SINGAPORE UNIVERSITY OF TECHNOLOGY AND DESIGN

A TRENDS AND FORESIGHT REPORT ON CYBER-PHYSICAL LEARNING

LAUNCHED AT THE

Cyber-Physical Learning Alliance Summit (CPLAS 2024) | Mexico

Dear readers

It is a great pleasure to launch this "Trends and Foresight Report on Cyber-Physical Learning at the first Cyber-Physical Learning Alliance Summit (CPLAS 2024), in Mexico.

This report is a follow-up to the previous "Whitepaper on Cyber-Physical Learning (CPL)" launched at the National Technology Enhanced Learning Conference in October 2022, and aims to capture the trends, the latest developments in CPL at the Singapore University of Technology and Design (SUTD), partner universities and institutions and envisions the future of learning in higher education.

This report is put together by *Learning Sciences Lab* of the SUTD's Office of Digital Learning (ODL) in collaboration with various partners and stakeholders. I thank all the authors and contributors for coming together to put this together. My special thanks to Tecnológico de Monterrey from Mexico, The Hong Kong University of Science and Technology from Hong Kong, and our Singapore partner institutions: Institute for Adult Learning (IAL), Singapore Institute of Technology (SIT), Singapore University of Social Sciences (SUSS), Ngee Ann Polytechnic (NP), Singapore Polytechnic (SP), Nanyang Academy of Fine Arts (NAFA) and LASALLE College of the Arts for their collaboration and contribution in making this possible. My thanks to our SUTD contributors and ODL campusX team for their tireless efforts and work in advancing CPL. I would also like to thank our collaborators from the wider educational ecosystem.

We hope that you find this Trends and Foresight Report on Cyber-Physical Learning to be informative and useful for your institutional endeavours in digital transformation and we invite you to collaborate with us on our SUTD campusX initiatives and programmes.

Yours sincerely
Professor Pey Kin Leong
Associate Provost (Digital Learning), Office of Digital Learning
Singapore University of Technology and Design

Edited by

Dr Nachamma Sockalingam
Program Director, Learning Sciences, Office of Digital Learning
Singapore University of Technology and Design

With

Professor Pey Kin Leong
Associate Provost (Digital Learning), Office of Digital Learning
Singapore University of Technology and Design

Citation of report

Sockalingam, N. & Pey, K. L. (2024). A Trends and Foresight Report on Cyber-Physical Learning. Singapore University of Technology and Design. URL.

Citation of chapters/case studies

Chapter Author Last Name, First Initial. Middle Initial. (Year Published). Title of chapter in sentence case. In Editor First Initial, Editor Second Initial, Editor Last Name (Ed.), Title of book in sentence case (Edition, Volume, Page No.). Publisher Name. URL or DOI.

ISBN

978-981-18-9183-0

TABLE OF CONTENTS

TABLE OF CONTENTS

"My hopes for Cyber-Physical Learning are three-fold.

First, to deliver on the promise of digital technology and e-pedagogy, and move beyond the teaching and learning practices in place before COVID-19.

Second, that we recognize potential pitfalls of Cyber-Physical Learning, especially in terms of ethics.

Third, that we push the boundaries of partnerships in Cyber-Physical Learning."

Mr. Lai Chung Han
Permanent Secretary, Ministry of Education
@ The Singapore Cyber-Physical Learning Alliance Launch
Singapore University of Technology and Design
29 Nov 2023

1. EDITORIAL NOTE

Nachamma Sockalingam

The COVID-19 pandemic has had a profound impact on education in general (Educause Horizon Report, 2023). It has reshaped and redefined how higher education is delivered around the world, in terms of growth and transformation, despite constraints and collapses (Figure 1.1). Online and blended learning have become prevalent worldwide. There is an increased demand for learning platforms, enhancement of technological tools, globalization of education, push for life-long, work-oriented education, reskilling and upskilling, and opportunities to learn anyplace, anytime, anywhere. Nevertheless, there are also challenges.

Growth

- Online/Hybrid Learning
- Institutional digital transformation

Transformation

- No code/Low-cost tech tools
- Accessibility
- Collaboration

Constraints

- Geo-political factors
- Cultural factors
- Economical factors

Collapses

- Mental well being
- Human-human interaction and communication
- Meta-living

Figure 1.1. Future of Learning (Credit: Nachamma Sockalingam, 2023; Adapted from Educause 2023 Report)

The pre-existing digital divide and growing concerns about social connectivity, mental wellness, and health are becoming more pronounced. There are also questions about the quality of education and the possibilities of alternative assessments.

Overall, it is obvious that digital learning is the way forward and the emphasis on digital literacy of students and the professional development of teachers are unquestionable. One underrepresented aspect is data privacy and security in higher education. The ever-growing prevalence of online/blended learning raises concerns about the usage of sensitive student data and data privacy, emphasizing a growing demand for ethical guidelines, data protection, and cybersecurity in education.

Digital Learning is the way forward

With the transforming higher educational landscape, there is a need for periodical stocktaking, market research study, and benchmarking of educational practices to continue to evolve. It is to this end that SUTD published the first whitepaper on Cyber-Physical Learning (CPL), which focused on the challenges and need for CPL, the strategy and vision of CPL at SUTD, and examples of CPL from various institutions. The report concluded with a call for collaboration and partnerships in CPL.

This issue of "Trends and Foresight" report builds on the foundation laid by the first whitepaper and captures the developments since then by looking at the trends of teaching and learning in higher education over the past ten years in the educational research literature and examines the developments of CPL at the various institutions over the year in terms of Science, Technology, and Ethics of CPL. The report also seeks to understand various educator's perspectives on the future of learning. The main aim of this Trends and Foresight report is to take a timeline journey and scan the landscape of CPL to inform us of the trends and foresight.

One notable contribution of this report is the numerous innovative projects and user case studies from various local and international institutions. We have a total of 8 case studies from SUTD and numerous others from 7 other institutions. These examples are in various stages of development, implementation, and evaluation. Most reports on digital learning/CPL tend to offer examples and case studies from a Western perspective, and this report attempts to address this to some extent by providing various innovative efforts by several Asian higher educational institutions, spanning different disciplines, from the Arts to Sciences.

An important value-add in this report is the primer on the ethics of CPL. Although most institutions invest much time and effort in the advancement of Technology and Science of CPL in digital learning, the Ethics of CPL is often overlooked or not prioritized. However, this is an important aspect of teaching and learning, especially CPL. We recognize this crucial missing link and would like to draw the attention of readers to the Ethics of CPL.

It is said that it takes a village to raise a child. Likewise, it takes the CPL Alliance (CPLA) network to inspire and advance CPL. We hope this publication brings together the CPLA network and serves as a useful platform to showcase the members' efforts and endeavours in digital learning.

We aim to foster a community of CPL practitioners in higher education so that we can share and learn from each other.

We hope that you find this report inspiring and helps you in advancing digital learning and CPL at your institutions, foster new ideas, and forge partnerships so that there can be inter-institutional educational collaborations and research. Even though this report is primarily meant for institutions of higher education, it will be relevant for primary, secondary, pre-tertiary, and continuous learning institutions, and we invite everyone in the educational ecosystem to explore.

Our objective is also that the report sheds light on areas of expertise amongst partners and collaborators and aids the connection between experts and practitioners. Further collaborations will help us to advance CPL and disseminate the effective and efficient use of CPL in higher education.

We invite interested institutions and educators to join the CPLA network and contribute to this meaningful endeavour.

References

Sockalingam, N., Lo, K., Kurniawan, O., Herremans, D., Raghunath, N., Cancion, H. G, C., Kejun, H., Leong, H., Tan, J., Nizharzharudin, K., & Pey, K. L. (2022). *A white paper on cyber-physical learning*. Singapore University of Technology and Design. Retrieved from: https://www.sutd.edu.sg/SUTD/media/SUTD/LSL_WhitePaper_Cyber-physical-Campus-Higher-Education.pdf

Pelletier, K., Robert, J., Muscanell, N., McCormack, M., Reeves, J., Arbino, N., Grajek, S., Birdwell, T., Liu, D., Mandernach, J., Moore, A., Porcaro, A., Rutledge, R., & Zimmern, J., *2023 EDUCAUSE Horizon Report, Teaching and learning edition.* (Boulder, CO: EDUCAUSE, 2023).

2. BEGINNINGS OF CYBER-PHYSICAL LEARNING AT SUTD

Nachamma Sockalingam, Kenneth Lo, Pey Kin Leong

SUTD introduced the concept of Cyber-physical Learning (CPL) in late 2021 as an interest group. CPL is where both remote cyber and face-to-face physical students learn and interact effectively, seamlessly, and synchronously in the same lesson, by using technologies such as immersive technologies (e.g., Augmented/Virtual/Mixed Reality, metaverse learning, gamification), telepresence robotics, learning analytics, and personalized learning (Sockalingam *et. al.*, 2022).

As the name of our university, Singapore University of Technology and Design, suggests, technology and digital learning have been important elements of SUTD's education from the start. All our undergraduate students are introduced to programming, and our curriculum emphasizes technology-enhanced education, design thinking and innovation. However, the primary focus here is teaching *about* technology. In contrast, CPL focuses on *how we use* technology as a tool to teach and learn.

Educational Development at SUTD

Educational development refers to instruction (curriculum), instructor, student, organization, and community development in teaching and learning to promote excellence (Sockalingam, 2018, 2019). Educational Development at SUTD can be seen to be in 3 phases.

SUTD was founded in collaboration with the Massachusetts Institute of Technology (MIT) in 2012. In the initial seven years of the foundational period with MIT, much of the faculty educational development was conducted by MIT. This was important to ascertain that SUTD used similar "building blocks" as MIT in shaping its active, interactive learning pedagogy (Graham, 2018).

In the next phase of educational development, SUTD's Office of Education (OED) formed the Learning Sciences Lab (LSL) to drive and deliver educational development programs (Sockalingam, 2018; Graham, 2018). LSL's vision was to enhance the overall quality of teaching through its innovative faculty educational development initiatives. Some examples of key initiatives included introducing the Educational Leadership Programme with Advance Higher Education (United Kingdom), the Scholarship of Teaching and Learning Programme, Pedagogy Innovation Research and Grant Support, and Pedagogy Innovation Publications in the form of monthly talks, annual Pedagogy Day conferences, and annual pedagogical magazine, EduSCAPES. These faculty educational development initiatives aimed to be holistic and addressed several aspects of teaching and learning, particularly in the instructors, community, and organizational aspects (Sockalingam & Pey, 2018). These programs were well-received. achieved good participation and feedback from faculty members and stakeholders, and had a lasting positive impact, despite being run by a small team and limited resources.

The onset of COVID-19 suggested that we need to change the strategies at SUTD and prepare for future education. This marked the third phase of development at SUTD. Given that there was an urgent, and high-priority need to embrace digital learning for future education, and support the transformation of Digital Learning at SUTD, SUTD's Office of Provost radically restructured the Office of Education and initiated the Office of Digital Learning (ODL), to drive the Digital Learning Transformation at SUTD in 2022 (Sockalingam *et. al.*, 2022).

Digital Transformation at SUTD: SUTD campusX

The Office of Digital Learning's mission is to enable innovative digital learning pedagogies, technologies, and services for the continuous education of lifelong tertiary learners. ODL aims to continuously develop new digital learning platforms, tools, and practices that push the boundaries of future learning with improved fun and joy in group-based teaching and learning. Such new educational platforms, technologies, and models will set a new benchmark and standard for personalized learning for both individual and group-based learning. SUTD aims to achieve this through the innovative CPL approach envisioned as the SUTD campusX initiative.

The COVID-19 pandemic made us realize that technology is going to be a "game-changer" in higher education. While SUTD continued with its regular track of undergraduate curricula and teaching under the purview of the Office of Education, the Office of Digital Learning sets out to innovate and create a new set of teaching and learning approaches and technology tools.

SUTD envisioned CPL as the digital transformation approach. We define CPL to be more holistic and broader in nature than blended/hybrid learning. CPL includes additional aspects of the educational ecosystem such as information systems architecture, 5G network, cloud security, technology, pedagogy, learning analytics, learning mode, instructional materials, assessment, student wellness, data privacy, and security, etc. Ethics of cyber-physical learning is also included as one of its key pillars.

The objective of CPL is to create seamless and immersive learning such that there is equity in the way physical and cyber students experience a synchronous hybrid learning class. CPL encompasses student-to-student and student-to-instructor interactions in both physical and online modes.

Common challenges in such interactions could be that cyber students are inadvertently neglected, or that physical students do not get to experience an immersive virtual simulation, or that the instructor is not able to give equal and adequate attention to both physical and cyber students. In sum, the learner experience and therefore outcomes of the cyber students and physical students (and instructors) may be impacted, and this is strongly dependent on the course content and materials, especially when using active and interactive pedagogies. The question is how to ensure that all stakeholders (physical/cyber students and physical/cyber instructors) can work together effectively and efficiently, and experience enhanced digital learning. The purpose is also to enhance inclusivity and equanimity.

To this end, SUTD kickstarted the SUTD campusX initiative in late 2021 to leverage the latest digital learning pedagogies and cutting-edge technology to advance itself as a future-ready and frontier university to prepare lifelong tertiary learners and innovators. This is achieved through the latest and best-practice pedagogies and technologies such as learning analytics, gamification, robots, artificial intelligence, augmented reality, and virtual reality to provide human and design-centered education experiences in the form of personalized, immersive, collaborative, and socially connected learning.

Human-Centric Technology of Learning

A group of 78 faculty and staff members is currently involved in SUTD campusX initiative, in designing, developing, and testing the efficacy of new technologies and pedagogies for cyber-physical teaching and learning. SUTD campusX's vision is to pioneer a fun, safe, and inclusive educational experience at SUTD, where lifelong tertiary learners can leverage innovative cyber-physical techno-pedagogies to personalize their learning journeys and achieve optimal learning outcomes.

From consultations with students, adult learners, instructors, and SUTD leadership team), SUTD campusX has identified three important themes focusing on user experience and learning outcomes. These are:

- Learning Intimacy/Learning Socialization: How can students (cyber and physical) learn better in a personalized manner?
- "Anywhere, Anytime, Anyone" Learning: How can students have various options to learn from any distance?
- Safeguarding Governance: How can students learn in a fun, safe, and inclusive environment?

We address these three themes through "Learning Science" and "Education Technology".

Learning science involves educational pedagogies, teaching and learning principles and methods, including learning analytics (both real- and post-time); while education technology involves applications, software, hardware tools, methodologies, and models that provide seamless and immersive learning experiences (such as virtual/augmented reality, gamification, robotics, learning analytics, and artificial intelligence). The two enablers ("Learning Science" and "Education Technology") interact through various campusX programs and initiatives (e.g., partnerships, research, and innovation projects), and it is through these interactions that outputs contributing to the development of the key infrastructures and platform of campusX are generated.

One such output is knowledge, expertise, and competency to create a campusX pedagogy/andragogy known as the Science of Cyber-Physical Learning (SoCPL), that is suited to the human- and design-centric curriculum of SUTD, termed SUTD Technology of Cyber-Physical Learning (ToCPL). Ethics of cyber-physical Learning (EoCPL) involves comprehension and the capability to discern appropriate rules and guidelines to provide a fun, safe, and inclusive learning environment. Thus, SUTD's blend of Techno-Pedagogy has three important dimensions (Figure 2.1). Readers can find out more about the background context of CPL at SUTD in the first white paper (Sockalingam *et. al.*, 2022).

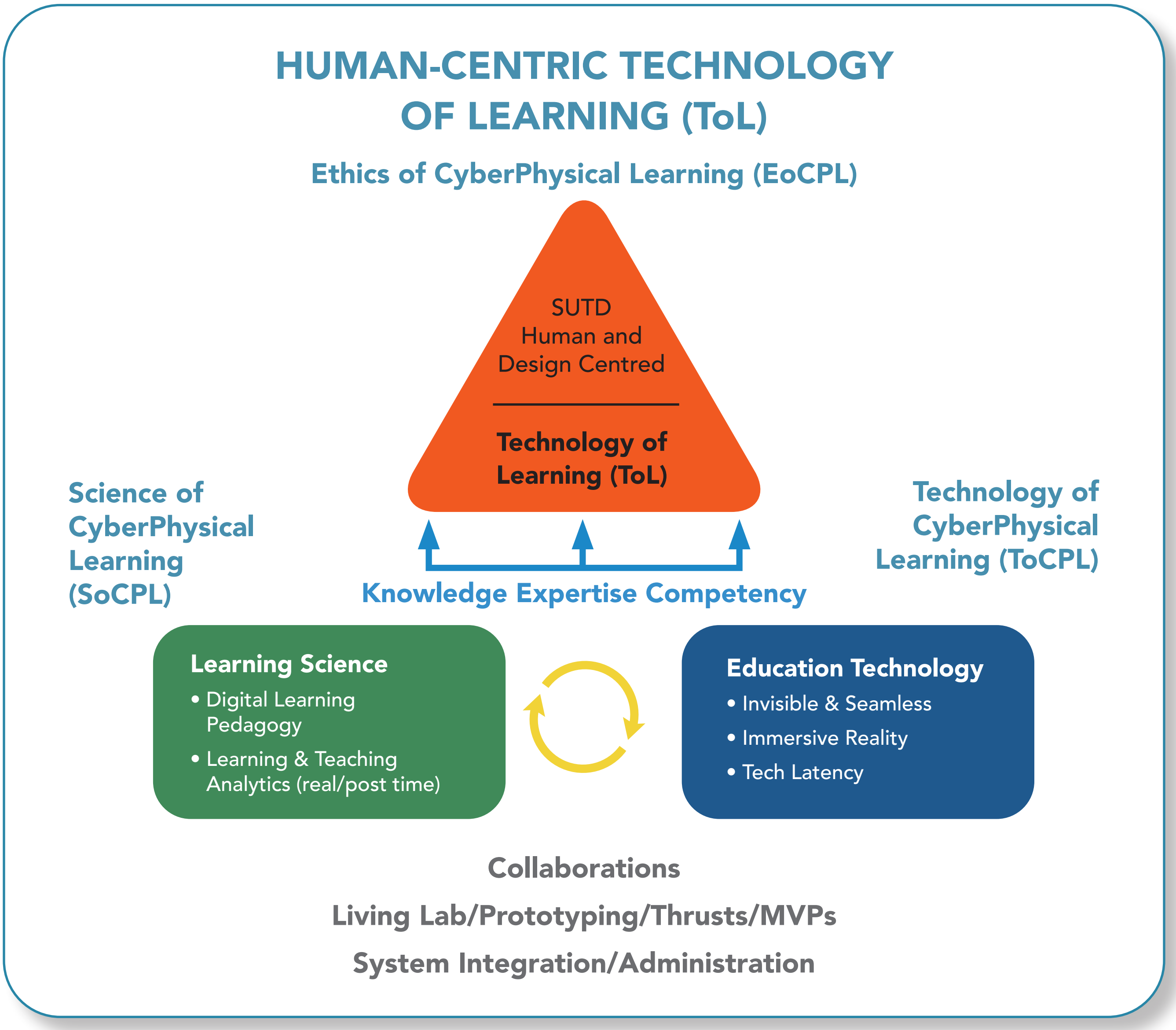


Figure 2.1. SUTD campusX - Human-Centric Technology of Learning (Credit: Kenneth Lo, Judy Teo, Pey Kin Leong, 2022)

References

Graham, R. (2018). *The global state of the art in engineering education*. Massachusetts Institute of Technology (MIT) Report, Massachusetts, USA.

Sockalingam, N. (2018). Educational development at SUTD. In *EduSCAPES 2018*. https://www.sutd.edu.sg/SUTD/media/SUTD/2018-SUTD-Pedagogy-Newsletter_1.pdf

Sockalingam, N., & Pey, K. L, (2019). Benchmarking educational development centres in Singapore's universities. In *EduSCAPES 2019*. https://www.sutd.edu.sg/SUTD/media/SUTD/Eduscapes-2019.pdf

Sockalingam, N., Lo, K., Kurniawan, O., Herremans, D., Raghunath, N., Cancion, H. G, C., Kejun, H., Leong, H., Tan, J., Nizharzharudin, K., & Pey, K. L. (2022). *A white paper on cyber-physical learning*. Singapore University of Technology and Design. Retrieved from: https://www.sutd.edu.sg/SUTD/media/SUTD/LSL_WhitePaper_Cyber-physical-Campus-Higher-Education.pdf

3. STRATEGY AND VISION OF CYBER-PHYSICAL LEARNING AT SUTD

Pey Kin Leong, Kenneth Lo, Nachamma Sockalingam

The COVID-19 pandemic has made us realize that higher education must focus beyond the mode of delivery and that we need to rethink and redefine every aspect of how we operate as institutions for the new age of teaching and learning. This is even more prominent when we use learner-centered pedagogies such as that at SUTD where teaching and learning are in teams, using interdisciplinary learning curricula, and driven by hands-on, project-based learning pedagogies (Sockalingam, Pey, and Lim, 2021). While institutions that use lectures as the primary pedagogy can swiftly adopt online/blended learning by using asynchronous lectures and flipped learning, we realized that experiential and project-based learning are not well-supported by the existing technologies to be conducted online.

