time, its objectives were aligned with the educational initiative of "Thinking Schools, Learning Nations," which placed a strong emphasis on fostering critical and creative thinking skills. MP1 sought to enhance these skills by strengthening connections between schools and the global community, allowing both educators and students to broaden and enrich their learning experiences through collaboration with international partners (Koh & Lee, 2008). Additionally, it aimed to promote creative thinking, lifelong learning, and social responsibility by encouraging innovation in education, signalling a positive start to utilise technology for higher-order thinking skills. The focal point for MP1 was "Building Foundations", especially regarding infrastructure and capacity building.

ICT Masterplan 2 (MP2) spanned from 2003 to 2008, underscoring the emphasis of "seeding innovations." It aimed to leverage the groundwork laid by MP1 to enhance educational processes and cater to diverse learner needs, in line with the "Teach Less, Learn More" initiative. This phase was marked by a shift towards student-centric pedagogy with schools enjoying greater autonomy in their ICT integration planning. It outlined six key objectives: promoting active learning, integrating ICT into curriculum, supporting teacher development, enhancing school capacity, fostering research in ICT education, and expanding ICT infrastructure. Recognising variations in ICT integration, Ministry of Education (MOE) of Singapore adopted a differential approach, setting baseline competencies while encouraging advanced schools to push boundaries through recognition schemes and industry collaborations. Numerous schools acknowledged the importance of technology in readying students for the future and reshaping school methodologies. Nonetheless, they were aware of their insufficient proficiency in incorporating ICT into lessons, as school leaders grappled with establishing a unified pedagogical approach centred around student learning, which teachers could readily adopt (Law et al., 2008).

The third iteration (2009–2014) of the Masterplan for ICT in education (MP3) built upon the foundations laid by MP1 and MP2 to focus on "strengthening and scaling", aiming to further enhance the learning environment for students and equip them with essential competencies for success in a knowledge-based economy. Notably, emphasis was placed on fostering self-directed learning (SDL) and collaborative learning (COL) skills, alongside promoting cyber wellness to cultivate responsible and discerning technology users among students. The plan envisioned teachers possessing the capability to design and implement ICT-enhanced learning experiences that nurture these skills, while school leaders would provide guidance and create conducive conditions for effective ICT integration in teaching and learning. There was a continued focus on ubiquitous learning, necessitating a robust ICT infrastructure capable of supporting learning opportunities anytime and anywhere.

MP4 (2015–2019) brought attention to the need for "deepening learning, strengthening practices". In light of this, MOE has implemented a framework aimed at fostering essential competencies such as communication, collaboration, and information skills; critical, adaptive and inventive thinking skills; and civic, global and cross-cultural literacy (MOE, Singapore, 2023c). Furthermore, there is an increased emphasis on a "values-driven, student-centric approach" to education, aiming to instil students with lifelong values essential for success. The direction of MP4 aligned closely with this overarching vision, focusing on nurturing future-ready and responsible digital learners, as well as broadening the curriculum to develop 21st century competencies. Cyber wellness remained a key focus area, with the goal of MP4 being to ensure "quality learning in the hands of every learner—empowered with technology." To achieve this goal, MOE has identified two key enablers: teachers as designers of learning experiences and environments, and school leaders as culture builders. Additionally, MOE has outlined four approaches for realising this vision: Deeper integration of ICT into curriculum, assessment, and pedagogy; sustained professional development; translational research, innovation, and scaling; and a connected ICT learning ecosystem.

Gleaning insights from the previous ICT Masterplans, the current Educational Technology (EdTech) Plan/EdTech Masterplan (2020–2030) is driven by the vision of transforming education through technology to prepare students for a technology-transformed world. The outcome goals include: 1) nurturing students to become digitally-empowered, future-ready learners and innovators; 2) developing teachers to be technologically-adept, collaborative learning designers; 3) empowering schools to create intelligent, responsive and digitally-equipped learning environment, and 4) enabling a networked EdTech ecosystem. In a nutshell, this phase aims to make education more self-directed, personalised, connected and human-centred. See Figure 2 for the summary of the key developments of Singapore's ICT trajectory.

