CONTINUAL IMPROVEMENT: SENSE-MAKING OF CONVERGENCE OF INSTITUTIONAL INITIATIVES ON DIGITAL TECHNOLOGIES

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ABSTRACT

The introduction of various educational initiatives in Singapore Polytechnic (SP), notably those based on using digital educational technologies (EdTech) tools at different levels of applications (institution, program, cohort, individual) had resulted in faculty feeling overwhelmed by the changes while trying to balance the demand of their day-to-day teaching duties. Examples include flipped classroom, growth mindset, self-directed learning and learning analytics, etc. Consequently, faculty failed to see the underpinning pedagogical considerations driving these initiatives and often tend to focus on implementing whatever a particular initiative required, “just to keep up”. On the other hand, the CDIO Framework has been used as a basis for continual improvement to guide various curricular redesign efforts over the years, whereby each initiative is implemented by referencing the relevant CDIO Standards. This paper proposes using the “lens of CDIO” to help faculty “connect the dots” between the seemingly disparate efforts to make sense of the situation, via a generic convergence model. For context, the paper first shares the key features of the initiatives for flipped classroom, learning analytics and ALeRT, which stands for Assessing Learning Regularly for Timely Support. The paper then shares how they can be harmonized via an initiative called Data-Enabled Flipped Learning (DEFL in short), within which another initiative of differentiated instructions was introduced. The stated overall aim of DEFL is to support the development of students’ self-directed learning competency. The paper provides explanations of how DEFL can be supported by the CDIO Framework as well as where it is situated in Academic Quality Management Framework of SP, to highlight the importance of the convergence as part of the institution’s drive towards continual improvement of its programs. Thereafter the paper also suggests how current on-going initiatives and future ones can also be harmonized using the proposed model, suggesting the model’s scalability to accommodate other initiatives. Examples where in-progress initiatives can be situated include a faculty digital competency framework and future learning workspaces. Lastly, the paper concludes with a discussion emphasizing the importance of having a ”human-in-the-loop” and continual faculty professional development for the integration of digital Edtech tools into the curriculum, calling for a concerted effort of faculty to engage with these tools in a productive way focusing on innovations in teaching and learning that maximize student learning outcomes.

KEYWORDS

Convergence, Flipped Learning, Learning Analytics, Digital EdTech Tools, CDIO Syllabus, Standards: 1-12

INTRODUCTION AND SCOPE OF THIS PAPER

From its inception, it is envisioned that programs that adopted the CDIO Framework for design or redesign will be able to deliver an education that is "constantly improved through quality assurance process with higher aims than accreditation" (from CDIO website, at https://www.cdio.org/cdio-vision). Over the years, various paper presentations had attested to the usefulness of the CDIO Framework in assisting programs to achieve good program quality assurance, as well as supporting program accreditation (Verhaevert, 2022; Truong, Ha & Le, 2018; Cheah et al, 2013; Georgsson & Holmgren, 2012; Levy, 2011; Gray, 2010).

Singapore Polytechnic (SP) adopted the CDIO Framework to underpin the revamp and redesign of project-based learning in a pilot study in 2004; that lead to the subsequent implementation in all engineering programs in 2007. Other non-engineering programs also used elements of CDIO in selected courses. Over the years, various initiatives have been introduced by SP to continually improve its programs so that they remain up-to-date and relevant to meet the demands of Singapore's workforce.

In recent years, SP has been leveraging the use of digital educational technology (EdTech) tools to drive these initiatives institution-wide. These initiatives aimed at improving SP's education system at different scales, from the individual-level up to the whole cohort-level. Programs adopting the CDIO Framework used it to continue to provide guidance in carrying out the required/necessary changes to the curriculum.

The non-exhaustive list below shows selected examples of recent-past efforts and current on-going initiatives.

- Flipped Classroom (Class-level)
- Self-Directed Learning (Individual-level)
- Teamwork Measurement (Group-level)
- Assessing Learning Regularly for Timely Support, or ALeRT in short (Individual-level)
- Learning Analytics – and later AI in Education (Cohort-level)
- Sustainable Development (Cohort-level)

Use of EdTech tools – digital or otherwise – needs to be built on pedagogical principles and theory of teaching and learning (Cowling et al, 2022). The introduction of these initiatives, coupled with the use of digital EdTech tools, had led to the unintended consequence of faculty feeling overwhelmed by the changes while trying to balance the demand of their day-to-day teaching duties. Often, they fail to see the underpinning pedagogical considerations driving these initiatives; other than they are all part of the institution's effort to improve the quality of its education.