Many collaborative activities tend to be restricted when conducted online unlike what is possible in face-to-face lessons. For instance, a jigsaw activity (https://www.jigsaw.org/) requires students to teach in teams and move from team to team to discuss. Even though Zoom offers breakout rooms, we find that this activity is limited online to the teachers since the teacher does not get the overview of the entire class as well as the team engagement one shot as would have been possible in a face-to-face class. When the teacher is in a particular breakout room, he/she may not know the engagement in the other breakout rooms - which would have been available as peripheral vision otherwise (Sockalingam & Liu, 2020). Hence, it is important to innovate new pedagogies as well as technologies that cater to both online and face-to-face learning. In addition, technological developments such as Generative Artificial Intelligence, and Immersive technologies offer opportunities for transforming learning.

In the last 20 months, we undertook a concerted effort to set up a holistic physical and technological infrastructure, policies and practices, frameworks and models, partnerships and collaborations to inform, guide, shape, and contribute to our CPL approach and SUTD campusX initiative. Our efforts are strategic and operational (Figures 3.1 and 3.2).

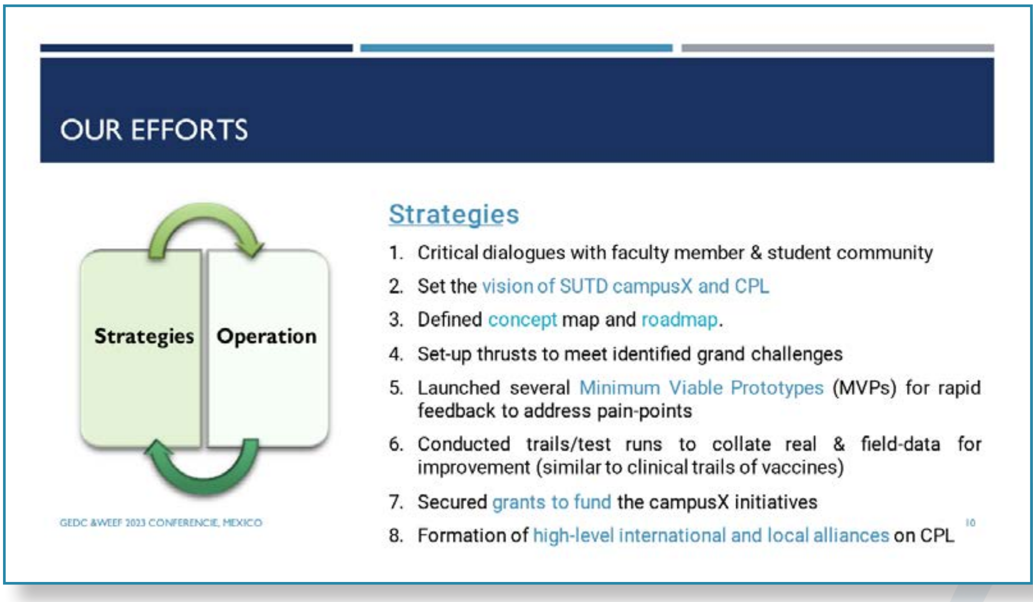


Figure 3.1. SUTD campusX Strategies (Credit: Nachamma Sockalingam, Kenneth Lo, Pey Kin Leong, 2023)

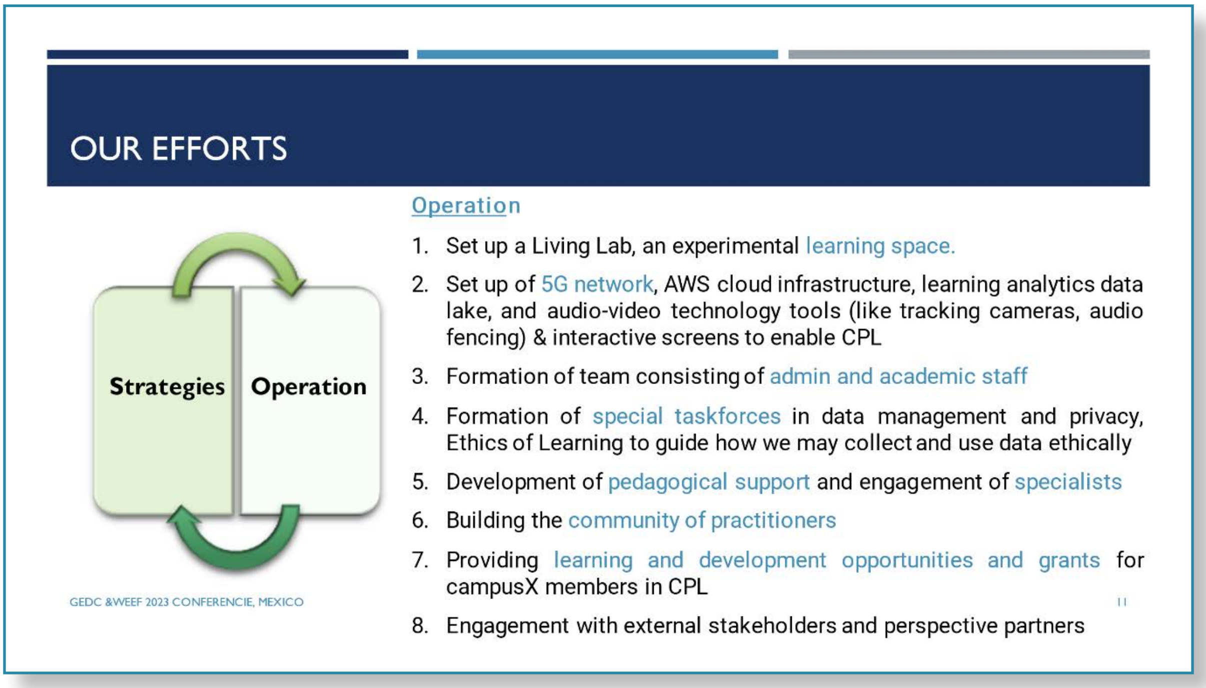


Figure 3.2. SUTD campusX Operations (Credit: Nachamma Sockalingam, Kenneth Lo, Pey Kin Leong, 2023)

Six-Thrusts of SUTD campusX

Given there are various aspects to focus on in digital learning, SUTD undertook several user studies/focus groups to define its needs. In this process, we have identified a total of six thrusts under SUTD campusX as our immediate priorities and they are:

1. People-centric learning and design
2. Immersive realities learning
3. Metaverse and blockchain for learning
4. Socially interactive educational robotics
5. Advanced learning analytics, especially real-time analytics
6. Enhanced learning through innovative technology

Over the past 12 months, the pursuit of CPL at SUTD has been carried out extensively by about 78 faculty and staff members under the SUTD campusX programme. When we first started, we had just about 40 members. Today, we also have an extensive network of alliance members for both local and international institutions. Cases studies from our partner institutions are presented in a later chapter.

Agile Approach

In contrast to the typical academic-oriented research approach towards teaching and learning, we embarked on a more agile educational technology design and development process to innovate technologies that are necessary for hands-on, experiential, and student-centric learning. We call this P2P; "Proof of Concept to Practice" approach (Sockalingam, Lo, Pey, 2023).

In this approach, our campusX team members use an iterative and agile design-thinking approach (Figure 3.3) to find out the needs and pain points of users, ideate with stakeholders, especially the users, to design, develop, test, evaluate, and iteratively fine-tune in phases while scaling up progressively to ensure sustainability. SUTD campusX members create Minimum Viable Projects (MVPs) that undergo a few rounds of iterations and critics by various stakeholders including the SUTD Entrepreneurship Centre. In our experience, this approach has been effective in getting stakeholder participation and buy-in as well as ensuring there is a larger application beyond SUTD.

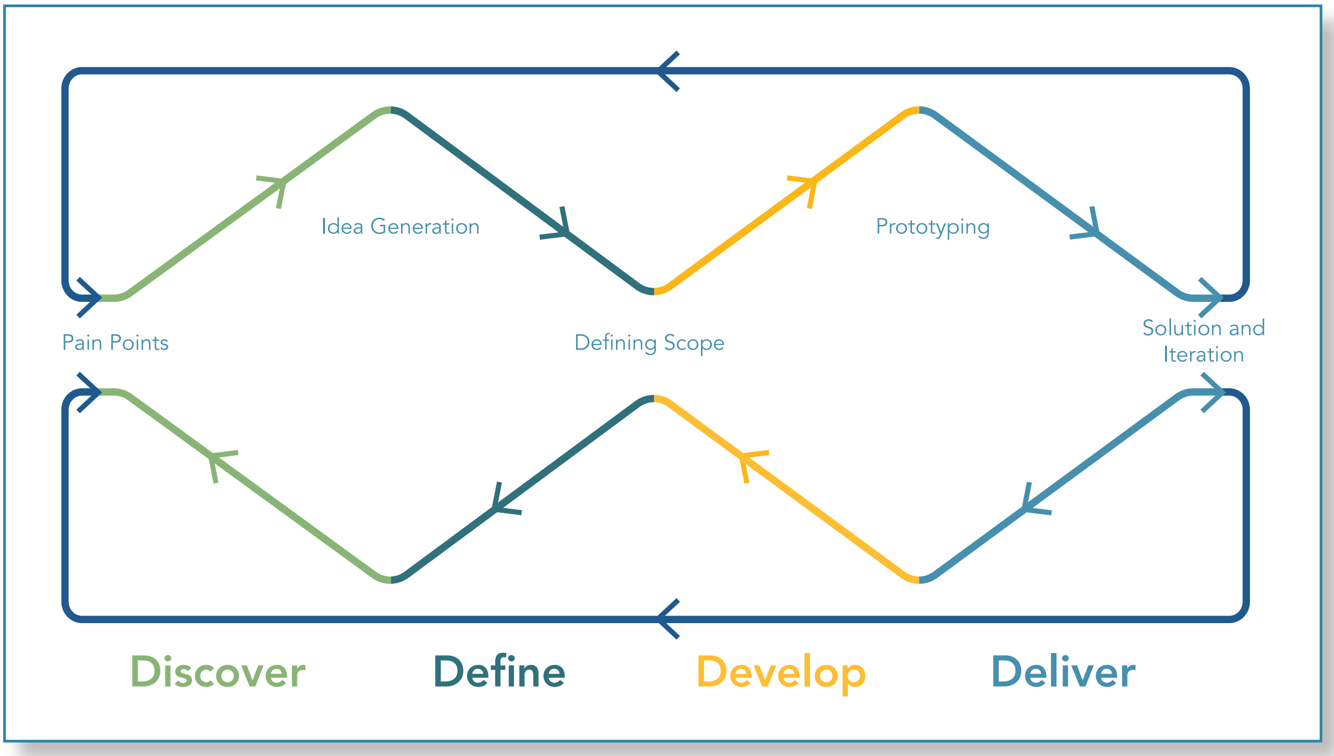


Figure 3.3. Design Thinking Approach for Minimum Viable Product Development (Credit: Nachamma Sockalingam, 2023)

Minimum Viable Products

Currently, we have used the MVP approach to generate and design several CPL solutions. These include a Telepresence Learning System, a Digital Archive platform to store 3D scans and documents of design artifacts, a generative-AI GPTLearn platform that aids learning using prompt engineering, a web-based learning analytics tracking system to provide awareness of student learning using a student dashboard. We are also setting up audio fencing capabilities in classrooms for more authentic and genuine cyber learning by cutting out the noise from sound, and this will serve as the baseline CPL classrooms at SUTD. You can find more details of the projects in the next section.

These projects are all in different phases of development. At present, we are in the second iteration of the TLS. Miniaturization of the TLS has been carried out in collaboration with SIMTech of A*STAR to ensure the set-up is portable and flexible for trial runs on Pre-Employment Training (PET) and Continuing Education and Training (CET) classes. Further finetuning for the next version of the TLS will incorporate enhanced User interface/ User Experience (UI/UX), and feedback from users. We plan to have a few rounds of iterative and progressive fine-tuning and upgrading.

SUTD campusX has been fortunate to provide demonstrations and showcases of the innovative learning technologies and practices developed at SUTD to many local and international visitors and partners to seek their feedback. Such feedback and advice from the external parties further help us to shape and sharpen our approach. In particular, the SUTD-developed TLS and Skill Tree have garnered much attention and interest due to their usability and application for both full-time and part-timer (such as work-and-learn) learners, and adaptability for the Future of Learning.

Most of our partners are keen to know about the trial results followed by how to adopt it in actual classes, especially for credit-bearing modules as grades have an impact on students' future and raise concerns about fairness in "assessments or quizzes" and this can potentially affect students' mental wellbeing. As such, a more human-centric and design-thinking approach is needed to address these concerns.

This is where "People Centric Learning and Design" Thrust comes in, to provide the instruments to measure student satisfaction and learning. Together with the robust data management framework by the SUTD Data Protection Office (DPO), campusX is now set to pilot studies in the next 2-3 terms before launching in our Freshmore classes in AY26. In summary, SUTD campusX is now fully prepared to launch a series of trial runs by working with faculty and students under the six Thrusts.

Measures of Success and Achievements

SUTD campusX has adopted a university-wide, yet, user-centric, bottom-up approach to addressing the critical pain points of instructors and learners during synchronous CPL. The success of such programmes will very much depend on the degree of adoption of various campusX innovative learning practices and technologies, and their learning experiences and learning outcomes. The first of these is adoption.

Currently, a series of trial runs have been planned and are being rolled out to the SUTD Freshmore classes starting September 2023 since these classes involve the entire cohort of students. Progressively, there will be trials in pillar years. The current roll-out includes

1. A 1D-Design project using AR catapult to simulate the projectile governed by Newton's laws of motion of the Physical World of Term 1,
2. A pilot run of the "Skill tree" developed under Thrust 3 for more than 170 newly matriculated students to track their inside- and outside-classroom skill development over the next 3 terms, and how such new skills can help students to better plan their future study in the pillar years to further enrich existing skills that they are competent in and new skills that they are looking for,
3. 3D documentation of students' design artifacts (both physical and digital) in virtual world for future deployment in teaching and portfolio enrichment, and real-time tracking of student study.

Such an approach of collating real-time and evidence-based field data is akin to clinical trials of critical and "undeveloped" drugs in the medical world for urgent medical deployment such as COVID-19 vaccines. We aim to have a fast turnaround time to improve the teaching practices to benefit the CPL pedagogy/andragogy as much as possible while detailed applied research can still be carried out later with partners such as NIE, IAL and international Alliance partners to study the complete impact quantitatively.

References

Sockalingam, N., & Liu, J. (2020). Designing learning experiences for online teaching and Learning. In *EduSCAPES 2020*. https://www.sutd.edu.sg/SUTD/media/SUTD/Eduscapes-2020.pdf

Sockalingam, N., Pey, K.L., & Lim, S.C. (2021). Transforming engineering education: a case study of Singapore University of Technology and Design (SUTD). *Special Issue of Advances in Engineering Education*. https://advances.asee.org/transforming-engineering-education-a-case-study-of-singapore-university-of-technology-and-design-sutd1/

Sockalingam, N., Lo, K., Kurniawan, O., Herremans, D., Raghunath, N., Cancion, H. G, C., Kejun, H., Leong, H., Tan, J., Nizharzharudin, K., & Pey, K. L. (2022). *A white paper on cyber-physical learning*. Singapore University of Technology and Design. Retrieved from: https://www.sutd.edu.sg/SUTD/media/SUTD/LSL_WhitePaper_Cyber-physical-Campus-Higher-Education.pdf

Sockalingam, N., Lo, K., & Pey. K.L. (2023). SUTD campusX: An institutional digital transformation approach to higher education. Presented at the *World Engineering Education Forum (WEEF) and Global Engineering Dean´s Council*, Mexico.

4. PAST TRENDS OF CYBER-PHYSICAL LEARNING IN THE LITERATURE

Nachamma Sockalingam, Zoe Yeo Lock Yan, Ella Lee Miu Yee, Joel Teo

When embarking on innovation and development projects, it is useful to refer to past and existing literature, so that we can define the scope of work, learn from past findings, and envision the way ahead.

The internet is filled with a plethora of information on digital learning. In the recent Horizon Report 2023 (Pelletier. *et. al.*, 2023) technology experts and educators were asked to describe the key technologies and practices they believe to have a significant impact on the future of postsecondary teaching and learning. Following a rigorous selection and voting process, the following six items were identified as key technologies and practices (in no order of importance):

1. AI-Enabled Applications for Predictive, Personal Learning
2. Generative AI
3. Blurring the Boundaries between Learning Modalities
4. HyFlex (i.e., students enrolled in a course can participate on-site, synchronously online, or asynchronously online as preferred)
5. Micro-credentials
6. Supporting Students' Sense of Belonging and Connectedness

Many other trend reports on the internet by various stakeholders are in general alignment with this and cite technologies such as Artificial Intelligence, Virtual and Augmented Reality, Digital Twins, Metaverse, Internet of Things, Blockchain Technology, Cloud Computing, Gamification, and Chatbots as the technologies to look out for. These reports and citations are useful indeed. However, these tend to focus solely on technology and adopt a more futuristic perspective. They do not shed light on the trends and developments in Cyber-Physical Learning (CPL). In addition, these reports mostly represent the Western perspective. There is a gap in representing the Asian context, and this report addresses some aspects of that.

Most trend reports on education technology tend to focus solely on technology and adopt a more futuristic perspective, with a Western focus

One of the aims of this trends and foresight report is to present the trends in CPL at SUTD, partner universities, and beyond ensuring a wider representation from Asia. In this chapter, we present the trends from the literature, focusing on educational technology in CPL.

Defining Cyber-Physical Learning (CPL)

Cyber-Physical Learning is a term coined by the Singapore University of Technology and Design (SUTD) in 2021 (Sockalingam *et. al.*, 2022). CPL is where both remote cyber students and face-to-face physical students can learn and interact effectively, seamlessly, and synchronously in the same lesson, learning the same materials, by using technologies such as immersive technologies (e.g., Augmented Reality (AR)/ Virtual Reality (VR)/ Mixed Reality (MR), metaverse learning, gamification), telepresence robotics, learning analytics, and personalized learning.

CPL can be seen as a holistic summation of digital processes and systems to transform higher education institutions. This includes the entire ecosystem of teaching and learning, such as the physical learning environment, Information Technology (IT) infrastructure, Teaching and Learning solutions produced by the interaction of learning sciences and educational technology, and ethical guidelines on the use of CPL. The concept and definition of CPL is relatively new.

A search on the keyword "Cyber-Physical Learning" in the Web of Science (WOS)[2] resulted in very limited citations - only 6 citations were found to be using the term "Cyber-Physical Learning" (Table 4.1).

Year	Number of articles
2016	1
2017	1
2018	1
2022	1
2023	2

Table 4.1. Web Of Science Search on the term "Cyber-Physical Learning"

Data from Web of Science, provided by Clarivate. Web of Science and Clarivate are trademarks of their respective owners and used herein with permission.

The Web of Science was chosen for its annual curation of high-impact factor publications, representing top-quality academic content by topics. Additionally, Web of Science is accessible to us at SUTD. However, only indexed articles can be found in Web of Science. This means that even publications such as this Trends and Foresight paper, and the White Paper on Cyber-Physical Learning (Sockalingam *et. al.*, 2022), and other such non-indexed information may not be found in Web of Science. Still, we decided to continue with Web of Science since it is the go-to database for peer-reviewed, evidence-based articles on CPL. The search results are suggestive that CPL is indeed a new concept and terminology.