4 Applying the Four Dualities on ICT to Singapore's Education

This section examines the reconciliation of the four dualities inherent in the use of ICT throughout Singapore's longitudinal trajectory to incorporate ICT to enhance teaching and learning.

4.1 | Resource Orientation (Centralisation vs. Decentralisation)

Singapore's ICT integration in education evolved from a centralised model, where the MOE focused on substantial investments in infrastructure and standardised hardware procurement to ensure widespread access, to a more balanced approach incorporating decentralisation.

It was discernible that many activities were coordinated centrally at MOE's level due to the limited ICT capacity at the ground level during MP1's embryonic stage of foundation building. Significant investment was made in ICT infrastructure to ensure widespread access for students. Efforts included decreasing the student-computer ratio, providing high-speed multimedia services island-wide, and centralising hardware procurement to maximise cost efficiency. To add on, the reconfiguration of school spaces and centralised management of renovations served to address the duality of access issues in education.

Access to hardware and connectivity continued to improve over the successive waves of ICT journey, as seen from MOE's provision of enhanced wireless ICT infrastructure to facilitate different modes of lesson delivery, platforms for resource and expertise sharing as well as 1:1 access to hardware to support ubiquitous learning access different contexts. Of paramount importance is the introduction of the "Student Learning Space (SLS)", MOE's nationwide core platform for teaching and learning. Representing a significant initiative aimed at providing students with equitable and self-paced access to high-quality digital resources, the SLS is designed to foster social interaction, enabling