This paper suggests an approach using the "lens of CDIO" to help faculty "connect the dots" between the seemingly disparate efforts to make sense of the continual improvement process. It first introduces selected recent SP initiatives involving the use of digital EdTech tools, namely flipped classroom, learning analytics, and differentiated instructions. Introduced over a spaced period, these initiatives eventually merged to form what is known as the Data-Enabled Flipped Learning (DEFL in short). Using the "lens of CDIO", how each initiative is implemented can be discerned through the application of relevant CDIO Standards. A convergence model of institutional initiatives guided by the CDIO Framework is then presented. The paper further discusses how current on-going initiatives, and future ones can also be harmonized using the convergence model.

THE CHALLENGE OF EDUCATIONAL INITIATIVES IN SP

The rapid convergence between digital EdTech tools and pedagogies provides great opportunities for faculty to tap into to increase teaching effectiveness, and improved students learning experiences and hence the learning outcomes (Brasca et al, 2022). Research had shown that faculty attitude can be an important factor in technology adoption in teaching and learning (Burch & Mohammed, 2019; Salas, 2016). Many authors had written on challenges faced by faculty that resulted in less-than-ideal adoption and use of digital technologies in education (see for example Mundy et al, 2012; Steel & Hudson, 2001). Georgina & Hosford (2009): examined how faculty technology literacy and technology training impact the integration of technology into their pedagogy. Their results showed significant correlations between technology literacy and pedagogical practice integration. Burch & Mohammed (2019) noted that there is not a simple model when it comes to augmenting classrooms with educational technology, hence a broad generalization can be problematic.

In the case of SP, recent surveys indicated that faculty are comfortable with using digital technologies in the classroom (Lee et al, 2024). The challenge that we faced is one of lack of understanding on how the different initiatives fits into the overall "big picture of educational improvement" instead of just "addressing each initiative as one comes along". The numerous initiatives introduced in the last few years had left some faculty feeling overwhelmed. Many failed to see the "connections" of the initiatives; treating them as independent of one another, and therefore are challenging to implement within the limited curriculum hours. Many are caught in a race to catch up and a sense of "learned helplessness" – a psychological state where one feels he/she has no control over a situation and is unable to escape. As a result, faculty to focus too much on their implementation before "the next big wave", instead of understanding the rationale for an initiative.

Brief Summary on Selected Initiatives: Flipped Classroom, Learning Analytics, ALeRT and SDL

SP introduced flipped learning to engage students in 2015 by starting with the School of Mathematics and Science and the School of Electric and Electronic Engineering. Several papers have been written on the use of CDIO Framework to implement flipped classroom. See for example, a series of integrated learning experiences (CDIO Standard 7) based on case studies had been reported as being delivered in flipped classroom format for learning chemical process safety (Cheah & Sale, 2017; Cheah, Sale & Lee, 2017; Cheah, Lee & Sale, 2016). In such applications, besides learning the technical knowledge for chemical process safety, students also learnt CDIO skills such as teamwork and collaboration, critical thinking, systems thinking, ethical reasoning, etc.

The COVID-19 Pandemic that started in late-2019 put added impetus to expand the use of flipped classroom to a much larger scale, as all lessons are now conducted online, mostly in asynchronous mode. The pandemic also saw wider adoption of digital educational tools to enhance teaching and learning, including the introduction of e-experiments to replace physical presence in laboratories due to campus closure. This period sees a significant increase in e-experiments developed using digital technologies such as Augmented Reality/Virtual Reality, interactive video, and digital twin. The CDIO Framework was once again used to guide the design of these e-experiments. Examples include use of blended learning (CDIO Standard 8) to promote growth mindset, virtual collaboration and resilience; and integrated learning experiences (CDIO Standard 7) 'operating' a virtual heat exchanger (Cheah & Wong, 2021); as well as development of self-awareness and safety mindset (Yang & Cheah, 2020).