A closer examination of the various articles revealed that their definition of CPL was different from SUTD's. These papers tend to refer to CPL as learning using Cyber-Physical Systems (CPS). CPSs are technologically interactive networks of physical and computer-based components that are highly interconnected and integrated. CPS systems are prevalent in fabrication and manufacturing-linked projects. For instance, Mujtaba and Malik (2023) refer to "flipped classroom as another enhanced form of the hybrid method of cyber-physical learning, where *cyber networks are exploited to deliver learning instructions outside of class*".

Since there are limited articles on CPL, we decided to use a broader terminology - "technology in higher education" to widen our search for articles that included the use of technology in higher education. We present the findings as an animated visualization of technology trends in higher education over the last 10 years.

Methodology

We utilized the Web of Science database to map the trends of educational technology in higher education for the period of 2014 to 2023. Our objective was to identify the ten most frequently cited "technology use in higher education "related concepts or topics within indexed, academic literature over the past decade. We were also curious to know if and how the COVID-19 pandemic has impacted this list of citations.

To triangulate the findings, we also conducted a comprehensive search across platforms including academic databases, industry-specific websites, and respected repositories like Google Scholar, UNESCO, and Educause Horizon Reports. These platforms are renowned for their extensive coverage of scholarly literature and global educational reports, although they are non-indexed.

Step 1 - Keyword Search

Our search strategy was to use the keywords "technology" and the phrase "higher education" in the Web of Science search engine. Searching for these keywords in the "Topic" field yielded a list of broadly relevant publications across all dates.

Step 2 - Filtering by Web of Science Category

Next, we filtered the search results by selecting the Web of Science category "Education Educational Research", since that was identified to be the most applicable category related to research on higher education technology. There are currently approximately 250 categories in Web of Science as listed here: https://incites.help.clarivate.com/Content/Research-Areas/wos-research-areas.htm, of which 'Education Educational Research' is one of them.

Step 3 – Filtering by Citation Topics and Year

We then refined our search by filtering for the "Citation Topics Micro" category to review the sub-topics within the publication year range of 2014 to present.

2 Web of Science is a multidisciplinary research database that provides access to a vast collection of scholarly articles, conference proceedings, and other academic publications.

Step 4: Checking of data and classification

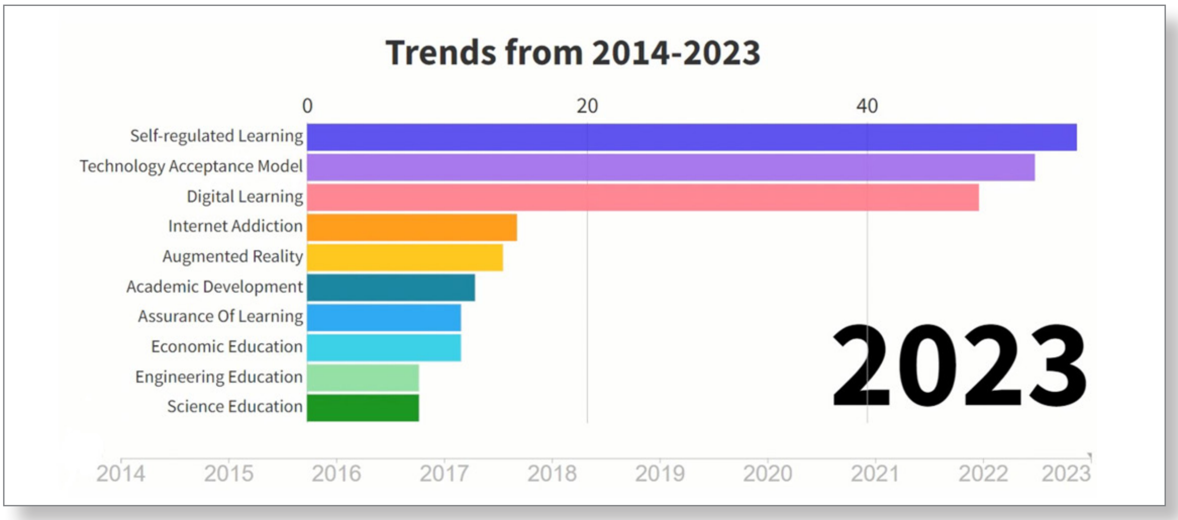
We then examined the listings generated by Web of Science to ensure their validity and relevance. We observed that there were several unrelated mentions to our interest. For instance, we had topics like "Business Ethics" and "Customer Satisfaction". Topics that did not align with any of our predetermined themes based on teaching and learning concepts (Figure 4.1) given below were consequently omitted from our list of educational technology trends.

- Learning outcomes
- Learning experience
- Teacher Training
- Technology
- Pedagogy (Teaching methods)
- Subject Matter (STEAM, Engineering etc)
- Learning Environment
- Student-related (e.g., wellness, recruitment)
- Career development/lifelong learning

Figure 4.1. Predetermined Categories based on Teaching and Learning Concepts (Credit: Nachamma Sockalingam)

Step 5: Creation of the Data Visualisation Model

We used "Flourish" as the primary data visualization tool after considering various open-source alternatives. The structured dataset by year was imported into Flourish. Here, we configured the visualization parameters, animations, and aesthetics, optimizing the chosen bar chart race to encapsulate the dataset's temporal evolution. We present this in Figure 4.2.



Accessible at https://public.flourish.studio/visualisation/15304769/

Figure 4.2. Visualization of Technology Trends in Higher Education from 2014 – 2023 (Credit: Zoe Yeo Lock Yan, Ella Lee Miu Yee, Joel Teo, 2023)

Data from Web of Science, provided by Clarivate. Web of Science and Clarivate are trademarks of their respective owners and used herein with permission.

Key Findings

1

The most striking observation was that articles relating to **"Self-regulated Learning"** and **"Technology-Acceptance Model"** topics were predominantly the top-cited over the last ten years in the Web of Science. These can be classified under the broader category of learning experience/outcomes. Self-regulated learning refers to the self-directive process undertaken by a learner (Zimmerman, 2002). The Technology Acceptance Model refers to the factors that determine the perceived usefulness and acceptance of technology in education and learning (Granić & Marangunić, 2019). Another learning outcome/experience-related concept that has consistently ranked in the top 10 over the past decade is **"Assurance of Learning"**, which refers to continual curriculum review and improvement (e.g., Ungaretti * Tillberg-Webb, 2011).

2

Internet Addiction, a concept that may be in our blind spot, has emerged as an important topic to look out for in the realm of digital learning. It has consistently secured a place in the top 10 for the past decade and has remarkably often ranked in the top 5. This is a topic that needs our attention. Interestingly this has not been reported in most well-known reports, including the Educause Horizon report (e.g., Pelletier. *et. al.*, 2023; Gavurova, *et. al.*, 2022)

3

The topic of "**Digital Learning**" has experienced a significant surge in citations since 2021, making it the most frequently cited over the past two years. This can be posited to be a result of the COVID-19 pandemic.

4

Despite the emergence of several new technologies, only **Augmented Reality (AR)** made it to the top 10 cited topics accordinga to Web of Science. AR ranks fifth in position this year. To compare, the Educause Horizon report identified AI and Generative AI as the trending technologies, and AR did not make it to the list. Given that Web of Science data is based on published articles, and market trend reports are more based on current developments, we can anticipate that the AI and Generative AI will eventually be one of the top-10 cited Web of Science papers, in the coming years. At present, AR is the most reported technology in education according to the Web of Science data.

5

The topic of **Academic Education** and **Teacher Training** consistently features as an important concept in the top-10 cited Web of Science papers, although its position has varied over the years. This is suggestive that academic development in digital learning is an important consideration.

6

Discipline/ Subject-based Implementation of digital learning has emerged as a popular topic over the last decade. This indicates that a "one size fits all" strategy in digital education is not feasible - there is a need to tailor subject/discipline-specific solutions in digital learning.

7

Over the last decade, topics such as "**Plagiarism", "Open-Educational Resources" and "Academic Entrepreneurship**" have also been making the top 10 list from time to time. With the growing importance of AI and generative AI in higher education (Educause Horizon Report 2023), such topics are likely to become more prominent in the coming years

8

Our findings align with another more detailed bibliometric study by Zhang *et. al.*, (2022) on online learning.

Reflections

In SUTD's first white paper on CPL, we surveyed students, faculty, and stakeholders on their perspectives on digital learning and CPL. We also referred to reports on trends of specific digital technologies. This helped us to establish the needs for digital learning, and the forms of digital learning as well as technology tools needed at SUTD as CPL. It also helped us identify key thrust areas we can focus on. These data points helped us to envision the SUTD campusX initiatives. We operationalized this through the "Proof of Concept to Practise" Minimum Viable Product approach. This essentially covers "what, why, and how" of transforming digital education at SUTD, and is largely based on contextual, experience-based knowledge.

In this literature survey, we have undertaken an academic and systematic approach to examining the top 10 cited topics related to technologies in higher education in Web of Science. This was illuminating in identifying topics that are important, popular, and relevant to the concept of CPL in the academic literature . Importantly, it has revealed that factors beyond technology are important for teaching and learning. For instance, topics like "Self-regulated Learning, "Technology Acceptance Model", and "Internet Addiction" may be topics that we may need to explore in CPL/digital learning. Indirectly, this exercise helped us to identify areas that SUTD and other institutions may need to focus on and revealed areas they may not have been previously identified.

Even though our objective of CPL is to make this as practice-oriented, as academic institutions, it is essential to take a knowledge-based, scholarly approach to explore and present the findings on CPL to a wider audience. Hence, we have taken the approach of examining the past trends in academic literature on technology in higher education over the last 10 years. Analyzing these past trends provides us rich valuable lessons about what has worked and what has not, while the futuristic foresight predictions and envisioning provide opportunities for creativity. Interestingly, this search did not identify topics such as Artificial Intelligence for Personalised Learning, and Generative AI as those predicted in the Educause Horizon report. We can anticipate that the current ongoing trends and developments will make it the peer-reviewed index in the years to come. The next step involves integrating lessons learned from the past and insights gained from futuristic envisioning to inform our current practices and shape our ongoing digital learning initiatives.

From our literature survey, we can learn that the indexed articles mostly focus on students' learning experiences and outcomes, as well as how prepared and receptive both our students and faculty members are to embrace new teaching and learning approaches. This is suggestive that most reports emphasize a human-centric approach. It is important to understand how both teachers and students are managing and coping with the changing times. Subject-specific considerations also play a vital role in tailoring these learning experiences, especially when using technologies such as augmented reality.

The objectives of indexed academic papers, market reports, and experiential knowledge are different, each with its utility. It is essential to consider the different perspectives in shaping our digital learning practices.

Based on the literature survey, here are some questions that we can explore

- How can we use the existing and emerging technologies to promote student wellness and connectivity with other students and instructors?
- What are the potential uses of technologies such as AI, Generative AI, and Immersive Technologies in higher education?
- What are the potential risks and unintended outcomes of technologies such as AI, Generative AI, and Immersive Technologies in higher education?
- How can we leverage learning analytics to understand how students are learning across different subject domains?
- How does internet addiction relate to student wellness, socialization, and learning?

In the next section, we will present various examples of CPL projects' developments at SUTD which attempt to address questions like these.

We need to take a human-centric approach to CPL

A limitation of our survey is that it only covered the past literature. This does not represent the papers published in CPL beyond those in Web of Science. Also, it tends to consider only the educational perspective, and does not represent the geopolitical, social, economical, and political contexts that may influence teaching and learning. As suggested earlier, this article and the trends and foresight report, as a whole, should be taken as an additional data point rather than as the only data point, to triangulate and infer context-specific understanding to make suitable strategic decisions on CPL.

Disclaimer

While every reasonable attempt has been made to ensure the accuracy and correctness of the information in this paper, the authors and publisher assume no responsibility or liability for any errors, omissions or inaccuracies in the content of this paper or for any outcome or results from the use of the information or contents of the paper. All information contained in this paper is provided on an "as is" basis with no guarantees of completeness, accuracy or usefulness or timeliness or of the outcomes or results obtained from the use of the information in this paper and without any warranty of any kind, express or implied.

References

Asad, M. M., & Malik, A. (2023). Cybergogy paradigms for technology-infused learning in higher education 4.0: A critical analysis from global perspective. *Education + Training*.

Gavurova, B., Khouri, S., Ivankova, V., Rigelsky, M., & Mudarri, T. (2022). Internet addiction, symptoms of anxiety, depressive symptoms, stress among higher education students during the COVID-19 *pandemic. Frontiers in Public Health, 10.*

Granić, A., & Marangunić, N. (2019). Technology acceptance model in educational context: A systematic literature review. *British Journal of Educational Technology, 50*(*5*), 2572-2593.

Pelletier, K., Robert, J., Muscanell, N., McCormack, M., Reeves, J., Arbino, N., Grajek, S., Birdwell, T., Liu, D., Mandernach, J., Moore, A., Porcaro, A., Rutledge, R., & Zimmern, J., *2023 EDUCAUSE horizon report, Teaching and learning edition*. (Boulder, CO: EDUCAUSE, 2023).

Sockalingam, N., Lo, K., Kurniawan, O., Herremans, D., Raghunath, N., Cancion, H. G, C., Kejun, H., Leong, H., Tan, J., Nizharzharudin, K., & Pey, K. L. (2022). *A white paper on cyber-physical learning*. Singapore University of Technology and Design. Retrieved from: https://www.sutd.edu.sg/SUTD/media/SUTD/LSL_WhitePaper_Cyber-physical-Campus-Higher-Education.pdf

Ungaretti, A. S., & Tillberg-Webb, H. K. (2011). Assurance of learning: demonstrating the organizational impact of knowledge management and e-learning. *Knowledge Management and e-Learning*, 41-60.

Zimmerman, B. J. (2002). Becoming a self-regulated learner: an overview. *Theory into Practice, 41(2)*, 64-70.

Zhang, L., Carter Jr, R. A., Qian, X., Yang, S., Rujimora, J., & Wen, S. (2022). Academia's responses to crisis: a bibliometric analysis of literature on online Learning in higher education during COVID-19. *British Journal of Educational Technology, 53(3)*, 620-646.

5. DEVELOPMENTS OF CYBER-PHYSICAL LEARNING AT SUTD

This section contains case studies and examples of minimum viable product and research projects from the six thrusts of SUTD campusX. In the next few pages, we present details on the technology tools, the motive for developing the tool, details and features of the tool, and the developments so far.

The six thrusts of SUTD campusX are:

1. People-centric learning and design
2. Immersive realities learning
3. Metaverse and blockchain for learning
4. Socially interactive educational robotics
5. Advanced learning analytics, especially real-time analytics
6. Enhanced learning through innovative technology

The various MVP initiatives are primarily focused on developing technology tools for higher education. Each project can be seen as specialized and individual work during the current developmental stage, and we present them as such. We plan to eventually integrate the various MVP projects that are logically connected (Figure 5.1). For example, the Telepresence Robot System utilizes both socially interactive educational robotics, immersive reality learning technologies, and learning analytics. While some projects are stand-alone, other projects cut across the various thrusts to become a larger integrated project eventually.

To date, ODL has managed to strengthen the underpinning framework, thrusts, teams, resources, and implementations of the various MVP projects in the last year. We have developed more campusX projects, and we are now moving into the testing phase in classrooms.

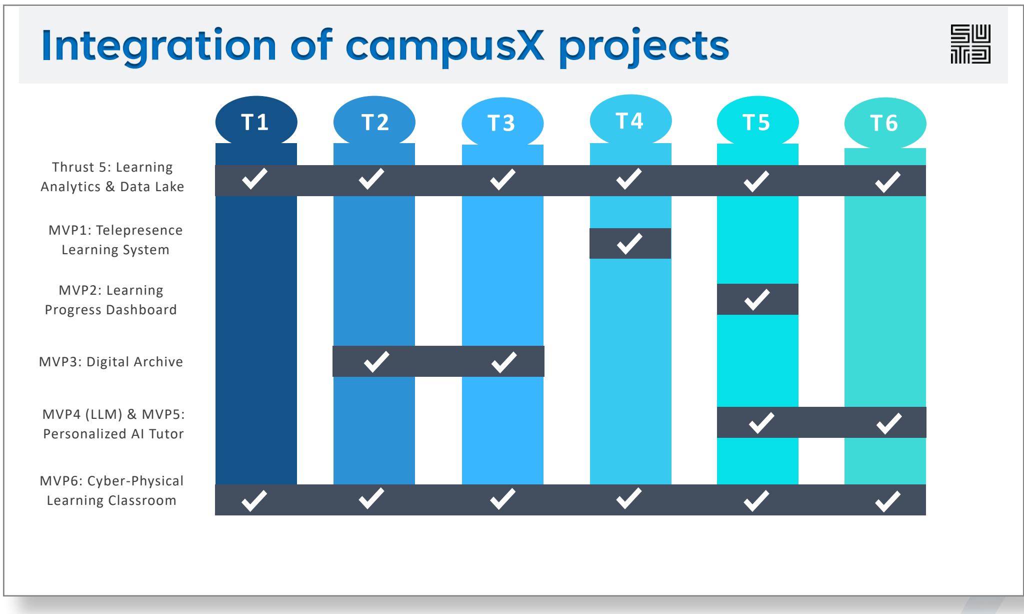
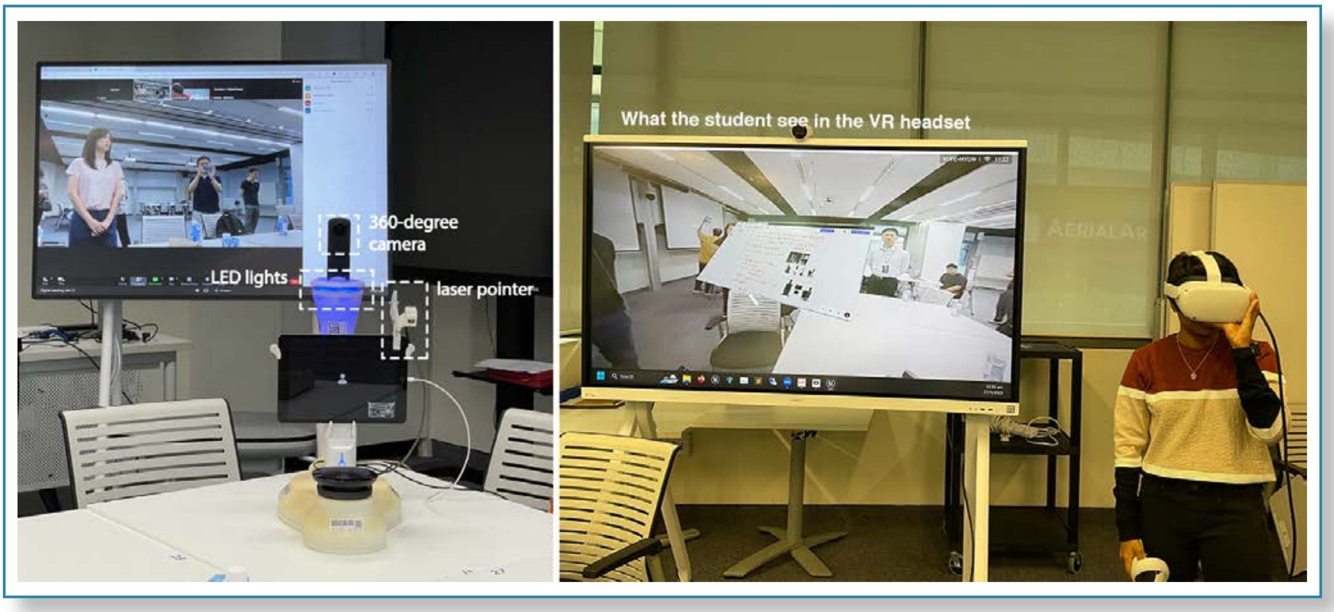


Figure 5.1. Integrated MVP Projects from the Six campusX Thrusts (Credit: Kenneth Lo, Judy Teo, Pey Kin Leong, 2022)

5A. TELEPRESENCE ROBOT SYSTEM

Hong Pin Koh, Oka Kurniawan, Jacob Chen, Nachamma Sockalingam



SUTD campusX TLS Version 1 with Video and Immersive Realities Features

SUTD campusX TLS Version 2 with Integrated Multiple Features

Telepresence Robot System

The Telepresence Learning System (TLS) involves a tabletop telepresence robot that serves as a physical platform for instantaneous video and audio streaming, enabling effective and immersive communication among both remote and in-person students and instructors. This innovative system aims to enhance collaborative learning experiences for small groups of 6-8 in cyber-physical learning settings.