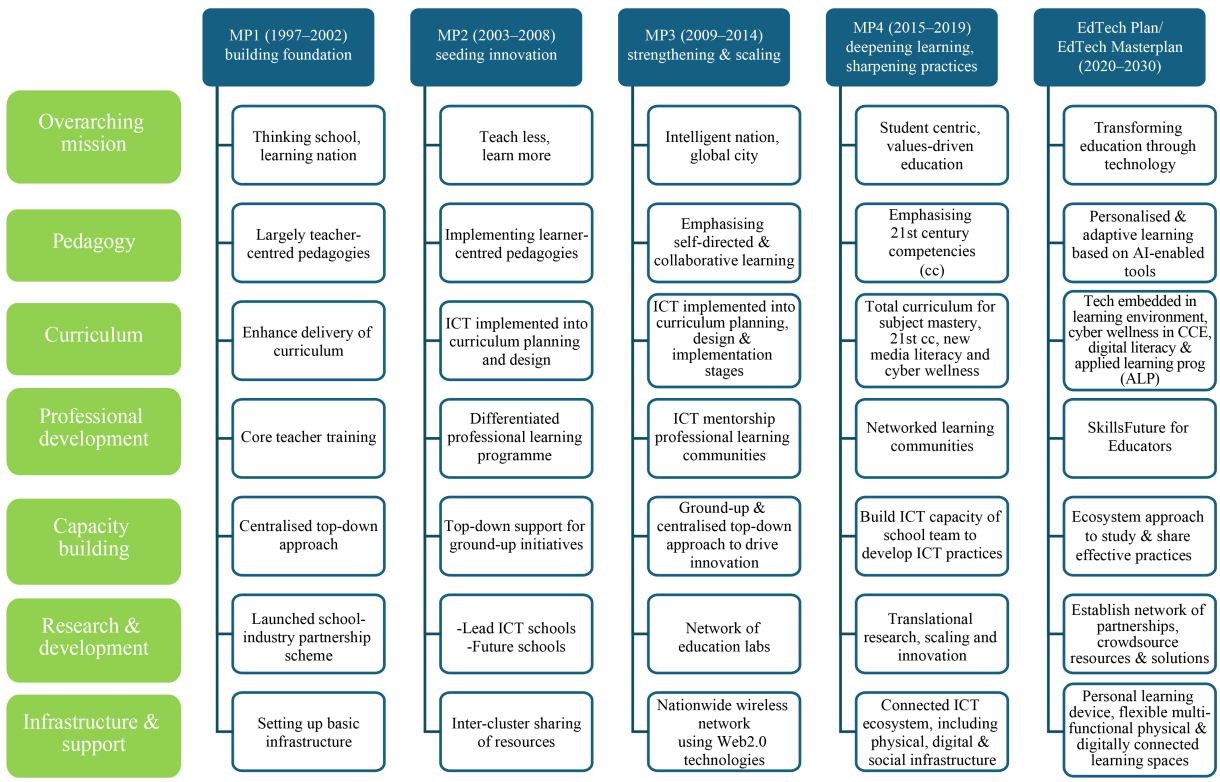

Figure 2 Singapore's ICT journey in education. CCE: character citizenship education.

collaboration among students and schools through its integrated portal. The digital resources, developed, acquired, and curated by MOE in collaboration with both internal and external partners, are also available to teachers. They include instructional guides and pedagogical supports, all aligned with curriculum priorities and recommended teaching methods to enhance teachers' ability to create tailored lesson plans. Bolstered by the infusion of AI-enabled tools, teachers can design lessons catering to individual student needs by taking reference from enhanced feedback and performance tracking data afforded by learning analytics. The adaptive learning systems can provide additional scaffolds for students who need more help in grasping essential concepts and skills while pushing the frontiers of higher ability students to progress at a faster pace to achieve mastery or explore other domains.

It is noteworthy to highlight that all secondary one school students would have their own school-prescribed Personal Learning Device (PLD) by 2024 and progressively, it is envisaged that by 2028, the use of PLD would be rolled out to all secondary school students. For economies of scale, MOE will coordinate the bulk tender for procurement of these devices. On top of that, it has provided a one-off subsidy in 2020 to help students defray the cost of purchasing these devices. To ensure no students would be deprived and left behind because of financial constraint, further subsidies would be extended to households that need more assistance. As part of MOE's complementary effort to ensure cyber wellness security, it rolled out Device Management Applications (DMA) to restrict the type of applications and websites accessible by students. These strategies were formulated based on the findings of MOE's pilot studies conducted with eight secondary schools in 2019, an attestation of evidence-informed policymaking (MOE, Singapore, 2020b).

Quintessentially, what MOE strives to provide centrally is no longer mere access to technical infrastructure or hardware, but socio-technical-pedagogical scaffolds with embodied cognition. Learners and teachers alike can leverage collective intelligence to augment their learning efficacies. MOE also acted as a central epistemic broker to source, use and translate research evidence into policies. To mete out the issue on access divide, MOE provided financial resources to help students fund the purchase of devices.

Whilst MOE still maintains a strong foothold on providing access to standardised hardware, software, and connectivity, there has been gradual moves to loosen up and advocate top-down support for ground-up initiatives. For example, as the ICT landscape matures, schools were given more autonomy to decide how they would like to deploy the ICT funds disbursed by MOE for further procurement of ICT-related services and equipment. During MP2, schools that have experienced success in integrating ICT may receive additional funding from MOE to continue their research in emerging technologies or to scale up their existing practices at a more significant scale. During the EdTech phase, teachers have the liberty to experiment and integrate add-on features within the standardised platform (UNESCO, 2023a). In totality, these measures created an inclusive environment by ensuring that all learners can have equitable and scalable access to digital education, thus removing significant impediments to online participation.

4.2 | Curriculum and Pedagogical Approaches (Customisation vs. Standardisaiton of Curriculum; Formal vs. Informal Learning with Respect to Pedagogical Approaches)

Singapore's approach to curriculum and pedagogy integrates customisation and standardisation, as well as formal and informal learning. MOE has progressively embedded technology into teaching, promoting higher-order thinking and personalised education. Additionally, schools now enjoy greater autonomy to customise curricula, creating white spaces for students to explore informal interest-based learning initiatives, moving beyond the initial standardised approach. These principles foster a diverse and inclusive learning environment, addressing the needs of all learners through multimodal and differentiated educational experiences.