In addition, the adoption of educational technology, in particular that of learning analytics, also contributed to the transformation of teaching and learning, especially in the context of flipped classroom. In 2019, SP introduced an initiative called ALeRT, which stands for "Assessing Learning Regularly for Timely Support" (see for example, Wan & Chong, 2020). Use of ALeRT strives to improve students learning by providing near-real time feedback to students data collected from students' responses to online quizzes and displayed on performance dashboard for each student. This is followed in 2022 with the introduction of differentiated instruction. Differentiated Instruction is a systematic educational approach in which teachers modify content, teaching and learning activities to honour the range of student backgrounds and maximizes their learning opportunities and capacities (Tomlinson, 2017).

Another important development in SP, just before the COVID-19 Pandemic was the introduction of self-directed learning (SDL) competency in students in 2018. This initiative was SP's response to Singapore's SkillsFuture Initiative, which was formulated to address the challenge of Industry 4.0 (Cheah & Leong, 2018; Cheah & Yang, 2018). One of the four strategic thrusts of the SkillsFuture Initiative was the development of lifelong learning competency among Singaporeans. Self-directed learning is one of the key competencies that supports the development of lifelong learning competency (Boyer et al, 2014). Diplomas adopting the CDIO Framework again used it to guide the design of integrated learning experiences to systematically integrate underpinning skills and attitudes needed – as per the CDIO Syllabus – to progressively develop SDL competency in students. See for example Cheah (2020), Cheah, Wong & Yang (2019).

Convergence: Data-Enable Flipped Learning

The SP Data-Enable Flipped Learning (DEFL) Model as shown in Figure 1 was introduced in 2022. It is the result of the convergence of flipped classroom, learning analytics (ALeRT) and differentiated instruction, mediated by the use of digital EdTech tools. It aims to enhance student learning outcomes by fostering their active engagement in the learning process to further enhance their SDL competency.

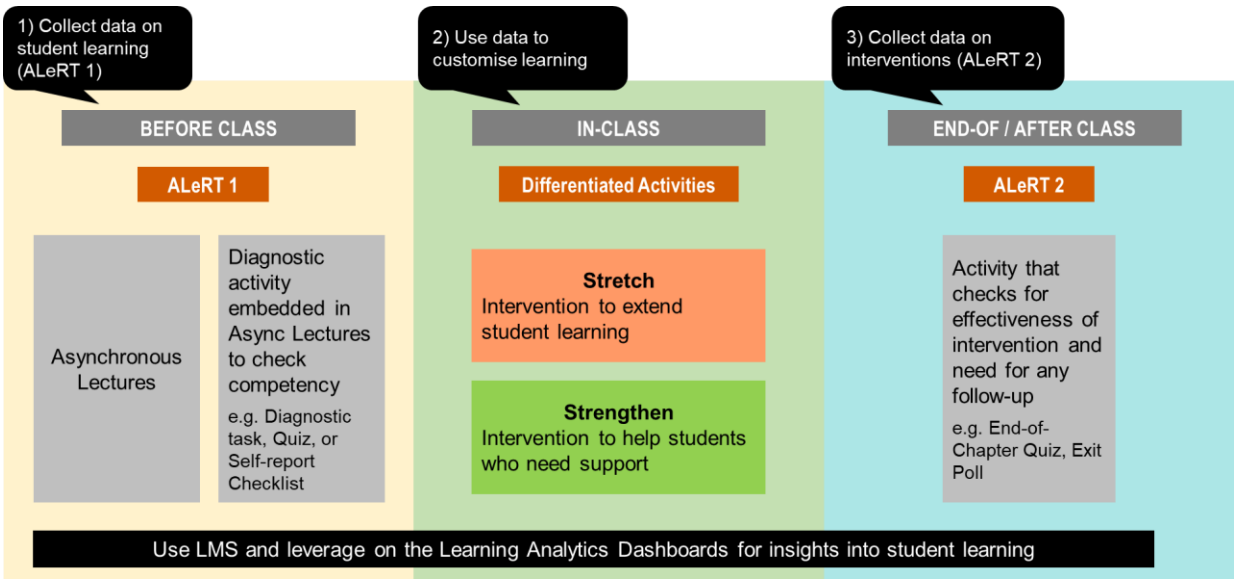

Figure 1. Singapore Polytechnic Data-Enabled Flipped Learning (DEFL) model.