Motive

Present video conferencing tools lack the means for seamless, immersive, and collaborative learning for cyber-physical learning context. In such settings, it is widely acknowledged that remote students face challenges with social presence and engagement, often trailing behind their physically present peers.

The TLS seeks to bridge this gap by harnessing readily available technologies in the market, to enhance the social presence and engagement of remote learners.

The core concept driving the TLS is to create a more immersive condition for collaboration and learning among remote and in-person students and instructors within the classroom, advancing towards the next frontier of digital education experience.

Solution

The TLS encompasses several pivotal features:

1. **13" Tablet Screen:** This tablet screen provides two axes of movement, ensuring optimal visibility for both remote and physical students.
2. **360-degree Camera:** Delivers a highly engaging experience. Online users have the flexibility to access the 360-degree camera through a standard web viewer or opt for an even more immersive experience through a Virtual Reality (VR) headset.
3. **Speakerphone:** Facilitating seamless communication between remote and in-person users, the speakerphone is an integral component of the TLS experience.
4. **LED Reaction Indicators:** Remote students can convey reactions through LED lights, which are notably more discernible to those physically present compared to the conventional emoticons found in standard video conferencing tools. This feature significantly enhances instructors' awareness of remote students' engagement and learning status.
5. **Short Throw Projector:** Originally a controllable laser pointer, this tool empowers remote students to draw attention to specific objects of interest on the desk, enabling collaborative interaction with physical objects.

These features collectively contribute to a dynamic and inclusive hybrid learning environment, bridging the gap between remote and in-person participants.

Developments

Our initial study revealed that remote students responded positively to the 360-degree camera and VR experience, citing it as a more immersive learning medium compared to conventional video conferencing methods. This innovation in the TLS significantly boosts the engagement of remote students. While the 360-degree camera provided visual immersion, we are also trying to integrate new avenues for remote students to actively participate and interact with the physical classroom using technologies such as controllable laser pointer and VR controllers. This is continual work in progress.

Furthermore, our study found that those physically present often struggle to gauge levels of comprehension by online students due to the virtual barriers inherent in CPL. This limitation arises from the restricted ways the TLS conveys social cues and gestures of multiple remote students through the small tablet screen and speakerphone. LED reaction indicators can therefore be helpful.

The team is also exploring audio-fencing using AI-assisted approaches for high-quality, and authentic voice transmission to remote students.

CPL also necessitates multitasking across various applications, screens or devices, leading to a complex and less intuitive learning and teaching experiences. When a remote student or instructor is focused on a task on their screen, they typically remain unaware of the activities of others, depriving them of valuable contextual learning cues. Hence, it is imperative to consider the needs of both instructors and students. We can use learning analytics for this purpose.

A variety of devices like mobile phones, laptops, and tablets offer distinct interaction modes. Tools such as drawing styluses, keyboards, mouse, and touchscreens, each serve a unique purpose in small-group learning. This may lead to the use of multiple devices for CPL. Consequently, there is a need for an end-user device/interface that seamlessly integrates these varied interaction modes.

The team is also exploring audio-fencing using AI-assisted approach for high quality and authentic voice transmission to the students.

5B. IMMERSIVE LEARNING SYSTEM – AUGMENTED REALITY CATAPULT

Cheah Chin Wei, Jacob Chen

SUTD campusX Augmented Reality Catapult to Teach and Learn Projectile Motion in Physics Class

Augmented Reality Catapult

We aimed to develop and deliver immersive learning technology and curriculum using Augmented/Virtual/Mixed Reality (AR/VR/MR) as an effective tool for cyber-physical learning.

This initiative aims to integrate digital and physical worlds to disentangle teaching and learning activities from physical constraints to enhance the learning experiences, allowing wider collaborative efforts in many forms among both instructors and students.

Motive

Physics is one of the hardest subjects for students to learn. Certain physics concepts are abstract and difficult to grasp completely by students especially when they need to transfer their theoretical knowledge and apply that in practical, real-life settings.

Even though we can teach some of these abstract concepts through physical experiments and hands-on activities to enhance understanding, such a curriculum mainly benefits students who are physically present in the classroom but not students who attend the course via online class. Hence, we planned to develop an AR catapult to teach physics for cyber-physical students.

Solution

This initiative focuses on working with instructors from different courses to create engaging Augmented/Virtual/ Mixed Reality (AR/VR/MR) content to address pain points in the courses especially those that involve visualization of difficult and abstract concepts.

We aim to allow students to engage and interact with virtual objects or environments to explore these in ways that may not be possible or difficult to achieve in a real physical environment/ context.

With the AR/VR/MR learning objects and curriculum, it is also much more convenient for both physical and cyber students to meet in the virtual environment and interact collaboratively in the learning process.

Developments

The team has developed an AR catapult curriculum for Freshmore course 10.015 Physical World to study the physics of projectile motion. Students often find it challenging to integrate information about the position, velocity, and acceleration of the projectile.

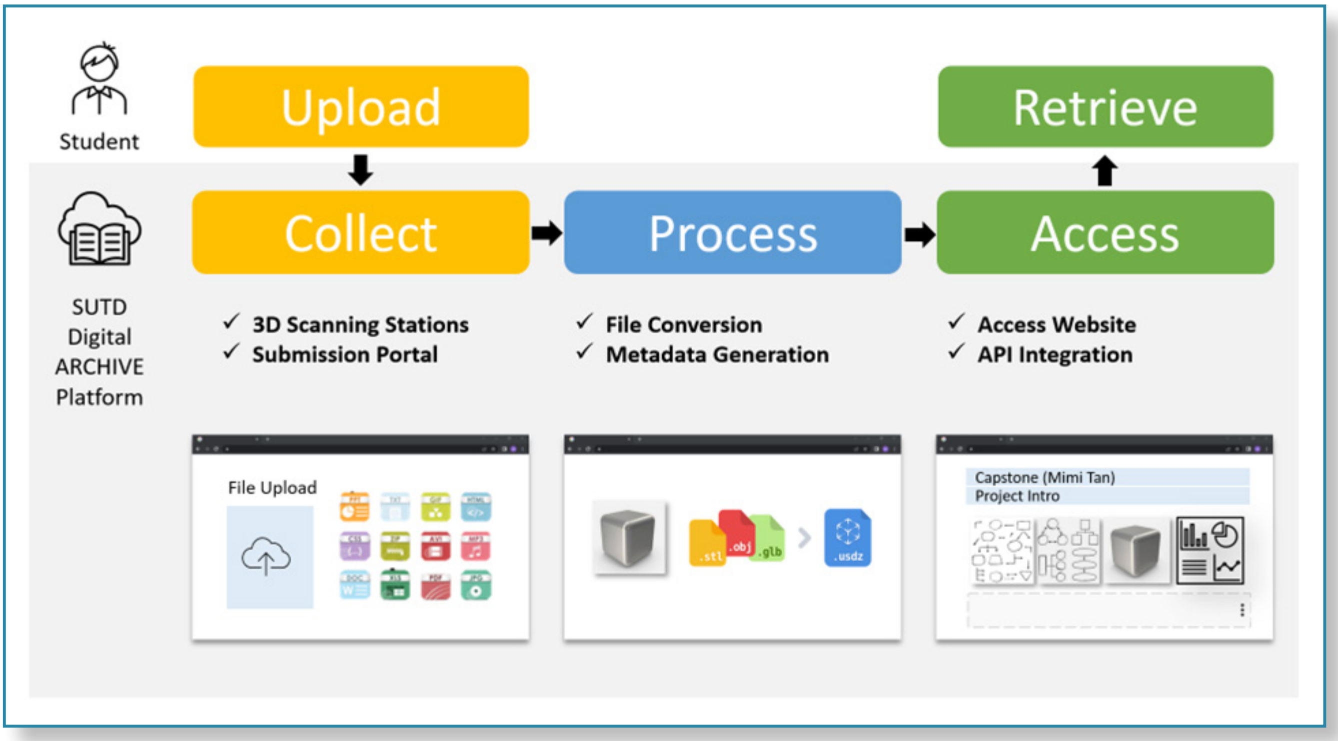
By creating a virtual projectile superimposed on the real environment with AR technology, students could work individually or collaboratively to understand the kinetics and dynamics of the projectile motion, with measurements overlaid on the trajectory of the virtual projectile in real space. Students can visualize the motion in detail and conveniently from different angles.

The AR activities were carried out in 3 cohort classes and the responses from students are overwhelmingly positive. Most students are completely engaged during the activities by proactively performing all necessary calculations for projectile motion physics to determine the firing solutions on the AR platform. Most students gave feedback in the post-activity survey that the activity is fun, engaging, and that the AR visualization helps with a better understanding of the projectile motion physics.

Our experience suggests that this endeavour is promising. We feel that a properly designed AR gamification platform coupled with carefully designed curriculum could be engaging to students and believe that it will enable active, interactive, and collaborative learning The AR gamification platform should also be designed to be easy to use and target common misconceptions of students. The platform and the associated curriculum activities should also be meticulously designed to guide students to proactively find out the solutions and answers. These are likely to be the key elements for designing a successful immersive learning activity that delivers meaningful learning objectives.

5C. IMMERSIVE LEARNING SYSTEM – DIGITAL ARCHIVE

Jacob Chen, Eva Maria Castro



SUTD campusX Digital Archive Process

Digital Archive

The SUTD Digital ARCHIVE (Advanced Repository and Collaborative Hub for Interactive Virtual Education) is looking at how can we facilitate the collection and consolidation of student-generated works, while also ensuring its usability, longevity, and easy retrieval and access. Beyond just a library of information, the organized consolidation of these resources would allow for the creation of a dataset that can be used for learning analytics and even machine learning in the future.

Motive

With SUTD's pedagogy of design- centric project-based learning, an extensive amount of project works and prototypes are produced every year. These range from more traditional papers, reports, and presentations, to videos, 3D CAD models, and physical models.

Due to the limitations of the current learning management system used, and the complex nature of some of the courses and deliverables, the collection and storage of these assets are fragmented, and managed by individual instructors or teaching assistants. There are no existing protocols or physical space to keep the collections, especially for the variety of (mechanical, electrical, and architectural) physical models, for the long term and we wanted to address this gap.

Solution

This is an internal campusX MVP project to create an end-to-end solution for

i. The collection and use of digitized and born-digital content (e.g., documents, images, websites, audio, video, 3D models, 3D scans, etc.).
ii. A robust and secure system to process and store the digital files and its metadata.
iii. Accessing and interacting with the archived digital content in an immersive environment/ platform.

Developments

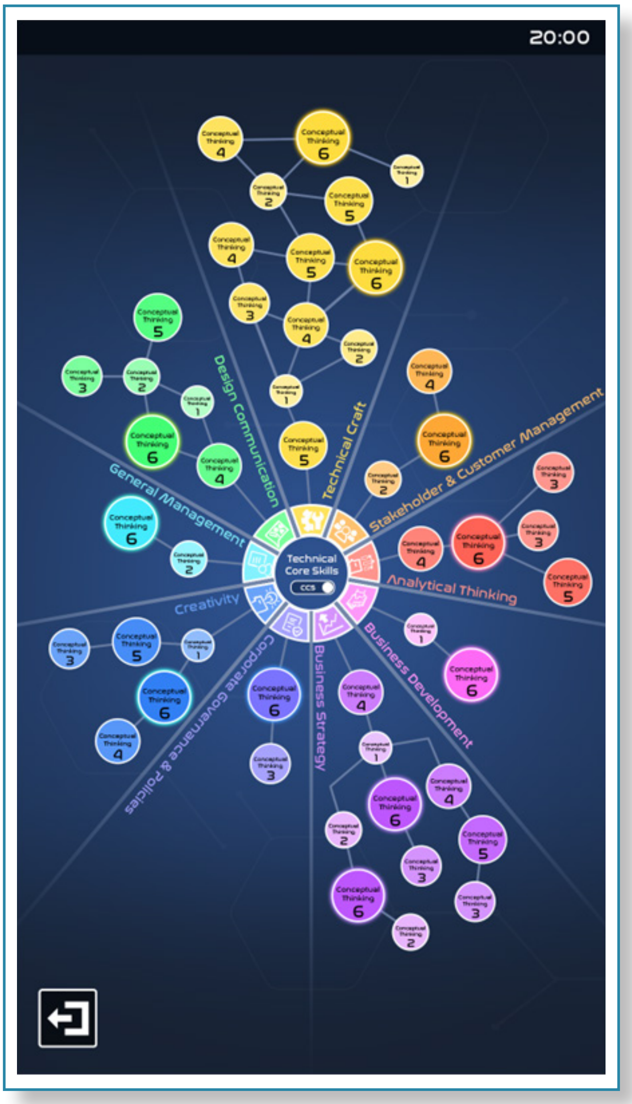
We are still in the early stage of development. Working closely with some of the instructors, we have identified gaps and potential interventions for our platform to improve the workflow for the instructors and students. Understanding the needs is the first step to product development.

One example of student content creation is product development as physical models. Photogrammetry has emerged as an increasingly accessible means of generating digital replicas of physical models. However, it still demands a certain level of technical proficiency to operate the requisite software and capture optimal images for processing. The team has initiated the development of a 3D scanning station designed to simplify the process of digitizing 3D models and prototypes. When fully integrated into our platform, this scanning station will offer a seamless solution that empowers students to convert physical models into digital formats within a matter of minutes and these digital assets will subsequently be processed and accessible on our platform within the span of an hour.

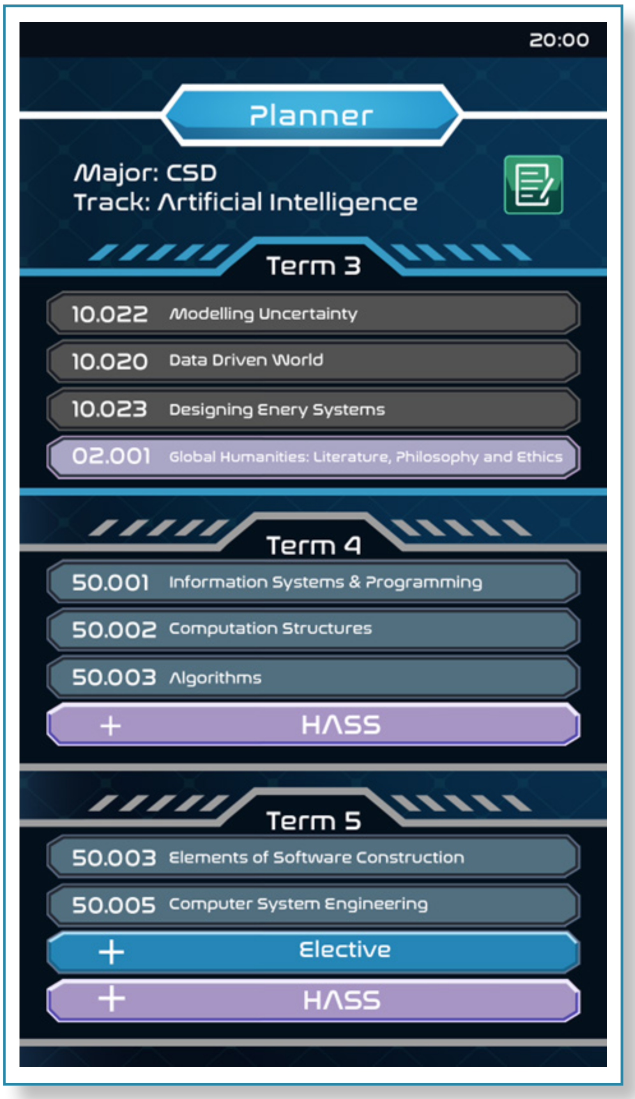
We are currently working with faculty members to develop the prototype of the Digital Archiving Process.

5D. GAMIFICATION AND SKILL TREE

Danny Chow, Dorien Herremans



A SUTD CampusX Skill Tree for Visualizing Core Skills Strength



A SUTD campusX Learning Path to Customize Learning Roadmap and Track Progress

Skill Tree

We are developing a gamified metaverse platform that is driven by a Skill Tree Mechanism. The Skill Tree guides students in their learning journey by helping students visualize their learning trajectory toward achieving their learning target. It also provides encouragement, feedback, and hints to support the students' choices in their learning journey.

Motive

Students do not have visibility of their skill development as they progress through their learning journey. They do not have a way to measure their skill competency and identify the gap that allows them to take action to improve it.

Solution

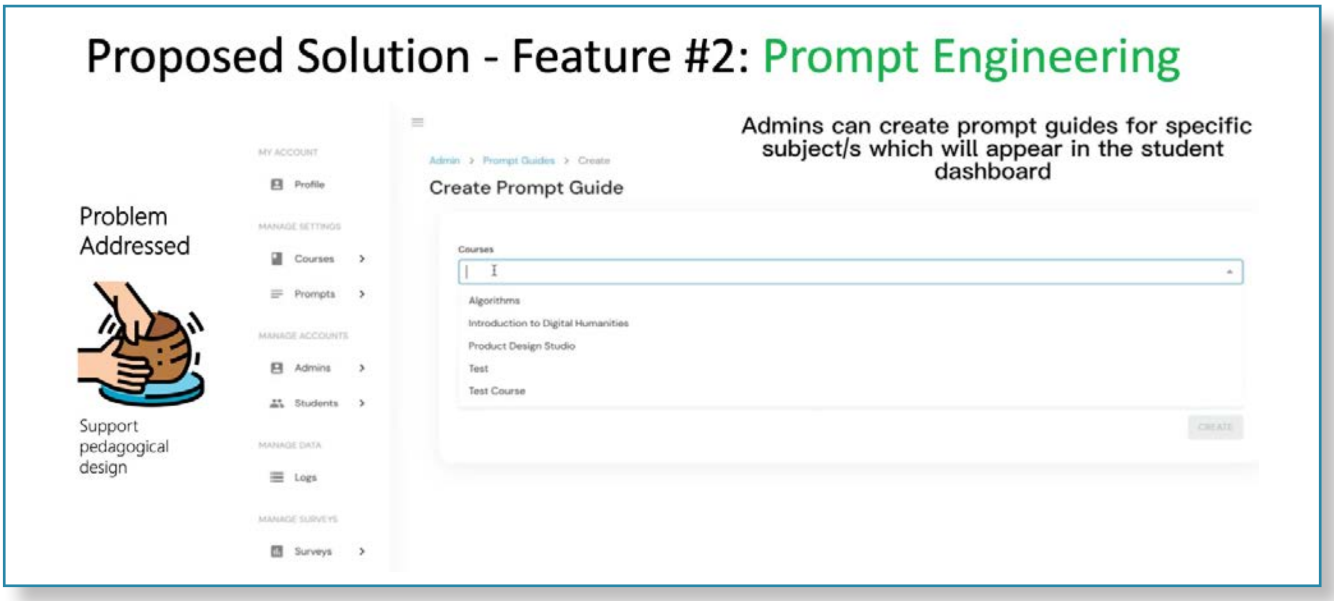
We have developed a mobile game prototype using a Skill Tree mechanism that gives students the tools to plan their learning journey and identify their skill competency gaps. It includes gamified activities to help students develop essential skills for better future job placement. In addition, we are currently implementing blockchain technology to store their achievements, allowing them to unlock new skill acquisition paths, and make their achievements easily verifiable by future employers.

Developments

We just started our trial-run study at SUTD using the gamified metaverse platform with Freshmore students. We also conducted a survey to understand what motivates students to sign up for the trial. Most of the respondents indicated they desired to be able to personalize their learning roadmap, followed by a desire to have visibility of their progress, as well as develop concrete skills for better future job placement. The pre-pilot study survey suggests that this project has the potential to be useful to students. The planned pilot study will run during the upcoming term at SUTD.

5E. SUPPORTING LEARNING WITH LARGE LANGUAGE MODELS

Kenny Choo



Prompt Guide Feature of SUTD campusX GPTLearn

GPTLearn

GPTLearn is a web-based platform designed to assist faculty in enhancing students' learning experiences by offering access to Large Language Models (LLMs) supported by pedagogical features such as prompt guides. LLMs are advanced machine learning models capable of understanding and generating human-like text, which have been customized in this application to align with educational objectives. Through GPTLearn, educators can leverage the capabilities of LLMs to further support the pedagogical outcomes of their students.