Over the years, the use of technology is increasingly embedded into curriculum, pedagogy, and assessment. There was consistent espousal by MOE to use ICT for higher order thinking skills, evident from MOE's emphasis on using ICT to promulgate creative and thinking skills during MP1, collaborative and self-directed learning during MP3, 21st century competencies during MP4 as well as personalised and adaptive learning during the current EdTech phase, signalling an edifying stance that permeated throughout the waves of reform.

In tandem with these developments, the curriculum has become more holistic. Considered forward looking, students are now encouraged to be self-directed learners to pursue their personal interests during dedicated home-based learning days that are incorporated into the curriculum time. The use of PLD supports students' informal and interest-based learning by providing them with seamless avenue to learn anytime, anywhere, thus encouraging them to construct knowledge progressively and take ownership of their learning during the ongoing process. Such bold moves, for the first time, operationalise time and space for informal learning pursuits, demonstrating MOE's strong intent towards enabling a learning agenda that is

broader than academic excellence.

Furthermore, to strengthen digital safety, security and responsibility of students and teachers, cyber wellness will be featured more strongly within the "Character and Citizenship Education (CCE)" curriculum so that users of ICT can be more adept at evaluating the authenticity of information, mindful about excessive use of media, develop healthy online identity, maintain meaningful online relationships and respect copyright issues (UNESCO, 2023b). These soft skills are aligned with the skills delineated in the revised version of Bloom's Taxonomy (Figure 1) which underscores the importance of human discernment to appraise ethical consequences related to authentic problems, actions, and choices.

Other than being more holistic, schools now also enjoy greater liberty in customising their curriculum, a departure from the earlier days of MP1 journey where there was pressing need to quickly build up basic competencies through a standardised approach. For example, during MP2 schools that act as trailblazers can offer customised ICT-enriched lessons. During the current phase, schools, including institutes of higher learning will also be enhancing their curriculum offerings to strengthen learners' digital literacy as well as build a pipeline of domain experts. Notably, computational thinking and content regarding appreciation of emergent technologies will be incorporated into lower secondary mathematics and science syllabus. There will also be more schools offering computing as O-level and A-level subject. Not only that, schools also have the prerogative to plan their home-based learning programmes (MOE, Singapore, 2020b).

These strategies, to some extent, can mitigate the representation divide which this study discussed in the preceding section. By taking into consideration data streams across time (within and beyond curriculum time), space (online and offline), and domains (informal transdisciplinary interest and formal disciplinary knowledge), there is less incidence for learners to be underrepresented. The provision of multimodal experiences, coupled with differentiated curriculum and multiple data points caters to the needs of diverse learners without over reliance on a single source of diagnostic avenue.

4.3 | Interpretation Acumen (Human Agency vs. Technological Automation)

With greater complexity comes greater demands on the teachers' ability to orchestrate meaningful learning experiences for students. Through comprehensive and continual professional development for teachers facilitated by MOE and multiple stakeholders, teachers can potentially become more adept at leveraging both human insight and technological tools, fostering adaptive learning and higher-order thinking skills, and bridging the gap between policy, theory, and practice.

MOE's Educational Technology Department (ETD) has in the past: 1) established communities of practice to engender professional discourse on ICT integration; 2) set up the ICT mentor scheme for school-appointed ICT mentors to meet regularly to exchange ideas related to their disciplines; 3) provided on-site consultancy support to promote action research, conduct coaching sessions to build up the capacity of core champions and strengthen the networked learning communities of mentee schools; 4) organised milestone courses, workshops and conferences to deepen the knowledge of middle managers and school leaders.