A use case of DEFL was presented by Wan, et al (2024). Briefly, there are three stages to the DEFL model, and they are briefly explained below:

- ***Stage 1 Before Class - Collect and analyse data on student learning (ALeRT1):*** Students go through the materials asynchronously in the Learning Management System (LMS) and complete quiz/quizzes in the LMS to assess their understanding. The assessment data is diagnosed and given to lecturers via the LMS Dashboard or downloadable reports. Lecturers analyze and use the data to plan for the In-Class Stage next.
- ***Stage 2 In-Class - Use data to customize learning (Differentiated Activities):*** Lecturers used different instruction to different groups of students as discerned from the diagnostic results. On one hand, "stretch" interventions are provided to better-performing students to further their learning. On the other hand, "strengthen" interventions are extended to weaker students who need more support.
- ***Stage 3 End-of/After Class - Collect data on interventions (ALeRT2):*** Another round of diagnostic survey is administered in the LMS for lecturers to assess the effectiveness of the interventions and identify additional requirements for any follow-up, for weaker students, such as further scaffolding or individual consultations.

The CDIO Framework provides guidance to the implementation of DEFL via the use of CDIO Syllabus and referencing the relevant CDIO Standards, as shown in Figure 2.

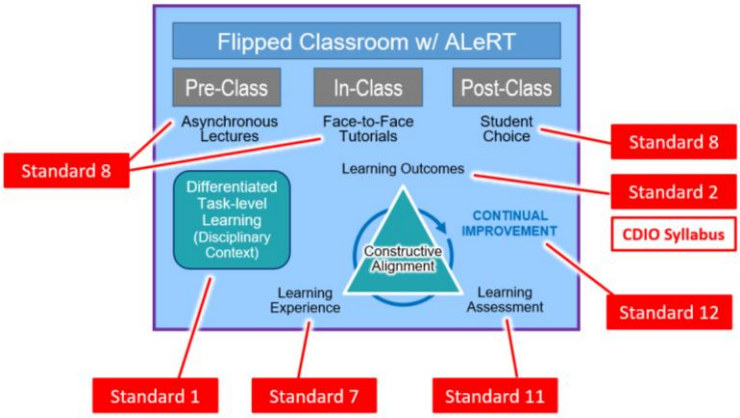

Figure 2. How CDIO Supports the Implementation of DEFL

USE OF CDIO FRAMEWORK TO ADDRESS RECENT SP EDUCATIONAL INITIATIVES

The "lens of CDIO" is one of continual improvement, where guidance is provided by Core Standard 12 Program Evaluation. It offers a good approach to help address the challenges faced by faculty in appreciating the myriad of initiatives aimed at improving student learning using EdTech tools. This will be expounded below.

Recap: Use of CDIO to Support Program Continual Improvement

Cheah et al (2013) had reported on the use of CDIO Self-Evaluation to complement SP's Academic Quality Management System that drives the continual improvement effort of all programs in the institution. The basic approach is straight forward: any initiative introduced can be viewed and understood from the "lens of CDIO" with regards to its implementation, by visiting the 3 fundamentals of the CDIO approach to curriculum design/redesign:

1. Need: What is the professional role and practical context of the profession?
2. Learning outcomes: What knowledge, skills and attitudes should students (and adult learners) possess as they graduate from our programs, and at what level of proficiency?
3. Curriculum, workspace, teaching, learning and assessment: How can we do better at ensuring that students and adult learners learn these skills?

With regards to continual improvement, the CDIO self-evaluation process from CDIO Core Standard 12 Program Evaluation had been shown to be complementary to the SP Academic Quality Management System (AQMS) and useful to guide program review (Cheah, Koh & Ng, 2013). Figure 3 shows the SP AQMS and how the different elements are supported by the CDIO Standards. DEFL is also shown, as part of the curriculum delivery system.