Motive

Large Language Models (LLMs) show great promise to be able to enhance student learning across diverse topics. However, what is less known is how students can/will utilize this to teach and learn. Similarly, instructors are also trying to better understand how LLMs may be imbued in their pedagogical practices but lack a means to i) deploy such a feature, ii) design instruction, and iii) to gather data. Hence, we wanted to understand how to use LLMs, and generative AIs to support teaching and learning in higher education.

Solution:

GPTLearn has the following features:

User Account Control – Instructors and students have secured access using emails and passwords.

Prompt Engineering – Instructors can create prompt guides to control the use of the LLM to support their pedagogical outcomes. For example, in a fundamental coding class, an instructor may include a prompt guide to the LLM: "to only give code hints, not solutions". Students will then not be able to obtain immediate answers.

Prompt Surveys – This is a mechanism to allow instructors to add questions that relate to pedagogy or data collection as students utilise the LLM and prompt.

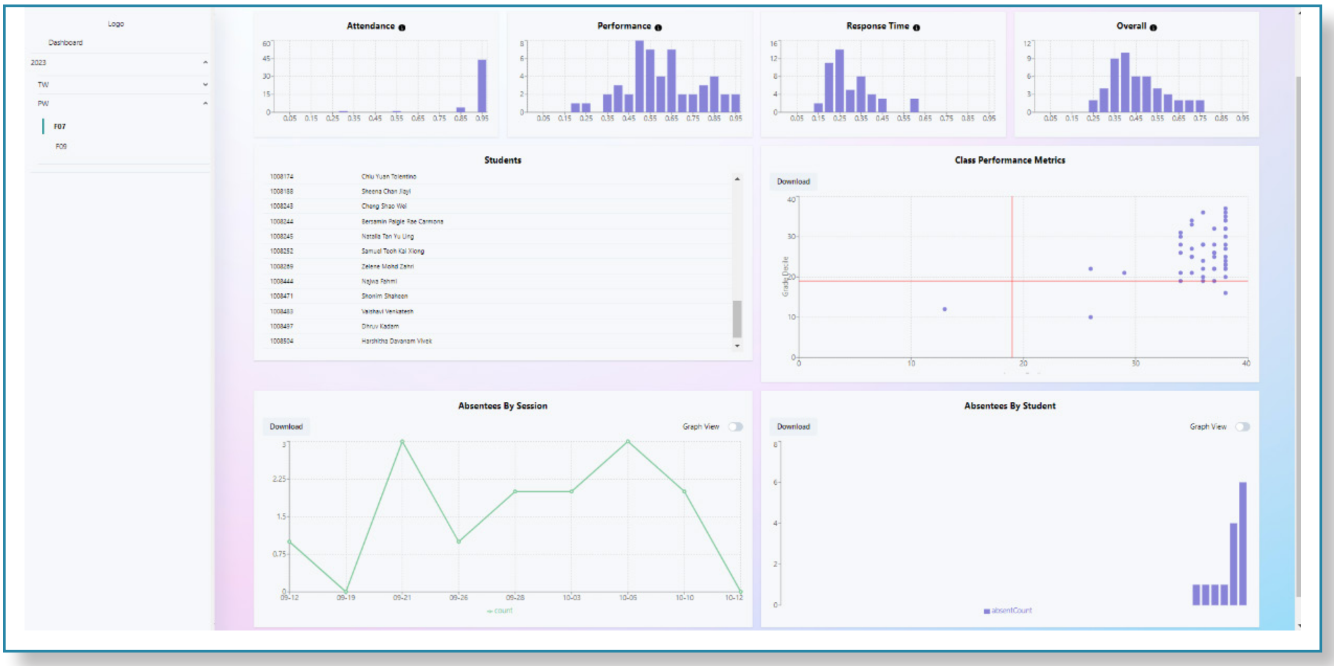
Data Logging – Stores all the data so that instructors may download the data to do analyse their instructional design and outcomes.

Developments

We have trialed a prototype of the GPTLearn system with Prompt Engineering and survey features over Term 5 in 2023 and have gathered data on student use. This data is still undergoing analysis. Some anecdotal observations are that students prefer user interaction features like what ChatGPT currently provides—that is, a session-based approach that has a memory of what they prompted beforehand. Such findings help us in designing better instructional plans using GPTLearn.

5F. LEARNING PROGRESS DASHBOARD

Lee Chee Huei, Natalie Agus



SUTD campusX Learning Progress Dashboard

Learning Progress Dashboard

This project aims to develop a learning progress tracking system that collects students' in-class clicker response data seamlessly for further learning analytics. We are developing a dashboard for instructors and students to visualize their performance and keep track of their learning progress.

Motive

It has been a challenge for many instructors to keep track of students' learning, especially those who are shy and quiet. If instructors can be alerted to weaker students' information, early intervention can be provided at a much earlier stage to help them. At SUTD, we have been practicing active learning pedagogy in various courses. One of the approaches includes using a clicker response system to actively engage students. We believe that students' responses to clicker questions reflect their level of understanding in the subject matter. By analyzing students' performance in this form of formative assessment, instructors can better understand how students learn in class and weaker students can be identified easier.

Solution

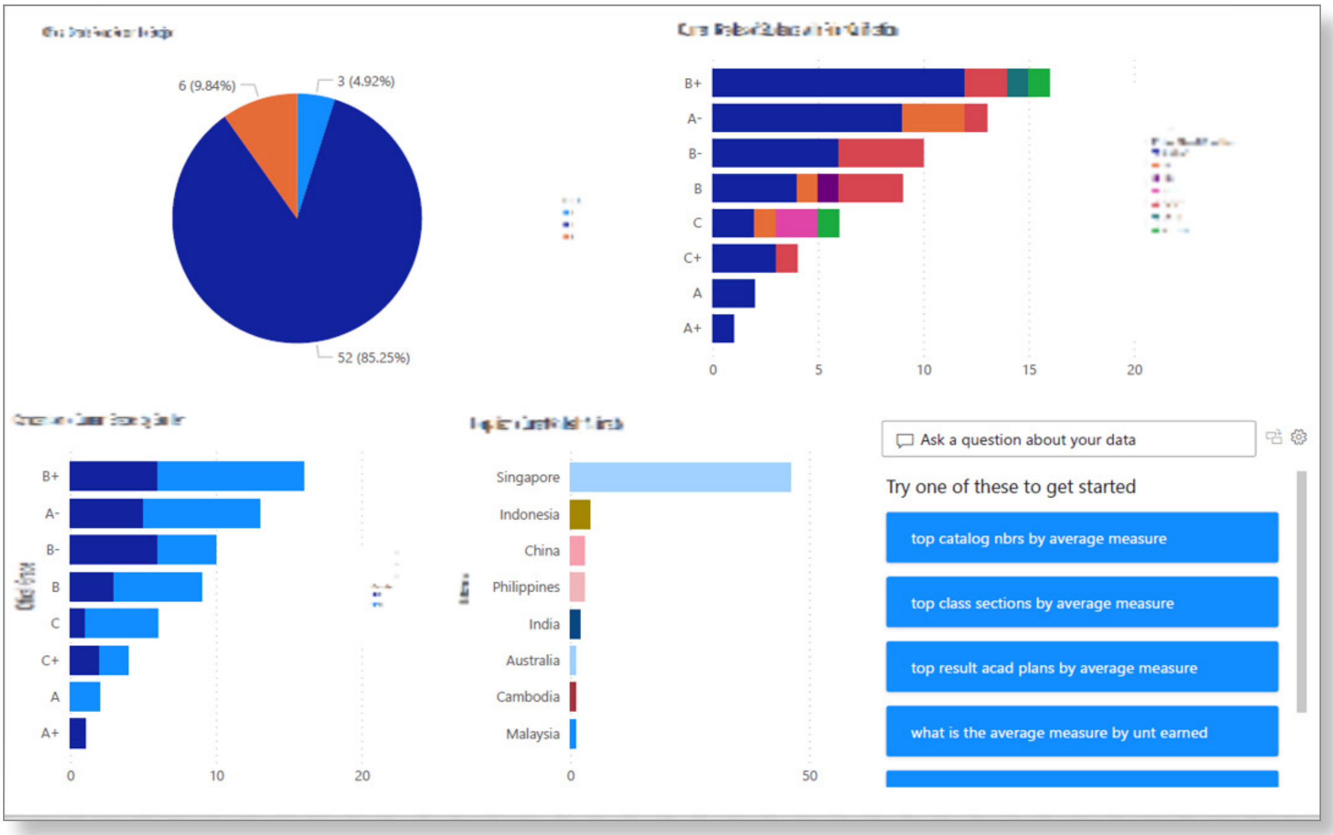
We are using ClassPoint, a PowerPoint plug-in software, to launch interactive quizzes in class. In collaboration with our industry partner, Inknoe Inc., the developer of ClassPoint, we developed an Application Programming Interface (API) to transfer students' data from the vendor's server to our own database for further analysis. The insights derived from this data are displayed on a web dashboard for instructors and students. The dashboard provides an overview of the class's performance and students' attendance. By utilizing this system, instructors can leverage the information to offer additional support for student learning if necessary. The whole system is built in-house at SUTD.

Developments

Currently, we are testing this prototype in a small number of classes. We find that this system is useful for tracking attendance and student engagement. The dashboard provides an intuitive visualization of students' performance and interactive features for instructors to identify weaker students. This makes it easy for the instructors to provide timely personalized support whilst saving them much time. We are now examining if there are correlations between students' clicker performance and their exam results. It can be useful for instructors to initiate early intervention when the system can alert instructors of those who need more help in class. We aim to encourage instructors to incorporate clicker response systems as a formative assessment to engage students in class, at the same time, this tracking system enables the learning analytics of students' responses.

5G. ADVANCED LEARNING ANALYTICS

Ng Lian Wah, Melvin Lee Ming Jun, Kwan Wei Lek



SUTD campusX Learning Analytics Dashboard

Advanced Learning Analytics

This project is to set up a data lake architecture that consolidates students' information and learning data from SUTD's Learning system and other data bases for learning analytics. We will be developing a dashboard that provides insights for instructors and students to visualize and analyze their learning progress.

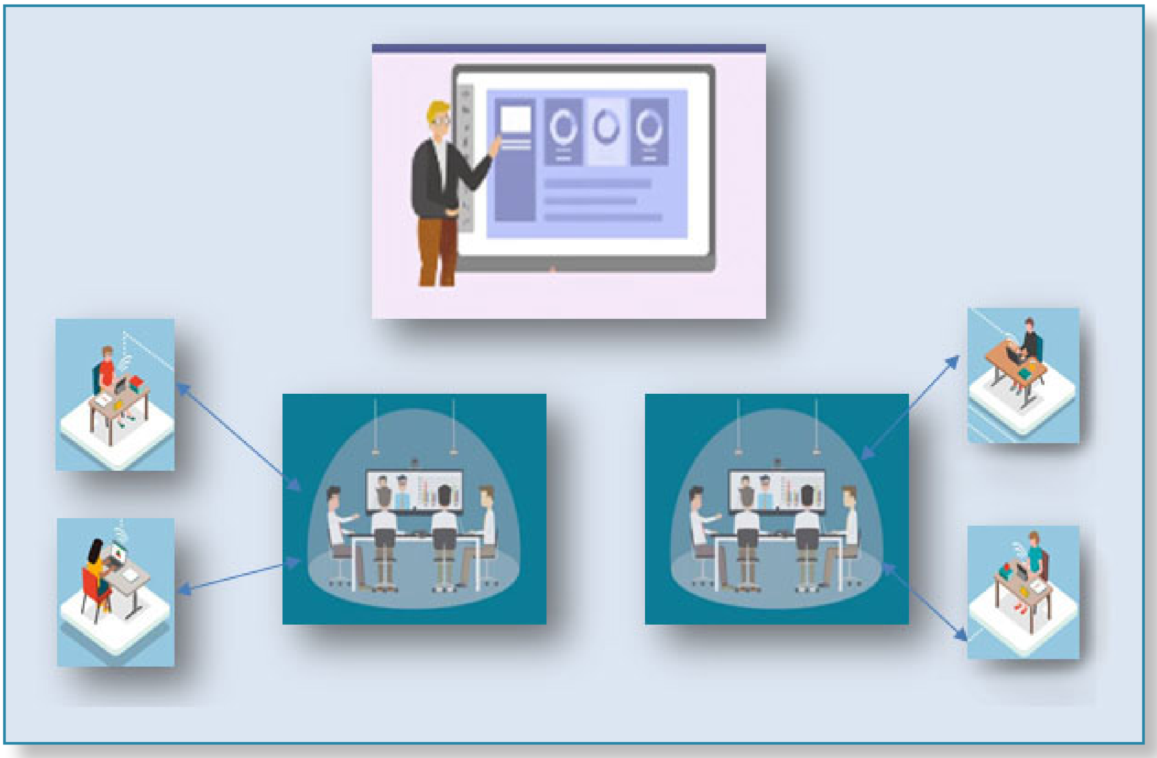
Motive

We seek more effective ways to enhance the earning experience through data-driven decision-making. The set up of data lake serves as a central repository where raw data from the various learning systems can be stored for analysis to test hypotheses, conduct studies, develop personalized learning, and provide educational insights. The data lake facilitates better collaboration between faculty, administrative staff, and data analysts for sharing of data and insights. The robust security features of the data lake will ensure that sensitive student data is well protected.

Solution	Developments
We are working with partners to implement a cloud-based data Lake with industry best practices for security and operational readiness. Amazon Web Services (AWS) has been identified as the cloud infrastructure. Microsoft Power BI has been identified as a tool for data visualization as SUTD has an existing subscription.	We have conducted multiple discussions with internal stakeholders to engage and learn about their concerns and needs on data security and data protection. We have also conducted numerous rounds of discussions and workshops with various stakeholders including faculty, campusX team members, and AWS team, and learned which and how AWS services can be implemented to address our requirements. A Data Lake Sandbox has been set up to experience the permission, security monitoring, and loggings. Further developments are ongoing.

5H. IMMERSIVE AND INTEGRATIVE CYBER-PHYSICAL LEARNING ENVIRONMENT

Shubhakar K, Nachamma Sockalingam, Jacob Chen, Judy Teo



Envisioned SUTD campusX Multi-Sensory Learning Lab

Immersive and Integrative CPL Environment	**Motive**
The Immersive and Integrative Cyber-Physical Learning Environment is a technology-enabled learning environment that combines remote cyber participants with physical in-class participants using immersive technologies, interactive digital whiteboards, and online communication platforms (e.g., Zoom, MS Teams) to transform the teaching and learning environment and experience. It complements the TLS.	Conventional online teaching methods (ex: Zoom, MS Team) have advantages and disadvantages. The main disadvantages of basic online teaching and learning are limited physical interaction with classmates/groupmates, loss of campus atmosphere, lack of face-to-face interaction with teachers, and inappropriateness for more dependent learners. These challenges are multiplied in CPL contexts as there are 2 learning contexts to take care. Some of the concerns and disadvantages can be addressed by adopting an immersive and integrative Cyber-Physical Learning Environment (CPLE) which looks at not just the technologies but also the learning space and interactions.

Solution

This Immersive and Integrative CPLE classroom examines the key characteristics and potential impact of such a cyber-physical learning environment on teaching and learning activities. Also, the learning environment can leverage data analytics and AI-driven insights to track learner progress, identify areas of improvement, and enhance the overall effectiveness of the educational experience. We use a design-thinking approach to develop the CPLE. This begins with a thorough needs assessment, identifying the target participants, learning objectives, and specific educational requirements and outcomes. Also, it involves the integration and advancement of cutting-edge technologies and pedagogy approaches to create a transformative educational experience.

Developments

The two key modes of pilot CPLE classroom at SUTD are (a) group-based activity and (b) lecturing/teaching activity.

a) **Group-based activity session:** Students engage in group-based learning activities involving both physical in-class and remote cyber participants. *Digital screens* with advanced features for annotations, content sharing, and broadcasting enable participants to have a collaborative learning experience by displaying annotations and sharing contributions flexibly among various groups or individuals not only in real-time but also across cyber and physical spaces. "*Audio Fencing*" feature in a CPLE also holds significant relevance for facilitating group activities, especially for online students, and enhances the overall experience by minimizing background noise and crosstalk to maintain focus on the core content of group discussion or activity, thus enhancing collaboration and engagement levels.

From user studies conducted, appropriately designed audio fencing feature plays an important role in supporting seamless and effective interactions between group-based cyber and physical learning activities.

b) Entire Class Lecturing/Teaching activity session: *The multiple digital screens and ceiling-mounted microphones* hold significant relevance for cyber-physical classrooms, making them more engaging, interactive, and effective, and thus enhancing the teaching and learning experiences. Multiple digital screen setup allows instructors to easily display teaching content with annotation and gallery views of remote participants, making instruction more efficient and clearer. This type of CPLE also maintains students' attention and supports different learning styles by providing a more dynamic and visually stimulating environment. In addition, gallery view of the remote participants on the digital screen allows the instructor to maintain visual contact with both physical in-class and remote cyber students simultaneously.

This fosters a sense of inclusive learning socialization and helps bridge the gap between physical and cyber participants. *Ceiling microphones* capture audio from overhead which ensures that instructor's and students' voices are heard clearly, regardless of their physical location in the classroom, thus enabling instructors to move freely around the classroom without degradation in audio quality. This is important as it ensures that cyber participants can always hear classroom interactions clearly throughout the lesson, no matter where the speaker (instructor or student) are in the classroom.

Moving forward, we plan to use the Tele-presence Learning System as a portable unit with Smart Board function for setting up a flexible and Smart classroom anywhere. This innovative approach will help us to make immersive learning possible in spaces beyond the traditional classrooms.

6. CASE STUDIES OF CYBER-PHYSICAL LEARNING AT PARTNER INSTITUTIONS

In this section, we bring you a compilation of the digital learning and CPL efforts and experiences at other institutions in Singapore and beyond. In 2022, we started with 5 CPL alliance partners. We now have over 14 international and local partners. Each of these institutions has its unique educational context and background. In bringing the various case studies together, we aim to have a platform to share, learn, and understand how the contexts shape the CPL and digital learning initiatives. Several of the CPLA partners have contributed to the section of case studies, providing an Asian and international perspective.

6A. THE INSTITUTE FOR THE FUTURE OF EDUCATION (IFE) EXPERIENTIAL CLASSROOM PROJECT AT TECNOLOGICO DE MONTERREY

Luis F. Morán-Mirabal, Hector G. Ceballos

Institution name: Tecnologico de Monterrey

Institution website: https://tec.mx/en

Programs offered: High school Programs, Undergraduate, and Postgraduate Programs in Science and Engineering, Business, Social Sciences and Government, Medicine and Health Sciences, Architecture, Arts, and Design.

Number of students: 87,000+ students in 26 campuses in Mexico

Number of faculty members: 11,115

Current educational models and pedagogical approaches use different educational technologies such as digital learning platforms, video conference systems, virtual and mixed reality headsets, mobile devices, and portable computer devices for in-person, remote, or hybrid participants. The combination of such technologies with different pedagogical approaches falls within Cyber-Physical Learning (CPL) environments where physical and digital processes are combined to enhance the overall learning experience.

The behaviours and interactions that take place between different stakeholders within CPL environments are key factors in understanding the effectiveness of modern educational models, therefore, a Living Lab approach where new technologies are tested in user-centered environments (Nesti, 2017) can help understand the use of educational technologies in different learning scenarios.

The Living Lab, which is part of the Living Lab & Data Hub initiative at the Institute for the Future of Education in Tecnologico de Monterrey, specializes in enabling research projects that involve experimentation with educational technologies in user-centered (i.e., students and faculty members) real-context learning environments (i.e., in-person, remote, and physical classrooms).

A signature project being developed by the IFE Living Lab is the Experiential Classroom, which consists of the equipment of a modular learning space with state-of-the-art sensors, devices, and educational technologies that allow researchers to collect, process, and analyze data related to the interactions taking place between students and faculty members in different CPL scenarios (Figure 6a.1). Although the Experiential Classroom physical site is still under construction (estimated to be ready by mid-2024), we have already initiated conducting experiments with different multimodal devices.