Working closely with the National Institute of Education (NIE), MOE has collaborated with researchers to: 1) unpack the tenets of self-directed learning and collaborative learning, culminating into monographs that serve to help practitioners demystify and operationalise the concepts; 2) evaluate the efficacies of ICT MP3 to highlight strengths and challenges; 3) train teachers and leaders on ICT-enabled learning as well as 4) set up the eduLab programme to encourage schools to apply for competitive grants to experiment with ICT-mediated pedagogies or scale up projects that have demonstrated proof-of-concept. These professional development opportunities aim to enhance teachers' comprehension of technology's function in curriculum, pedagogy, and assessment, as well as their proficiency in designing professional development (PD) sessions for integrating technology and establishing frameworks for monitoring and evaluating technology within their schools. Overall, these professional development opportunities have been "broad-based, situated and systematic" (Toh & Looi, 2020).

However, with the advent of AI, educators now face the intensifying pressure to revisit the ways they orchestrate learning experiences before, during and after lessons, as seen from the proliferation of sensemaking discussion on how to form constructive partnership with generative AI to empower "educators and learners to reach new levels of creativity, critical thinking, and adaptability within the ever-evolving educational landscape" (Wong & Looi, 2024). During this EdTech phase, teachers are expected to be adept designers of learning experiences who can design physical and virtual learning environments to facilitate active learning, customise learning and implement interventions to cater to individual needs based on learning analytics as well as continually hone their craft for improvement through interfacing with content, machine and stakeholders (MOE, Singapore, 2023a).

To deepen teachers' technological-pedagogical-content knowledge, teaching and learning guides are made available on SLS. The introduction of the

enhanced PD roadmap for teachers, known as "SkillsFuture for Educators" (SFEd) further augments teachers' mastery of skills in the six prioritised areas of practice: assessment literacy, differentiated instruction, inquiry-based learning (IBL), e-pedagogy, character citizenship education (CCE), and support for students with special educational needs. Both MOE and NIE will facilitate a coherent PD experience for in-service and pre-service teachers so that they have "sharper clarity of purpose in assessment design and strengthen competencies to diagnose and address learning gaps"; know how to "differentiate their instructional and assessment strategies"; develop a "deeper understanding of IBL approaches in their disciplines"; "accelerate and deepen learning by making it more active and personalised"; keep abreast of "current content and skills, and be imbued with the conviction to deliver CCE effectively" as well as acquire "a wider repertoire of instructional strategies" to support students with special needs (MOE, Singapore, 2020a).

To further exemplify what success looks like, an innovation incubator, MOE's the Classroom of the Future (CotF) initiative leverages design thinking and other human-centric methodologies to redesign the teaching and learning experience for students and teachers to meet current and future needs. Spanning efforts across multiple divisions within MOE, CotF generates, prototypes, tests, deploys and scales learning solutions for technology-enabled classrooms (CotF, n.d.).

The multifaceted strategies outlined serve as scaffolds for educators to leverage human agency and technological automation to foster learning experiences that priortise higher order thinking skills and adaptive learning. Policymakers, researchers, funders, practitioners, and learners have collectively contributed towards expanding the database from which evidence can be drawn upon, bridging the gap between science, theory, and practice. SFEd underscores the importance of metacognitive skills, prompting educators to critically evaluate the decision-making process underpinning their pedagogical choices. There is growing appreciation for new ways of measuring learning impact through both formative and summative assessments. Moreover, by imbuing multiple perspectives from a range of stakeholders within the learning ecology, the authors posit that the issue of interpretation divide can possibly be mitigated, at least at the level of policy intent. By collaborating with different actors for professional development, the inherent problem of confirmation bias can be mitigated as educators become more sympathetic towards the various epistemological stances before reaching a profound understanding of the complex issue at hand.

4.4 | Achievement Outcomes (Peaks of Excellence vs. Equity in Outcomes)

Respecting differential peaks of excellence while promoting equity in outcomes is a perennial challenge that policymakers endeavour to navigate. The tension lies in fostering exceptional achievement while ensuring fairness and equal opportunities for all. To achieve this, MOE encouraged promising schools that had demonstrated results in ICT integration to do more for their teaching fraternity and students, and removed systemic barriers across the system to level the playing field.