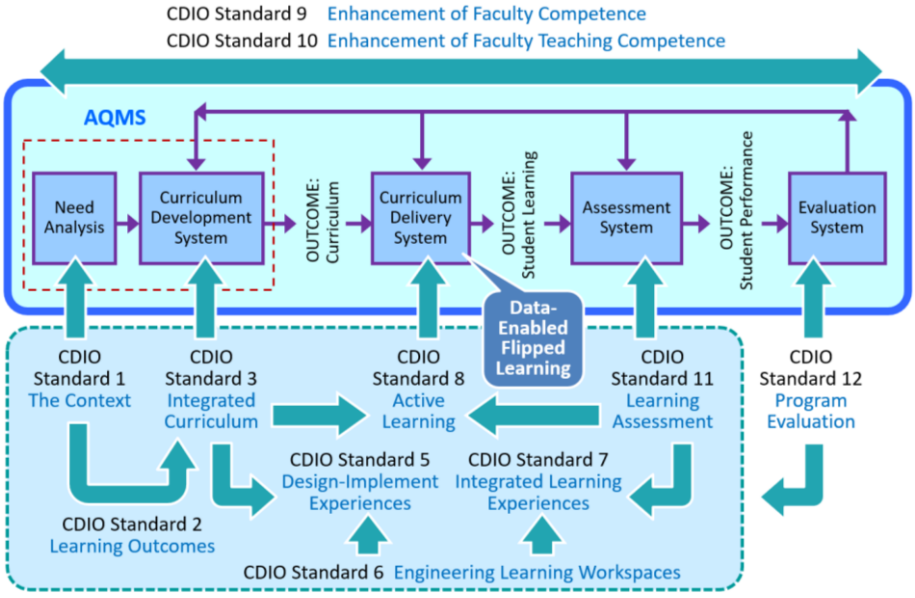

Figure 3. How CDIO Supports the SP Academic Quality Management System

Towards a Convergence Model of Curriculum Enhancement using CDIO Framework

Generalizing from the above, we can use the "lens of CDIO" to carry out similar analysis to investigate how other initiatives in SP fits within the continual improvement process. The model is shown in Figure 4, where initiatives in SP are grouped into 4 broad categories of Pedagogy & Competency Framework, Digital Technologies, Student Engagement & Learning, and Infrastructure and System Support. These 4 categories mutually support and impact one another, as shown by the 6 double-headed arrows. An example of SP initiative in each category is provided. The various core standards are shown "surrounding" the 4 broad categories of SP initiatives, which in turn are pushing towards developing SP's 6 graduate attributes.

Figure 4 also highlights a key aspect of continual improvement emphasized in CDIO Framework: The role of faculty in implementing the initiatives. These are the professional development of faculty teaching competence in personal and interpersonal skills, product, process, system, and service building skills, as well as disciplinary fundamentals (CDIO Standard 9); plus the competence in providing integrated learning experiences, in using active and experiential learning methods, and in assessing student learning (CDIO Standard 10).