The Experiential Classroom project is directly related to the field study of Multimodal Learning Analytics (MMLA), which combines the use of technological devices to collect, process, analyze, and report data on the interactions that take place within learning environments and their contexts (Ochoa, 2022). By applying multiple Artificial Intelligence (AI) techniques and algorithms (e.g., Support Vector Machines, Neural Networks, Natural Language Processing, Heuristics), MMLA focuses on analyzing multimodal data to study teachers' and learners' interactions with educational technologies (Morán-Mirabal *et. al.*, 2023). Moreover, MMLA aims to close the gap between technology (tools) and pedagogy (theory) by analyzing educational data traces and linking them to pedagogical constructs, behavioural indicators, and actionable feedback (Boothe *et. al.*, 2022). Figure 6a.2 illustrates a data collection set up.

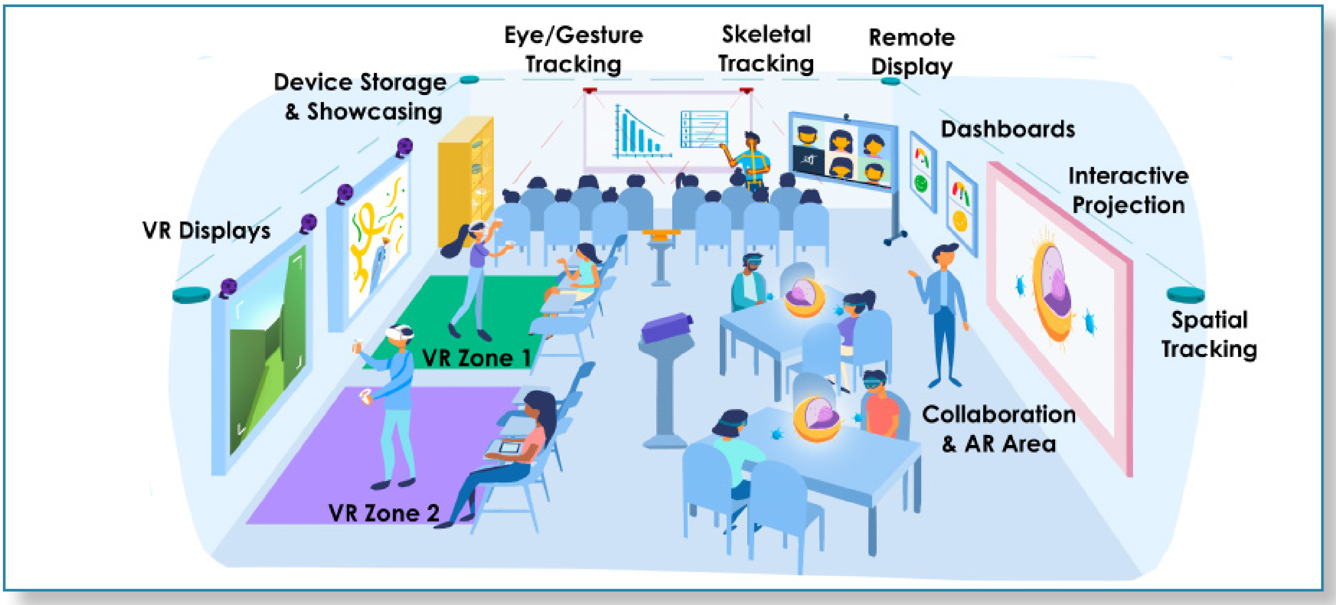


Figure 6a.1. IFE Experiential Classroom Layout

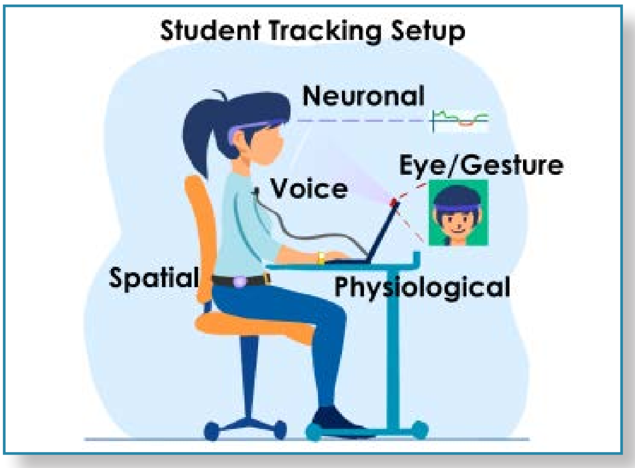


Figure 6a.2. Example of Data Collection Set-up at the IFE Experiential Classroom

In 2023, the Experiential Classroom conducted its first experiment, namely the "NPFC-Test" (Neuronal, Physiological, and Facial Coding Test), which aimed at capturing multiple modalities for valence, arousal, and emotion assessment. The NPFC-Test involved human-computer interaction within a 20-minute test that included different activities with audiovisual stimuli, concentration tasks, and self-reports. We collected raw data from brainwave activity using a portable EEG headband (Muse 2), digital biomarkers using a medical-grade smartwatch (Empatica Embraceplus), RGB video for facial gestures recognition using a high-resolution camera (Azure Kinect), and digital self-reports.

The data collected from the multimodal devices was processed and integrated into a dataset with 41 participants ranging from 23 to 46 years old (34% male and 66% female) with a maximum level of studies ranging from high school to doctorate level. The dataset has a one-second granularity and includes data such as the experiments' timestamp, the participants' IDs, the completed task type, the participants' self-reports on valence, arousal, and concentration, emotion probabilities computed with a residual masking network algorithm and the specific emotion detected using a support vector machine algorithm (Cheong *et. al.*, 2023), the participants' body temperature, electrodermal activity (EDA), blood volume pressure (BVP), the absolute band powers for alpha (α), beta (β), delta (δ), gamma (γ), and theta (θ) brainwaves based on logarithm of the power spectral density (PSD) of the EEG data (Clutterbuck, 2023), and the raw values collected in each of the four sensors of the portable EEG device.

The IFE Living Lab is currently documenting the experiment's dataset, which will be published as a data paper and will be offered to researchers, via the IFE Data Hub, for conducting MMLA research. We believe that the NPFC-Test dataset (Figure 6a. 3) will allow researchers around the globe to gain a better understanding of the relationship that exists between the collected multimodal attributes and the engagement shown by students in human-computer interaction cyber-physical learning scenarios (Bustos-López *et. al.*, 2022; Pekrun & Linnenbrink-Garcia, 2012).

Moreover, the IFE Living Lab is currently preparing a second multimodal experiment to be conducted in the Experiential Classroom, which seeks to assess teamwork and sense-making in remote learning

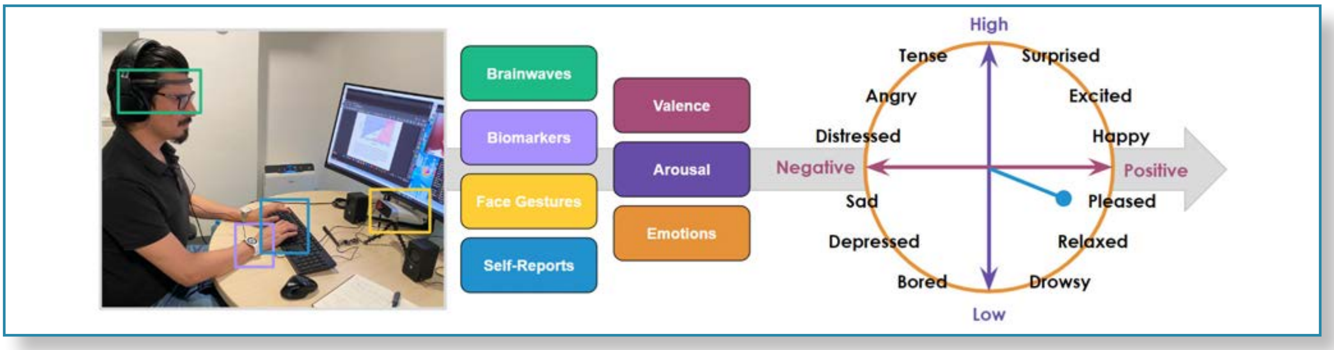


Figure 6a.3. Setup, and Relationship between Data Inputs and Outputs in the NPFC-Test

scenarios. The experiment, namely "GTL-Mars", is being developed in collaboration with the Global Teamwork Lab (GTL, 2015), which is currently led by the Massachusetts Institute of Technology (MIT), and consists of researchers from The Hague University of Applied Sciences (THUAS), the University of Groningen (RUG), and the University of Tokyo (UTokyo). The GTL-Mars will collect video, audio, and numerical data from students remotely working together to solve an optimization problem in a Mars colony simulation. The collected data will be processed and integrated into a dataset to analyze the emotions and conversational patterns shown by the participants throughout the experiment, allowing researchers to gain a better understanding of remote collaboration.

Throughout 2024, the IFE Living Lab will enable new experiments and research projects at the Experiential Classroom, introducing new devices, sensors, and educational technologies that allow the collection, processing, and analysis of visual, auditory, tactile, skeletal, physiological, neuronal, spatial, and environmental attributes and factors present in the teaching and learning process. Thus, fostering interdisciplinary collaboration with Tecnologico de Monterrey and inviting researchers and faculty members from around the world to engage in studying CPL environments and its applications.

References

Boothe, M., Yu, C. Lewis, A., & Ochoa, X. (2022). Towards a pragmatic and theory-driven rramework for multimodal collaboration feedback. In *LAK22: 12th International Learning Analytics and Knowledge Conference*, 507–513. LAK22. Online, USA: Association for Computing Machinery. https://doi.org/10.1145/3506860.3506898

Bustos-López, M., Cruz-Ramírez, N., Guerra-Hernández, A., Sánchez-Morales, L.N., Cruz-Ramos, N.A., Alor-Hernández, G. (2022). Wearables for engagement detection in learning environments: A review. *Biosensors*, *12*, 509. https://doi.org/10.3390/bios12070509

Clutterbuck, J. (2023). *Mind monitor technical manual. Mind monitor software.* https://mind-monitor.com/

GTL. (2015). *Global teamwork lab.* https://gtl.edu.k.u-tokyo.ac.jp/

Nesti, G. (2017). *Living labs: A new tool for co-production? Smart and sustainable planning for cities and regions: Results of SSPCR 2015 (pp. 267–281).* Springer International Publishing. https://doi.org/10.1007/978-3-319-44899-2_16

Morán-Mirabal, L.F., Avarado-Uribe, J., & Ceballos, H.G. (2023). Using AI for educational research in multimodal learning analytics. In M. Cebral-Loureda, E. Rincón-Flores, & G. Sanchez-Ante (Eds.), *What the AI can do: knowledge strengths, biases and resistances to assume the algorithmic culture (1st ed., pp. 154–174).* CRC Press, Taylor & Francis Group. https://doi.org/10.1201/b23345-11

Ochoa, X. (2022). Multimodal learning analytics - rationale, process, examples, and direction. In C. Lang, A. F. Wise, G. Siemens, D. Gâsevíc, & A. Merceron (Eds.), *Handbook of learning* analytics (2nd ed., pp. 54–65). Society for Learning Analytics.

Pekrun, R., Linnenbrink-Garcia, L. (2012). Academic emotions and student engagement. In: Christenson, S., Reschly, A., Wylie, C. (eds) *Handbook of research on student engagement*. Springer, Boston, MA. https://doi.org/10.1007/978-1-4614-2018-7_12

6B. ELEARNING AT THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY

Sean McMinn

Institution name: The Hong Kong University of Science and Technology

Institution website: https://hkust.edu.hk/

Programs offered: Undergraduate, Postgraduate

Number of students: 16,500

Number of faculty members: 780

The Hong Kong University of Science and Technology's e-Learning Strategy was updated in 2023 to outline the university's underpinning pedagogical approach to digital learning and set out the atmosphere and landscape to encourage and nourish the growth of innovative teaching and learning design.

The impact of the COVID-19 pandemic on the tertiary education sector has been substantial. HKUST's experience of switching to online delivery in 2019/20 boosted the growth of digital approaches to teaching, learning, and assessment, with almost all courses having a parallel digital footprint.

The emergence of generative Artificial intelligence (AI) tools such as ChatGPT has also brought new opportunities and challenges for digital education and learning in general. These tools can create personalized and adaptive learning experiences, facilitate metacognitive awareness through dialogic experiences and prompt engineering, generate feedback and assessment questions, facilitate online discussions and tutoring, and provide learning support for students. However, they also pose issues of quality, accuracy, ethics, privacy, and security of the generated content and interactions, as well as require students to develop critical thinking and digital literacy skills to evaluate and use them. Future advancements in AI will only add to the complexity of these opportunities and concerns.

Under this new normal, HKUST's e-Learning Strategy 2022-2025 has been further adjusted to align with global trends and to address the opportunities and challenges by adopting and exploring innovative pedagogies and technologies that leverage generative AI tools, virtual reality, and augmented reality.

HKUST's digital learning and Cyber-Physical Learning (CPL) vision is:

- To continue adopting and exploring appropriate technology and innovative pedagogy that provides high-quality course design, student-centered pedagogy, and flexibility of delivery and access to learning.
- To equip students and faculty with digital strategies and competencies necessary for future learning experiences.

Delivery of the curriculum through digital learning and CPL should take advantage of suitable technology and pedagogy that is evidence-based to achieve accessible, effective, and flexible learning experiences for all HKUST students. HKUST encourages the development of active learning components in courses using digital technologies, and the expansion of the following approaches to digital education:

i. Blended Learning, including flipped classroom

ii. Fully online learning (asynchronous, synchronous, or a combination of both) or self-paced online courses

iii. Mixed-mode (HyFlex) teaching

Our guiding principles are:

- Use technology effectively and innovatively to enhance and develop pedagogy.
- Maintain quality and control, evaluating and disseminating to support future development.
- Encourage faculty engagement and ownership.
- Ensure consistency across the university Virtual Learning Environment (VLE); for example, common templates, naming conventions.
- Ensure coherence with HKUST's Teaching and Learning Strategy.
- Incorporate flexibility in delivery of curriculum where appropriate.
- Ensure online materials comply with accessibility guidance and any national legislation. For example, intellectual property rights and data privacy.

Our strategic priorities include:

Learning Environments

Enhance physical and virtual learning environments to sustain current practices, enable flexibility and accessibility of learning (e.g. , mixed-mode teaching), and enable future digital education initiatives.

Innovative Pedagogy

Adopt and explore innovative methodologies, pedagogies and technologies that enhance digital learning, such as blended-learning, augmented reality, virtual reality, learning analytics, artificial intelligence, and gamification. For example, generative AI tools could be used to create personalized learning paths, generate feedback and assessment questions, facilitate online discussions and tutoring, and provide adaptive learning support for students.

Assessment Design and Practices

Design and implement innovative assessments that measure learning outcomes, align with course objectives, support learning processes, and ensure academic integrity, while considering the impact of technologies, especially AI, on assessment design and practices.

Quality Assurance

Ensure quality assurance and improvement in e-Learning and digital education, such as by learning analytics, course evaluations, external benchmarks, and surveys.

Faculty Development

Empower and support faculty members to develop competencies in designing, delivering, and evaluating e-Learning and digital education.

To support the above priorities, the university is committed to a strategy that achieves excellence in education through the implementation of digital education that:

- ensures learner-centred, active, and experiential learning
- provides students with accessible and flexible learning experiences and opportunities appropriate to their needs
- supports learning experiences that simulate real-world situations
- enables adoption and extends areas of innovative pedagogies, multimodal content delivery, and student engagement in physical and online, or appropriate combination of the two, learning environments
- fosters best practices for online assessments that measure learning outcomes
- involves the provision of a stimulating, participatory learning experience to cater to the learning needs of students anywhere
- addresses learning and well-being needs of students, including their range of content knowledge, critical thinking skills, literacies, special education needs, and increasingly diverse cultural background
- is evidence-based in design and implementation

Considering HKUST's e-Learning Strategy 2022-2025, this case study will share some of the innovative pedagogies and technologies that are shaping our approach to digital learning and Cyber-Physical Learning (CPL). This includes the following subtopics:

1. Educational Technologies for Creativity and Collaboration
2. Virtual and Mixed Realities in Design and Engineering
    a. Virtual Design Courses using Blender and Unreal Engine
    b. The Mixed-reality Teaching Laboratory
3. The Metaverse and Web 3.0
4. Generative AI in Education

By examining these subtopics, this case study aims to present both the successes and challenges HKUST faces in implementing its digital learning strategy.

Educational Technologies for Creativity and Collaboration

This subtopic explores the role of technology, specifically the use of Miroboard, in enhancing the creativity and collaboration of students. The focus is on how digital tools like Miroboard facilitate idea generation, collaboration, and aids in the application of the "4P's" of creativity: Person, Press, Process, and Product (Figure 6b.1).

The modern educational landscape calls for a more interdisciplinary approach, requiring students to engage in active, collaborative learning. While the benefits of such an approach are well-recognized, traditional classroom settings often limit the scope for active participation and cross-disciplinary idea exchange. As a student noted, the opportunity to cooperate, discuss topics together, and exchange ideas is invaluable for academic and career development.

Miroboard serves as a dynamic collaboration tool that supports the four dimensions of creativity (4P's). It allows students to actively engage in the learning process by generating a wide array of ideas and solutions. For instance, students used Miroboard for a short design activity related to pandemic management. The platform enabled them to iterate through the 4P's multiple times, deepening their understanding of how each component is interrelated towards influencing creativity.

This iterative process helps deepen students' understanding of how these components are interconnected and mutually reinforcing. For example, by going through the process of brainstorming (Process) multiple times, students may better understand how individual abilities (Person) can be honed, how different environments (Press) can impact the brainstorming process, and how the final ideas (Product) can be influenced by these various factors. Miroboard's collaborative features enable students to work together on a shared canvas, allowing them to collectively iterate through the 4P's—Person, Process, Product, and Press. This peer-involved, iterative process deepens their collective understanding of how these components are interconnected and mutually reinforcing, thereby enriching the group's overall creative capacity.

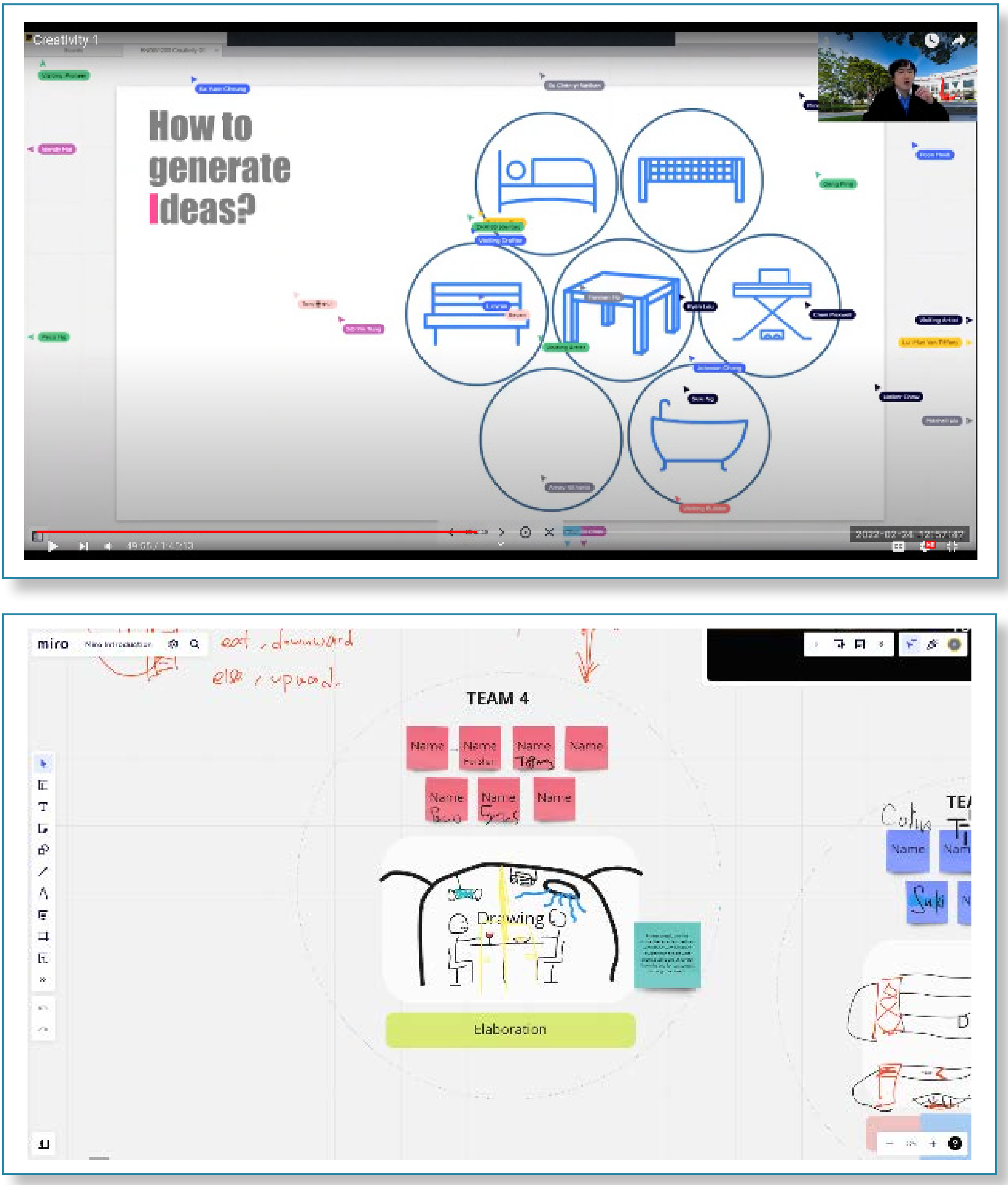


Figure 6b.1. Miroboard for Idea Generation and Collaboration

The integration of Miroboard into the course curriculum was seamless, with students quickly adapting to the tool's functionalities. Faculty members found it effective for facilitating real-time collaboration and idea sharing, thereby complementing traditional teaching methods.