The development of peaks of excellence is perhaps most evident during MP2, where schools that have demonstrated higher level of readiness in integrating ICT were given more autonomy and resources to continue with their experimentation. For example, 15%–20% of schools were recognised as LEAD ICT@Schools (Leading Experimentation and Development in ICT) ready to achieve a higher level of information technology (IT) use for at least one subject across one level. At the pinnacle was FutureSchools@Singapore (FS@SG). For these schools, they were ready to integrate ICT across all subjects and levels at a school-wide level. These schools received additional funding from the National Research Foundation to work with partners from MOE, government agencies, industry, and Institutes of Higher Learning to scale up their innovations. Serving as peaks of excellence, these schools had the mandate to spread their exemplary knowhow to other schools in the system, which is akin to the practice of trickling the accrued benefits downstream.

Concomitantly, MOE also established baseline ICT standards across all schools to ensure minimal standards were achieved, thus safeguarding against the huge disparity in performance across schools and over time. With exemplary schools acting as trailblazers consolidating the insightful lessons learned, MP3 and MP4 focused on improving the sharing and dissemination of best practices, paving the way for more open experimentation across the system whereby interested schools can put up grant proposals to secure competitive grants for school-based innovations.

As part of MOE's concerted efforts to promote equity, funds for the purchase of assistive technology plays a crucial role in supporting the teaching and learning of students with physical disabilities and/or special education needs in both mainstream and special education schools (MOE, Singapore, 2020c). Additionally, MOE collaborates with the Ministry of Social and Family Development (MSF) and Infocomm Media Development Authority (IMDA) to expand the accessibility of technology to vulnerable groups, such as

households with lower incomes. Social service agencies are also actively involved in ensuring that school-going children from these households have access to broadband connectivity for online learning (UNESCO, 2023a). These measures significantly contribute to mitigating the risks of a citizenship divide by ensuring equal access to opportunities regardless of family background.

5 Conclusions and Future Work

Singapore has made the early choice to harness rather than resist technology (which includes AI) for enhancing teaching and learning. It is one of the first countries to embrace the use of ChatGPT in early 2023 since the launch of this generative AI in November 2022 (Wong, 2023). The government has demonstrated the tenacity to navigate unchartered waters as well as consolidate the insights gleaned from each wave of ICT-mediated reforms. Although no stranger to riding the eddies of technologies, the rise of AI has brought unprecedented challenges to the educational landscape, as delineated in the five dualities (centralisation vs. decentralisation; standardisation vs. customisation; formal vs. informal learning; human agency vs. technological automation and peaks of excellence vs. equity in outcomes). The issue here is not to create a false dichotomy but to flesh out the intricacies involved so that issues can be debated and deliberated from multiple perspectives. While Singapore appears to be well poised to take on the new challenges, it is still early days in terms of evaluating the benefits of leveraging AI and data analytics for learning. Some food for thought: Are teachers and school leaders willing to invest time to understand the science of data literacy? Are they comfortable about the redistribution of power brought about by technology? Do they view the influx of data as complementary or distracting forces? Afterall, the crux here is social acceptance whereby sentiments are rooted in the motivational and psychological readiness of the stakeholders.

There are also broader societal forces that can threaten the integrity of teaching and learning. This includes ethical issues underpinning the usage, storage, and retrieval of data. Data breach is real and occurs more frequently than not. These lurking menaces can divert precious time away from the main task of teaching and learning. The sixth duality which we could have also considered is innovation vs. regulation. Which is the lesser evil? How and should data governance be reinforced?

Lastly, the human touch remains critical. Educators can attain digital fluency, yet their connection with learners transcends mere analysis of algorithmic data. Making time for face-to-face interactions, understanding students' family funds of knowledge and using discernment to design and implement human intervention remain precious. The current EdTech plan emphasises parental engagement, which beyond any doubt, is an important puzzle of the learning ecology. More discussion and documentation are needed to understand how parents can play a role in elevating students' learning and how deep school-learners-parental partnership can be forged. Together, the interweaving interaction between humans and advanced technologies will help educators gain a more holistic and realistic portrait of their learners.

Conflict of Interest The authors declare that they have no conflict of interest.

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