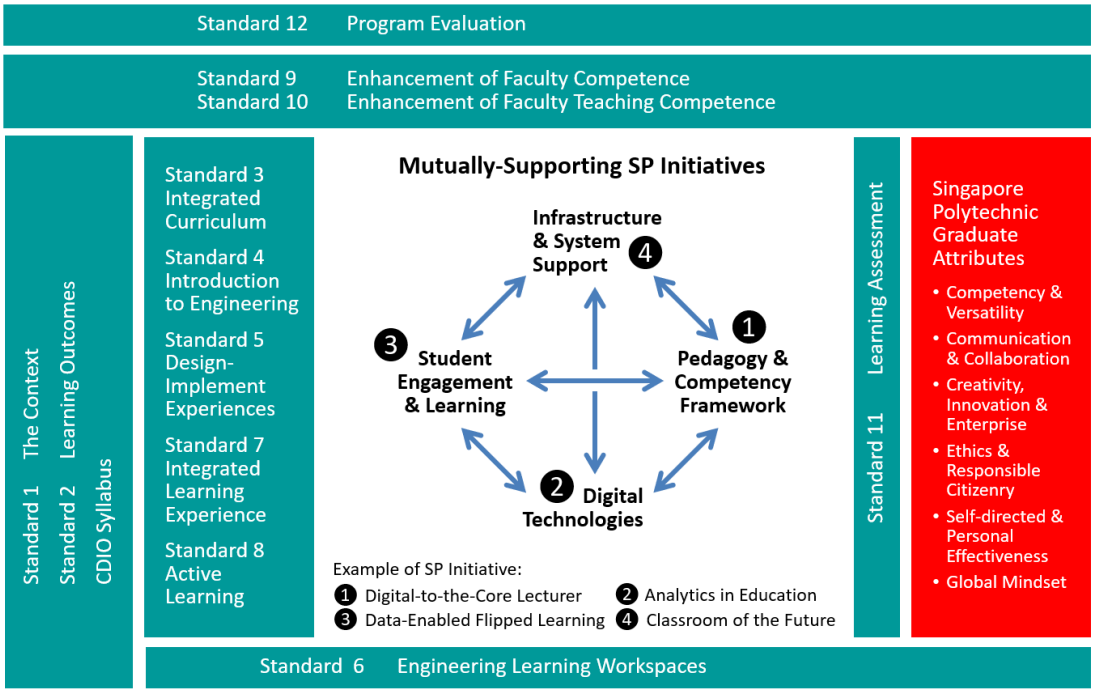

Figure 4. Convergence Model of SP Initiatives Guided by CDIO Framework

Convergence: Adding other Existing SP Initiatives to the DEFL

Continuing with the DEFL example covered earlier, this model can be used to demonstrate how other initiatives contribute to the continual improvement effort; i.e. helping faculty to "connect-the-dots" in understanding how and why each initiative is introduced. More importantly, it emphasizes the importance of continuing professional development of faculty not only in data literacy, but also in designing learning tasks that leverage of the affordances of EdTech tools. To this end, SP introduced an initiative titled "Digital-to-the-Core" (DTTC) lecturers which seeks to equip lecturers with the capability to use EdTech for teaching and learning. Another initiative introduced, is the project on "Classroom of the Future" (CotF). Collectively, DEFL, DTTC and CotF can be seen as a wider effort towards utilization of digital technologies to improve student performance – more specifically, a convergence on how DTTC and CotF supports DEFL, is shown in Figure 5.

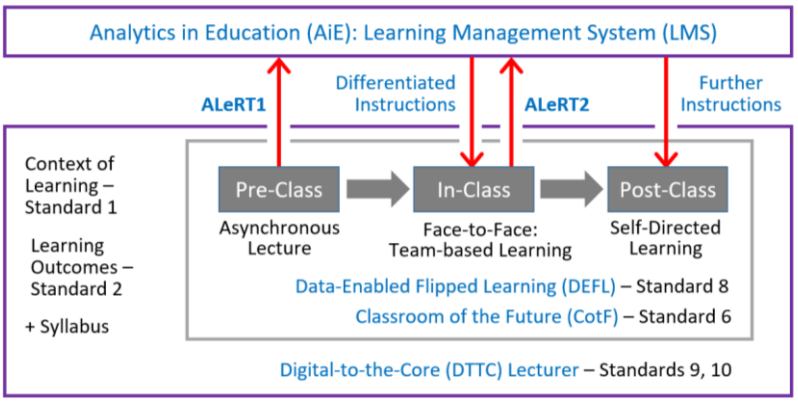

Figure 5. Convergence – How DTTC and CotF supports DEFL

DISCUSSIONS: USEFULNESS OF CONVERGENCE MODEL

While not directly related to convergence of any EdTech tools, one aspect worth mentioning of the model is that it highlighted the role of the CDIO Framework. This is significant because not all of the 43 programs in SP that implemented DEFL since 2022 has adopted CDIO. It is therefore attractive for these programs to adopt the CDIO Framework.

In addition, it is also noted that most modules that implemented flipped learning had used the online learning component to promote student learning of domain (technical) knowledge, more or less as replacement of traditional face-to-face lectures. It is therefore imperative for these modules – whether the program adopted CDIO or not – to include the integration and the development of skills and attitudes that go hand-in-hand with the application of the module's domain knowledge.

It would be relatively straight-forward for programs that adopted CDIO to introduce skills and attitudes development in DEFL. More importantly, programs that implemented DEFL but yet to adopt CDIO can benefit from guidance provided by the various CDIO Standards. These programs can integrate various skills and attitudes that support the acquisition of domain knowledge, e.g. virtual collaboration, ethical reasoning and resilience, much in the same manner for programs that have adopted CDIO.

The convergence model (Figure 4) is also broad in its "coverage" of the various SP initiatives. This means that it is scalable to accommodate other initiatives not yet introduced at the present, which may fall into any one of the 4 categories. Further convergence can be expected, when lifelong learning (which builds on SDL competencies), use of data analytics for sense-making (e.g. via data visualization), virtual collaboration becomes more important in the near future. At the regional and global levels, we already witnessed the use of big data from industrial internet of things technologies to support sustainable development. That is also the reason for SP to introduce its common core curriculum to acquaint students with skills that can be used to address sustainability issues (see for example, Cheah, Lim & Chao, 2022).