The need for technology interventions like Miroboard arises from the limitations of traditional classrooms in fostering active, collaborative learning. In a conventional setting, the 4P's of creativity—Person, Process, Product, and Press—may be explored in a more linear or isolated fashion, limiting the depth of understanding and collaborative synergy. Miroboard's interactive and collaborative features, however, allow students to collectively engage with these elements in real-time on a shared canvas. This peer-involved, iterative process not only transcends physical space but also deepens their collective understanding of how these components are interconnected and mutually reinforcing.

Student feedback has been overwhelmingly positive. Many highlighted the tool's ability to turn theory into practice and to facilitate multidisciplinary collaboration. They found the platform beneficial for "future study and career development." These responses indicate that technology can indeed act as a significant enabler in creative and collaborative learning experiences.

However, it is important to note that the effective implementation of tools like Miroboard requires a shift in both faculty skill set and mindset. Faculty development programs are essential to acquaint instructors with the technical affordances of these tools and to challenge traditional pedagogical views on how creativity and collaboration can be taught. Given the success of this initiative, plans include expanding the use of Miroboard across other courses that could benefit from enhanced collaborative learning. For example, some HKUST Language and Common Core courses are already using Miroboard to encourage peer and collaborative work.

Virtual and Mixed Realities in Design and Engineering

This subtopic explores the integration of *Blender* and *Unity* animation softwares in the Cornerstone Engineering Design Project, focusing on how these technologies enhance the teaching and learning of virtual 3D design and modelling in an experiential context. Traditional engineering courses often rely on physical prototypes for design projects. While effective, this approach can be time-consuming, resource-intensive, and may lack the flexibility to explore complex design options quickly.

By incorporating Blender and Unity, students can quickly convert their design ideas into virtual 3D models, offering a more efficient and expressive medium (Figure 6b.2). The technologies allow for both realism and unlimited design capabilities, providing students with a new dimension to express their creativity and design skills.

Figure 6b.2. 3D Modelling of Learning Space Design (Video Link).

During initial lessons in the course, students were guided through both online and face-to-face experiences to develop their skills in the modelling software. The course structure enabled them to rapidly gain competence, allowing them to bring their design ideas into the 3D space and work collaboratively on design solutions.

However, there are limitations to consider. First, the constant evolution of software tools like Blender and Unity requires ongoing faculty development to keep pace with new features and affordances. Second, students often need additional support to learn these complex software tools, which can become even more challenging when versions are updated. Therefore, supplemental training sessions or resources may be necessary to ensure both faculty and students can maximize the potential of these technologies.

The Mixed-Reality Teaching Laboratory

The Mixed Reality Teaching Laboratory at HKUST enriches multi-modal content delivery in courses like Engineering Solutions to Grand Challenges of the 21st Century, enhancing student collaboration and participation (Figure 6b.3). Traditional laboratory settings may restrict the extent of experimental activities due to limitations like physical space, equipment availability, and the need for real-time, synchronous participation. These factors can inhibit the depth and breadth of practical learning experiences.

The Mixed Reality Teaching Laboratory allows for a more dynamic, interactive learning environment. Students equipped with goggles and a controller can engage in virtual experiments, transcending the limitations of physical space and equipment. Additionally, collaborative whiteboard software enables real-time teamwork, making the course more participatory.

However, there are important caveats to consider. While virtual simulations provide a valuable learning experience, they may not always accurately reflect real-world lab conditions, potentially leading to gaps in students' practical understanding. This divergence between the virtual and the real requires careful instructional design to ensure that learning objectives are fully met. Faculty development will also be needed to understand the pedagogical nuances of integrating virtual simulations effectively. Additionally, as with any technology, students may need extra support and training to become proficient with the virtual lab equipment, especially given that such platforms may frequently update and evolve.

The Metaverse and Web 3.0

HKUST integrates Metaverse and Web 3.0 technology in education, focusing on how it enables students to become global builders in various professional fields. The introduction of the Metaverse concept transforms the digital educational experience from a 2D to a 3D perspective. Courses at HKUST are experimenting with allowing students to actively participate as Metaverse builders, gaining hands-on experience in the development of Web 3.0 and 3D modelling (Figure 6b.4). This equips them with skills applicable to a variety of professional fields, including architecture, engineering, and even the e-sports industry. By doing so, students have engaged in the development of Web 3.0 which allows them to acquire new knowledge and skills that are directly applicable to emerging industries.

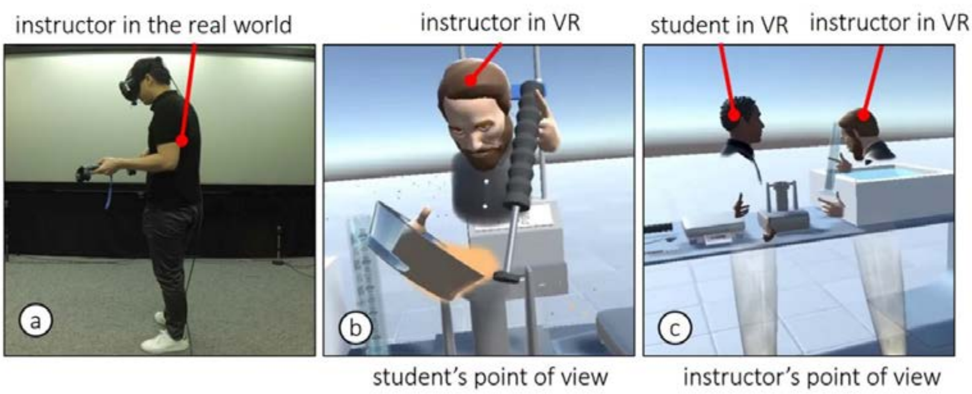


Figure 6b.3. Mixed Reality Learning Experiences at HKUST

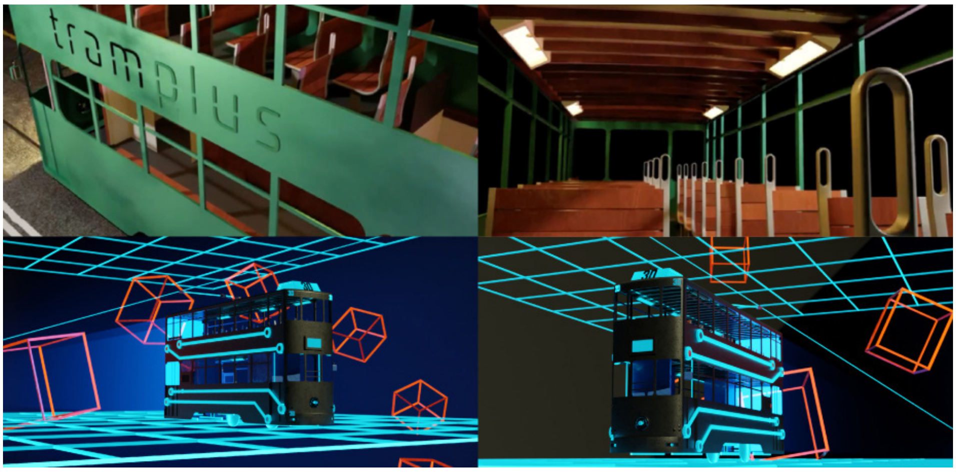


Figure 6b.4. The Tramplus X HKUST "3D Engineering Challenge" STEM Program

The Metaverse and Web 3.0 represent the next frontier in digital interaction and professional application. Traditional 2D educational platforms are insufficient for preparing students for the complexity and opportunities in this evolving 3D digital ecosystem.

However, there are several limitations and challenges to consider. First, the rapidly evolving nature of the Metaverse and Web 3.0 technologies necessitates constant faculty upskilling to stay current. Second, the high costs and availability of necessary hardware, like VR headsets, can create accessibility issues, potentially limiting the range of students who can fully participate. Third, while the Metaverse offers a new dimension of interactive learning, it also raises questions about the validity and reliability of these virtual experiences in representing real-world scenarios. Finally, students may initially experience disorientation or discomfort while adapting to the 3D virtual environment, requiring additional support and orientation sessions.

Generative AI in Education

Genrative AI tools are now being utilised in various courses at HKUST, including Creative Sound Design course, an AI Literacy & Critical Thinking course, and a module on AI-assisted Design thinking. Traditional teaching methods in creative disciplines and critical thinking courses may not fully leverage the capabilities of modern technology, limiting opportunities for active, collaborative learning and real-world application. Additionally, they may not utilize the potential of AI to be an active dialogic partner, allowing students to collaborate with chatbots to explore new ideas, consider feedback and perspectives they may not have considered, or test an idea or theory.

In the Creative Sound Design and Computer Music course, AI tools are deployed to accelerate the processes of music and video creation while also facilitating peer feedback, thereby fostering an active learning environment. Meanwhile, the course on AI Literacy and critical Thinking integrates AI education with active learning exercises, with a particular emphasis on exploring the societal and ethical dimensions of AI. Additionally, a newly developed teaching and learning module focuses on AI-Assisted Design Thinking, incorporating generative AI tools directly into the design thinking process to enrich the student experience. Each of these interventions serves to modernize the educational experience, making it more dynamic, interactive, and aligned with real-world applications.

Students in these courses are introduced to a range of AI tools that serve as catalysts for experiential learning. Peer feedback mechanisms and diverse assessments are used to promote collaborative and self-directed learning.

The inclusion of AI tools addresses the need for more dynamic, interactive, and real-world-aligned educational experiences. AI serves as a 'creative partner' for students, enhancing efficiency and expanding the scope of what they can achieve. Preliminary self-assessments have been positive, with students reporting enhanced learning experiences, greater efficiency in creative tasks, and a culture of independent and collaborative learning.

While AI tools offer numerous advantages, there are challenges, such as the need for ongoing faculty development and ethical considerations surrounding AI use. Future iterations of these initiatives will focus on refining the AI tools used and optimizing peer feedback mechanisms. Experience and materials will be shared with the wider HKUST teaching community to encourage the adoption of these tools in other courses.

Concluding Section: Reflecting on the Journey and Looking Ahead

As HKUST navigates through the evolving landscape of e-learning and digital education, several lessons have emerged that are crucial to our pedagogical approach. Technologies like Miroboard and 3D design software have revealed the immense potential for interdisciplinary learning, enriching both creativity and collaboration among students. However, the rapid pace of technological advancements necessitates an ongoing commitment to faculty development. While we have recognized the transformative possibilities of virtual and mixed realities, it's essential to address the disparities between these simulations and real-world experiences. The question of accessibility remains a constant concern, especially as we delve deeper into resource-intensive platforms like the Metaverse. Moreover, as we incorporate more AI-driven tools, ethical considerations, and data privacy must be at the forefront of our initiatives.

Looking ahead, our short-term plan prioritizes faculty training in e-learning and digital education. With the growing importance of digital learning and CPL, it's imperative to provide comprehensive training sessions through New Faculty Orientation and Professional Development workshops. Furthermore, we acknowledge the value of stakeholder feedback and will continue to analyze it to refine our digital teaching and learning strategies. While we have not yet fully implemented learning analytics, we recognize this gap as an area for future growth. Given our increasing engagement in digital learning and CPL, we have access to rich datasets that, when analyzed securely and ethically, can provide invaluable insights to inform practice and policy. In the long term, we aim for greater flexibility in course delivery to meet the diverse needs of our students. Our courses will increasingly include digital artifacts like lecture recordings and supplementary materials to enrich the learning experience. We also aspire to establish a robust system for learning analytics, building on our short-term focus on data-based decision-making. As we look intoo the future, these lessons and goals will guide us in creating a more dynamic, ethical, and inclusive educational experience. The focus will not just be on the implementation of new technologies and pedagogies but on their continuous refinement to ensure they are evidence-based, ethical, and accessible, thereby laying the groundwork for a holistic, high-quality education for all our students.

6C. CYBER-PHYSICAL LEARNING @ THE SINGAPORE INSTITUTE OF TECHNOLOGY (SIT)

Ong Chee Ming, Karin Avnit, Lim Li Siong, Budianto Tandianus, Julia Teo Kwok Lee, Steven, Wong Kai Juan

Institution name: Singapore Institute of Technology

Institution website: https://www.singaporetech.edu.sg/

Programs offered:) Undergraduate, Postgraduate, CET

Number of students: ~10,000

Number of faculty members: ~400

The Singapore Institute of Technology (SIT) became Singapore's fifth autonomous university in 2014 to provide an applied learning pathway towards a university degree. Applied learning is defined as a pedagogy that links the knowledge, skills and attitude taught in the university to an industry context including real-work applications and the acquisition of professional traits. The university is set to move to a permanent campus in 2024, one that is built with a blended learning paradigm involving both online (cyber) and face-to-face (physical) learning opportunities. In this case study, we will trace the development of blended learning at SIT and how it complements SIT as the "University of Applied Learning". Starting from a strategic perspective, we will then expand to specific examples that supports the desired pedagogical outcomes and the academic development that is required to achieve those outcomes. The case study will conclude with our lessons learnt, as well as how SIT sees the future of learning.

A Definition of Blended Learning

SIT's blended learning pedagogy relies on both online (cyber) and face-to-face (physical) to realise its vision of an applied learning environment. Refer to Figure 6c.1 below for SIT's model of blended learning.

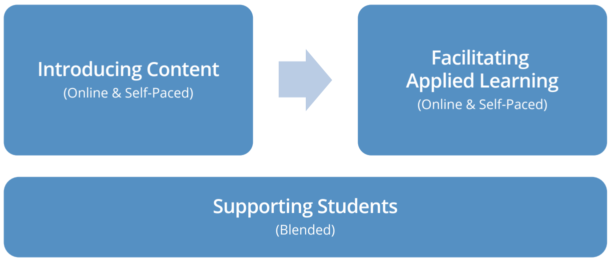


Figure 6c.1. SIT's Model of Blended Learning (SIT Practice Guide for Blended Learning, 2023)

In this model, the online mode is used to introduce content in an asynchronous manner, applied learning is facilitated through face-to-face sessions. Academic staff provide support to students in both the online and face-to-face modes i.e., blended.

History of Blended Learning at SIT

As an autonomous university set up in 2014 to provide an applied learning pathway towards a degree, it was envisioned that SIT would appeal to students who prefer a hands-on approach to learning. Such a pedagogy would place emphasis on active learning and an authentic learning environment as the two important dimensions of applied learning. Figure 2 illustrates the range of applied learning activities that takes place at SIT.

As seen from Figure 6c.2, traditional modes of teaching through lectures and tutorials are kept to a minimum as these are considered relatively passive and remote from the industry context. In the planning of the physical learning environment, experiments were done with flexible seating arrangements and computer-on-wheels (COWs) to form an Applied and Collaborative Learning Environment or ACE rooms at its temporary campus (Figure 6c.3).

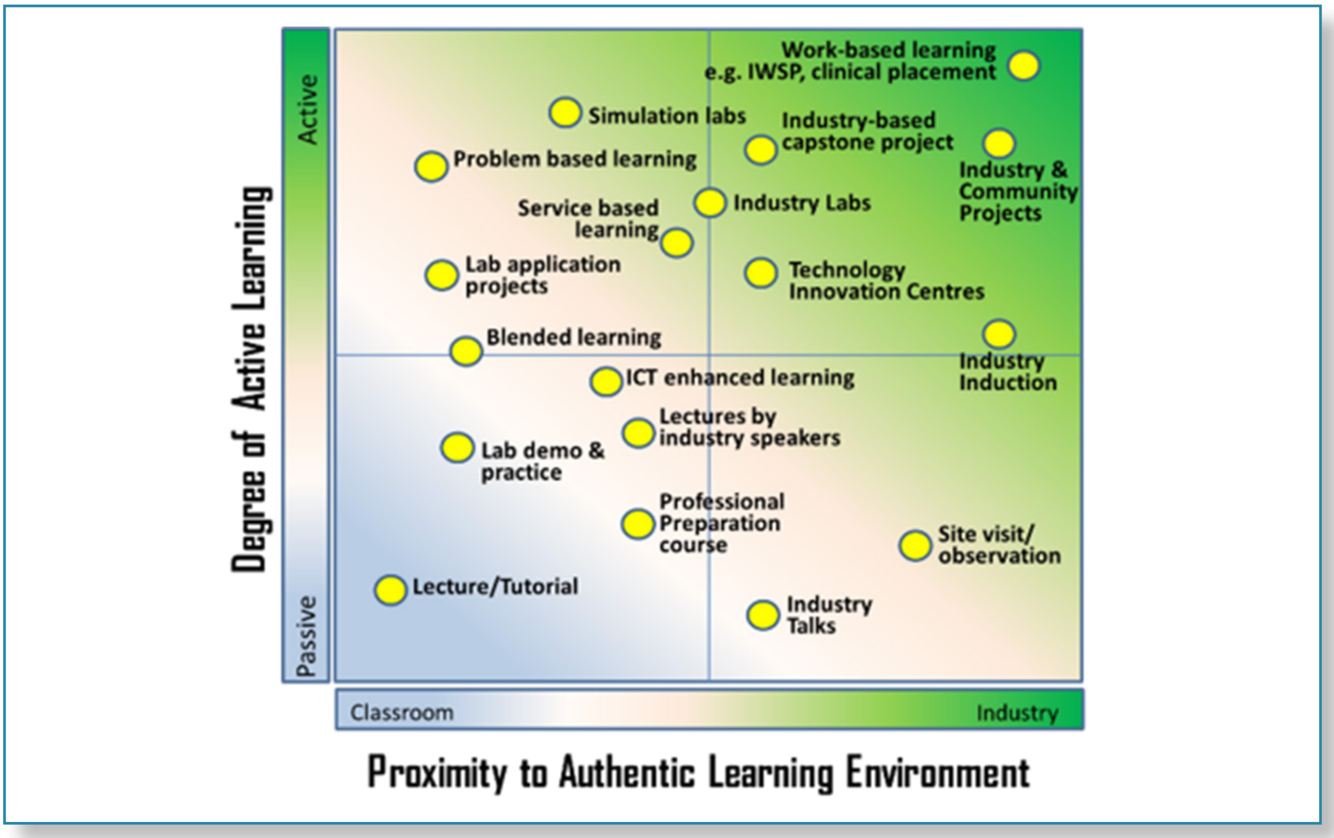


Figure 6c.2. Applied Learning Activities at SIT (Lim *et al.*, 2020)

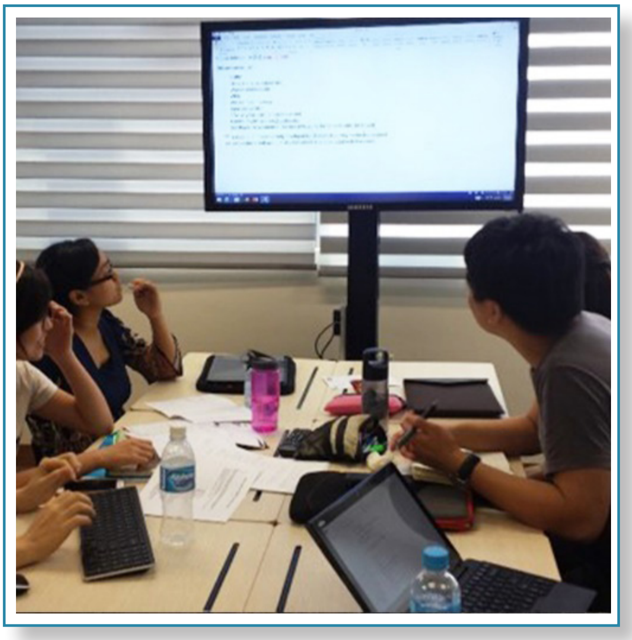


Figure 6c.3. Applied and Collaborative Learning Environment (ACE)

Active learning spaces such as ACE rooms and lectorials (a tiered environment to support both a didactic lecture and a collaborative tutorial) formed the basis of SIT's plans for her permanent campus in Punggol, estimated to be ready in 2024.