Plausible Future Convergence: Possibility of Adding Yet-to-Formulate Initiatives

The concept of DEFL has the potential to further enhance student engagement by adopting it to other learning touch points such as laboratory experiments or projects. This allows the development of skills and attitudes that in classroom settings, cannot be adequately developed due to the lack of learning context afforded by suitable engineering learning workspaces.

A hypothetical application modelled after DEFL is shown in Figure 6. Although hypothetical, it is in fact highly plausible. As noted earlier, many e-experiments have been introduced during the COVID-19 pandemic. Similarly, a large number of video recordings have been curated or assimilated during the period. In fact, a new initiative called Video Content Management System (VCMS) is already underway at the time of this paper. Many experiments requiring students' physical presence in the laboratory or workshop already require students to engage in some form of preparation prior to the laboratory or workshop sessions, and likewise require students to apply or explain how they are going to apply what they learnt from the laboratory or workshop to other scenarios. A Laboratory of the Future can also be envisioned. Hence, Figure 6 shows a fictitious initiative Evidence-based Virtual Experiment that can serve similar function as DEFL that brings together various initiatives mentioned here. Faculty competency under the DTTC initiative also needs to be further enhanced.

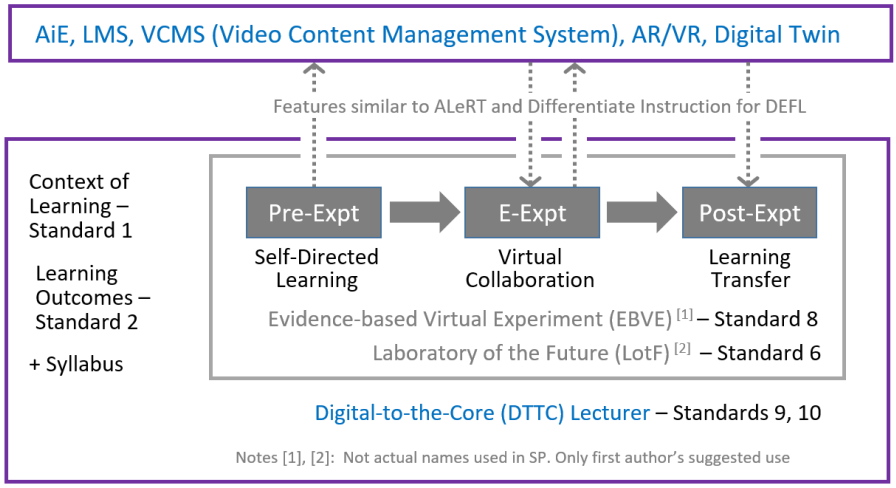

Figure 6. Convergence – Application of Hypothetical but Plausible Scenario

Convergence: Human-in-the-Loop

The discussions thus far will not be complete without referring back to the aspect most impacted by permeation of digital EdTech tools into teaching and learning: the faculty themselves, and the resulting confusion among them of the many initiatives introduced. In today's educational context, with the prevalence in use of technology, most notably artificial intelligence in the learning environment, the role of faculty as "human-in-the-loop" – a term largely credited to Monarch (2021) – in now greater than ever. The present convergence of initiatives (DEFL, differentiated instructions, and CotF), along with the proposed future convergence as described previously, are now 'merged' into the larger DTTC initiative as part of SP Initiative of Analytics in Education (AiE).

From the "human-in-the-loop" perspective, a faculty now embodied multiple roles of not only in using Digital EdTech tools in teaching and learning, but also the overseer of its ethical applications. At this point, it is worth mentioned an earlier effort of Technological Pedagogical Content Knowledge (TPACK) framework (Mishra & Koehler, 2006), which identifies three types of knowledge that an educator brings when planning to integrate technology into a lesson: technological knowledge, pedagogical knowledge, and content knowledge. While each of the 3 key domains of knowledge is important in its own right, it is their creative combination that can create effective learning experiences for students.

The convergence also prompted us to rethink the saying "pedagogy before technology" (Watson, 2001). Many faculty, who are not part of a pilot group for were tasked to lead any digital Edtech tool initiative, often felt they are playing catching up when a technology is seen as imposed on them following the pilot effort. They may not feel comfortable over the choice of such tools with respect to their specific modules; a very opposite situation of "technology before pedagogy". While not desirable, attempts to defer technology use for later consideration is also problematic, as technology use in today's context is now very much interconnected with the teaching approaches, learning scaffolds and assessment methods used. Literally leave out technology till later can result in faculty susceptible to an inadequate appreciation of complexity relating to how is interwoven into educational activity (Fawns, 2022). He advocated the use of an "entangled pedagogy" – a model that encapsulates the mutual shaping of technology, teaching methods, purposes, values and contexts (Fawns, 2022).

As the saying “We shape our tools, and thereafter our tools shape us” goes, the relationship between human and technology is two-way: Humans create inspiring and empowering technologies but also are influenced, augmented, manipulated, and even imprisoned by technology, depending on the situation and how the technology is used (Hurme & Jouhki, 2017). The human elements are intertwined with the process of using digital EdTech tools. The “human-in-the-loop” approach is important in ensuring that technology use – albeit in an “entangled” manner – remain focused on improving student learning.

Implications for Faculty Professional Development

During the COVID-19 Pandemic, the emphasis on using digital EdTech tools is to ensure continuity of education to students, despite campus closure. The rapid pivoting to online teaching and learning during this period much curriculum had being digitized and transmitted via technology rather than transformed by it (Cowling et al, 2022). Such a pivot also meant that few faculty were sufficiently prepared for learning environment centered around technology (Cowling et al, 2022).

We therefore need to improve such online offerings post-COVID. Some offerings during the period of campus closure are temporary legacies that require undoing, while good practices need to be identified, retained and improved upon (Crawford, 2021). Examples are the largely PDF versions of the lecture notes, PowerPoint slides (without or with minimal narratives). Kehrwald & Parker (2019) referred to the act of putting learning materials online that are largely static as “shoveling”, and the digitized documents as “shovelware”. Furthermore, the growing availability and capability of digital EdTech tools will allow ever greater exploration of teaching and learning in new ways; which can even change the way technology is used. Generative AI is a case in point. Effective transition to the digital platform requires careful considerations of the cognitive, affective and behavioral changes that formed a part of the transition (Cowling et al, 2022). Adapting digital technologies to teaching and learning cannot be a one-size-fit-all approach that focused largely on technical knowledge. Of importance is the alignment between the digital EdTech tools used with the pedagogical and technical knowledge (Børte & Lillejord, 2024), where the choice of pedagogy or combination of pedagogies will address all the 3 aspects of learning: cognitive, affective and behavioral changes.

The SP DTTC Initiative is envisioned to serve such a need. In our context, a DTTC lecturer is one who goes beyond just “teaching” or “lecturing”, in using technological tools to draw insights via data analytics, to designing and delivering effective learning interventions that maximize. In its current form, it is still very task-oriented, focusing of competencies of lecturers in using digital technologies including learning analytics in the design of EdTech-enabled learning experiences. The development of the DTTC Framework is still an on-going process, as it has to be continually reviewed, revised, and updated to accommodate emerging new opportunities and/or challenges. A case in point is the ethical use of Generative AI (GenAI) in teaching and learning – yet another convergence! Recently, UNESCO just released its guidance document of AI framework for teachers (UNESCO, 2024) which will necessitate a new round of review.

The convergence model can serve as a basis for designing faculty professional development programs under the DTTC banner. This has the advantage of empirically testing the model. The goal of education is always to maximize student learning outcomes. Efforts need to be directed towards preparing faculty to leverage on affordances from digital EdTech tools to introduce educational innovations, guided by the CDIO Framework.

CONCLUSIONS

This paper showed that the CDIO Framework, which demonstrated its resiliency over the years, remains to be relevant with the DEFL Model. This is perhaps hardly surprising, since all SP initiatives are solidly grounded in strong teaching and learning foundations; which is the same approach that SP used in its adoption of CDIO. This paper suggested that the CDIO Framework can be used to reconcile various technology-based initiatives introduced in an institution, helping SP lecturers make sense of the mutual dependency between technologies and pedagogies used, on attainment of desired student learning outcomes. A convergence model is suggested in this paper, where it can be scaled to accommodate other future initiatives to continue to "connect the dots" for lecturers.

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