Attention was also placed on the online learning environment, beginning with her signature adaptive learning bridging course known as Math Quest, and extending to bite size learning modules and micromodules in the undergraduate courses. In 2019, SIT rolled out a series of Competencies for Online and Remote Teaching (CORT) to equip academic staff with the skills to develop the skills necessary to create online video lessons, conduct synchronous live online sessions, conduct asynchronous online discussions and conduct online assessment and give feedback online. The CORT experience helped SIT pivot to online learning during the pandemic in 2020 and gathered valuable inputs to put forth an SIT Practice Guide on Blended Learning in 2023, including some of the best practices of interactive online learning, face-to-face student engagement and the support provided to students in a blended learning environment.

Implementing the Flipped Classroom and its Variations

The flipped classroom pedagogy was selected as the default model for the implementation of blended learning in SIT due to its alignment with the applied learning pedagogy. While learners engage in asynchronous online learning of basic content, valuable face-to-face time can be used to focus on hands-on active learning that also build both technical and transferable skills needed for the workplace. It is hoped that learners also develop a mindset to be self-directed, resourceful and reflective while engaging with the online contents. Educational developers, instructional designers and media producers worked closely with academic staff to achieve this through high quality online lessons, engaging face-to-face classes as well as provision of support for learners in the blended learning environment. The support to students would be crucial for the blended learning vision to be achieved. To complement the flipped classroom model, variations were also suggested including online synchronous sessions that involved guest lecturers and extend the boundaries of the classroom, as well as a seminar approach that is highly active and collaborative. The implementation of a blended learning approach also served to provide opportunities for academic staff development and holistic student development.

GenAI Module for Academic Staff

As part of its applied learning pedagogy, SIT has placed emphasis on authentic assessment such as the use of projects and case studies. In the light of an explosion of generative AI (genAI) tools such as ChatGPT, it became imperative for academic staff to be able to defend the validity and integrity of current assessment practices. To do this, an online AI Module was rolled out in 2023 to all academic staff to learn about generative AI and included an assignment to apply genAI knowledge learnt from the module to review a current assessment task that has a significant weightage. In this assignment, academic staff were required to reflect and make changes to the assessment task and grading rubrics after stress testing their assessment using a range of genAI tools. These changes made should render the assessment valid and yet retain its authenticity. Academic staff that completed the exercise successfully were awarded a digital badge that signifies attainment of a fifth CORT competency. Educational developers and technologist were called to support the academic staff in this review to collaboratively acquire current generative AI knowledge and strengthen SIT's authentic assessment capabilities.

Alongside this AI module are 2 other digital foundation modules:

- **Adopting a Digital Mindset**: Focuses on understanding the significance of a digital mindset and how to effectively use digital tools for supporting digital transformation.
- **Data Analytics Fundamentals**: Covers fundamental concepts of data analytics and practical skills in data collection, preparation, analysis, and predictions using Microsoft Excel.

Together, these modules are designed to equip SIT teaching staff with essential digital literacy skills and knowledge to integrate digital technology with pedagogy.

XR and Digital University

Extended Reality (XR) for learning has been appreciated as one of the teaching tools in SIT especially during the COVID-19 pandemic era. This is evident from numerous XR applications for learning were developed. As a result, the proposed virtual campus platform (called UniverseSITy) is the culmination of various isolated XR projects in SIT in which the platform will unify the current and future effort into one common platform in the UniverseSITy.

Moreover, SIT is in the process of consolidating its activities in its permanent campus in Punggol Digital District (PDD). PDD is an upcoming smart district located at the northeast region of Singapore where industry, education, and government will have a close relationship in pursuing technological innovation. As the UniverseSITy will become a multi-fidelity and multi-modality platform that enables wide range of campus activities, ranging from merely virtual walkthrough, virtual classroom, to virtual experimentation, the UniverseSITy may also complement various aspects of campus life in Punggol which in turn will ease SIT in scaling up its activity as SIT community size is expected to grow over the years.

The virtual campus initiative will not be a one-off effort, as it will be built over the years incorporating various state-of-the-art or latest innovation in various aspects such as technology, pedagogy, way of life, and more. Currently we envision the UniverseSITy will be developed in multiple phases with the first phase focuses on virtual classroom for demonstrating its feasibility and benefit in teaching and learning. It can be later extended in the subsequent phases by enabling cyber-physical classroom through Living Lab.

Future of Learning

We see the future of learning being characterised by a convergence of technological advancements and a reimagining of the educator's role. Educators are no longer just disseminators of information; their focus shifts towards facilitating learning and nurturing holistic student development. Learning experiences become highly tailored to individual students. Technology enables self-paced learning and leverages AI and data analytics to provide customized content and assessments.

Traditional classroom settings evolve into blended and flipped models. Educators leverage in-person or virtual environments for high-level thinking activities, such as facilitated discussions, collaborative problem-solving, and real-world applications of knowledge. Learning environments, both physical and virtual, are purposefully designed to align with the pedagogical approach. They are equipped with cutting-edge technology, flexible furniture, and resources that facilitate active learning, collaboration, and exploration. These spaces are dynamic, responsive, and conducive to a variety of learning activities.

The curriculum is enriched and shaped through dynamic collaboration with industry experts. This integration takes various forms, from internships and co-op programs to industry-sponsored projects and guest lectures, ensuring students graduate with relevant skills and knowledge that align with real-world demands.

In this envisioned future, education transcends traditional boundaries, embracing the potential of technology while recognising the irreplaceable value of the physical human interaction and mentorship to provide highly personalised and engaging learning experience.

References

Lim, S. M., Foo, Y. L., Loh, H. T., & Deng, X. (2020). *Applied learning in higher education: perspective, pedagogy, and practice.* Informing Science Press.

Singapore Institute of Technology. (2023). *SIT practice guide for blended learning.* Unpublished Internal Document.

6D. CYBER-PHYSICAL LEARNING @ SINGAPORE UNIVERSITY OF SOCIAL SCIENCES (SUSS)

Feng Lin, Che Yee Lye, Jennifer Yeo, Lyndon Lim, Chye Seng Lee, Rebekah Wei Ying Lim

Institution Name: Singapore University of Social Sciences

Institution: https://www.suss.edu.sg/

Programs offered: Undergraduate, postgraduate, CET

Number of students: about 30000

Number of faculty: about 250 full-time faculty; over 1000 active associates per year

Singapore University of Social Sciences (SUSS) has been pioneering and championing continuous education and lifelong learning since its establishment. We offer over 90 undergraduate and graduate programs that can be pursued through full-time or part-time study options. Our programs are designed to be adaptable, modular, and interdisciplinary, serving the needs of both fresh graduates and adult learners. SUSS also offers continuing education and training modular courses, catering to the professional skill enhancement needs of Singapore's workforce.

Our student population primarily comprises part-time adult learners who often need to navigate the complexities of managing professional commitments, personal lives, and personal development. To better address the diverse and multifaceted needs of these adult learners, SUSS has been exploring technology integration to create an educational environment characterized by flexibility, accessibility, and industry relevance. Concurrently, we place a strong and deliberate emphasis on the pedagogy and learning science associated with the use of technology. Within the context of the three dimensions delineated by Singapore University of Technology and Design (SUTD) in the sphere of cyber-physical learning (CPL), namely, technology, learning sciences, and ethics, SUSS aligns closely with the learning sciences facet. Our approach to cyber-physical learning is driven by the imperative to enable both online and classroom learning through the use of pedagogically sound and technologically robust methods, all while adhering to ethical principles. In the subsequent sections, we illuminate a selection of SUSS initiatives that exemplify the technology, learning sciences, and ethics in CPL.

Technology

As an institution catering to diverse adult learners, SUSS has long had a system of implementing learning and teaching structures that cater to flexible and self-directed learning. The advancement in technology for mass online learning and extensive digitalisation of learning resources have enabled SUSS to continually innovate its provisions and meet the diverse needs of adult learners. One initiative with such focus on diverse adult learner needs and advancement in technology is the Adaptive Learning System (AdLeS).

AdLeS (Figure 6d.1) was developed in-house for SUSS learners to support personalised and self-directed learning. It utilises algorithms and data analytics to assess learners' performance and modify learning materials accordingly such that each learner engages with content that is most relevant and challenging to their current level of understanding. We embarked on the AdLeS journey in 2020, and developed and launched the first prototype--- the AdLeS Bridging learning model in 2021. Since then, the prototype has been expanded to two other models, i.e., the Flipped Learning and Revision learning models. Specifically, the Bridging learning model supports learners' academic bridging, the Flipped Learning model supports learners in understanding the knowledge before attending the classes that focus on the application of knowledge, and the Revision model helps learners to revise knowledge learnt in the class.

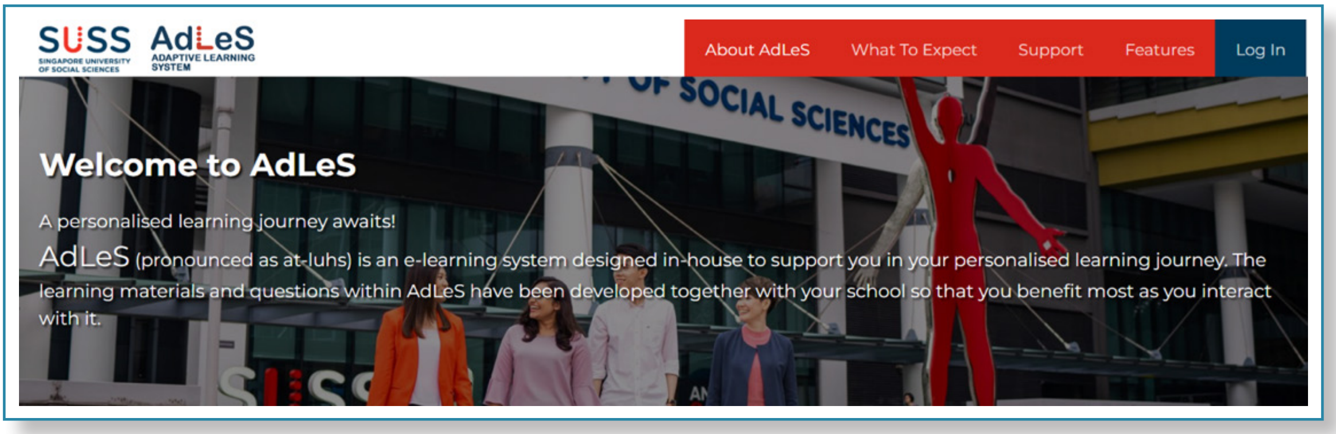


Figure 6d.1. AdLeS Homepage

All AdLeS learning models comprise four key elements: Prudence (initial diagnostic assessment), Adaptive Content, Adaptive Sequence, and Adaptive Assessment. It is a system that is intended to "learn" from learners' interaction with it and adjust content, sequence, and assessment to adjust learning pathways and pace of learning. AdLeS not only facilitates student-centred learning in online and physical spaces but also empowers both educators and learners with insightful data, enabling them to identify and address gaps in knowledge and skills effectively, thereby fostering a more supportive and effective learning environment.

Learning Sciences

For effective integration of technology, we place a significant emphasis on developing faculty and associates' understanding of the complex relationship between technology, pedagogy, and content knowledge (i.e., TPACK) (Mishra and Koehler, 2006). In our commitment to facilitate this integration, we have developed professional development in teaching and learning to promote faculty and associates' technological pedagogical content knowledge, empowering them to employ technology in pedagogically sound ways and exploring technological innovations to enhance content delivery. In the following, we showcase two initiatives aimed at developing technological pedagogical knowledge and technological content Knowledge.

Developing technological pedagogical knowledge (TPK) viz. Knowledge Building

The Teaching & Learning Centre (TLC) in SUSS has been developing and conducting a series of Professional Development in Teaching and Learning (PDTL) workshops aimed at enhancing the understanding of the integration of technology and pedagogy among faculty and associates at SUSS. One specific example of such workshops is the advanced session on "Designing Computer Supported Knowledge Building."

Knowledge Building is a computer-supported collaborative learning model in education, emphasising students taking collective cognitive responsibility to improve their community knowledge (Scardamalia & Bereiter, 2014). Knowledge Building often leverages the use of an online discussion platform called Knowledge Forum, which serves as a communal space where students collaboratively pursue inquiry and continuously refine their ideas, ultimately contributing to the creation of new knowledge. To help instructors understand the pedagogy of Knowledge Building and its associated technology, TLC designed and conducted a three-session workshop spanning one month, covering aspects including pedagogy, technology, practice, and reflection (Lin et al., 2023). It adopted a community-based approach combined with experiential learning (Kolb, 1984). In essence, participating instructors learned about the pedagogy of Knowledge Building and its technology by immersing themselves in the technology-supported knowledge-building process through professional development training. Ultimately, these workshops equipped instructors with the proficiency to design knowledge-building pedagogy using technology, all while thoughtfully integrating technology to support and enhance students' knowledge-building process.

Developing technological content knowledge (TCK) viz. Immersive Technology

The Use of Immersive Technology in Pedagogy Project is intended to introduce practice-oriented immersive technology to support teaching and learning in selected SUSS courses. The project started in 2021 and consists of five phases – concept and initiation, definition and planning, launch/execution, performance and control, and project close and post-project review. It is currently in the third phase – launch/execution. To date, we have 12 projects coming from all five schools in SUSS. 7 of them have completed content development with 1 in progress and 4 new projects in the tender phase. Two projects, both from NSHD (S R Nathen School of Human Development), have gone through trials and are currently being fine-tuned for actual implementation. Another two projects from SST (School of Science and Technology) and SBIZ (Scholl of Business) on Electromagnetics and Supply Chain Management respectively were launched recently in Oct 2023.

As an illustrative example, consider the GER 527 course, "Technology in an Aging Society." This course involves the study of Gerontechnology which aims to address the evolving needs of an aging population. It focuses on scientific research and advances in technology that can enhance the physical and mental health, social participation, and safety of seniors. Graduates of the gerontology program are expected to operate in technology-rich environments alongside their elderly clients. To facilitate this learning, a virtual reality (VR) environment has been developed. VR has the potential to create an immersive experience for learners by blurring the boundary between physical and virtual worlds (Suh & Prophet, 2018). It has been demonstrated to enhance learning and promote positive emotions among students (Mahmoud, et al., 2020). In our context, the VR setup offers students in the course an opportunity to experience a simulated real-world context in which they can develop their skills and knowledge of solving problems in a technology-rich environment (Figure 6d.2). With this VR learning set-up, students get to role-play how they will work with different types of seniors with dementia. Students can also interact with the environment with examples from different cohorts of older persons and reflect their needs e.g., psychosocial, physical, and physiology dimensions of older persons through set-up with the computer systems and contents. They can also learn how to make use of a VR environment to do rehabilitation exercises with the seniors as part of recovery process.

Ethics

The ethical considerations in the utilisation of digital tools are diverse and encompass a wide range of areas, including privacy, security, usability, accessibility, and societal impact, etc. (Chung, et al., 2015). At SUSS, we maintain a vigilant approach towards ethical practices in emerging technologies. For instance, when ChatGPT was introduced, SUSS promptly addressed the appropriate use of Generative AI and the associated ethical concerns. In alignment with the principles advocated by the Ministry of Education (MOE), we developed an assessment guideline outlining the appropriate use of generative AI tools. This guideline was issued to both instructors and students on the 23rd February 2023, with immediate effect.

Figure 6d.2. The Use of Immersive Technology in Pedagogy Project

In addition, TLC developed and conducted professional development training for faculty and associates, empowering them in understanding the limitations of ChatGPT and its ethical considerations, and in exploring the capabilities of ChatGPT using effective prompts to design lessons, instructional activities, and assessments. In tandem, a new workshop was also conducted to guide students in unlocking the potential of ChatGPT, including writing effective prompts to generate ideas for writing, summarizing content, planning for projects, and utilizing ChatGPT as a learning companion, etc. Furthermore, our commitment to fostering ethical and responsible AI usage is reflected in the updates made to our academic integrity workshops and resources. These enhancements encompass generative AI-related topics, including responsible use of generative AI and the proper citation practices.

References

Kolb, D. A. (1984). *Experiential learning: experience as the source of learning and development*. FT press.

Lin, F., Low, W. Y., Zhu, G.X., & Teo, C.L. (2023). Examining university instructors' conceptions and perceived changes in knowledge building professional development. *Proceedings of Annual Meeting of the International Society of the Learning Sciences*. 1058-1061.

Mahmoud, K., Harris, I., Yassin, H., Hurkxkens, T. J., Matar, O. K., Bhatia, N., & Kalkanis, I. (2020). Does immersive VR increase learning gain when compared to a non-immersive VR learning experience? In *International Conference on Human-Computer Interaction* (pp. 480-498). Cham: Springer International Publishing.

Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: a framework for teacher knowledge. *Teachers College Record*, *108*(6), 1017-1054.

Scardamalia, M., & Bereiter, C. (2014). Knowledge building and knowledge creation: theory, pedagogy, and technology. In R. K. Sawyer (Ed.), *Cambridge handbook of the learning sciences* (pp. 397-417). Cambridge University Press.

Suh, A., & Prophet, J. (2018). The state of immersive technology research: a literature analysis. *Computers in Human Behaviour*, *86*, 77-90.

6E. CYBER-PHYSICAL LEARNING 2.0 @ INSTITUTE FOR ADULT LEARNING (IAL), SINGAPORE UNIVERSITY OF SOCIAL SCIENCES

Samson Tan Yong Tiong

Institution name: Institute for Adult Learning (IAL)

Institution website https://www.ial.edu.sg/

Programs offered: Adult Education (CET)

Number of students: 800

Number of faculty: 60

In the wake of the COVID pandemic, digital transformation, and tech-enabled learning IAL has responded by developing online CET solutions and providing digital learning tools and resources. IAL is also committed to developing a comprehensive suite of programmes and services to meet the needs of the changing workforce. In cyber-physical learning 1.0, the IAL's focused on using MicroLearning as an approach to enable just-in-time learning with greater learners' agency, which underpins the needs for workplace learning (Hamilton, Hall & Hamilton, 2021; Dolasinski & Reynolds, 2020).

The disruption caused by the COVID pandemic has also highlighted the need to integrate learning spaces more effectively. IAL is working to create a comprehensive learning ecosystem that integrates physical and virtual spaces to provide learners with optimal learning outcomes. IAL is also investing in the latest technologies and trends to ensure learners stay ahead of the curve. This is in keeping with IAL's mission to raise the quality of adult education. As part of its innovation strategy, IAL has set up an innovation lab, in.lab, to encourage the development and adoption of proven innovations and learning technologies, thereby strengthening the different learning spaces with sound pedagogical practices.

Reimagining Cyber-Physical Learning for Adult Learning

The microlearning approach employed by IAL was well received and encouraged the use of more advanced learning strategies. With the success of microlearning, IAL is taking cyber-physical learning to the next phase by integrating formal and informal learning spaces seamlessly, enhancing critical dimensions of learning design, and supporting pedagogical innovation (Bennett, Knight & Rowley, 2020; Munday, 2022). This transformation seeks to create a learning environment that is conducive to collaboration and critical thinking, as well as encouraging learners to become more engaged in their own learning. A further goal of this transformation is to create a more immersive learning experience that integrates physical and virtual components (Tan, 2023a).

To design IAL's theoretical framework for cyber-physical learning 2.0, two digital learning frameworks are evaluated to provide insights into the rapidly evolving adult education landscape. The Community of Inquiry theoretical framework (Garrison, Anderson & Archer, 2000) capitalizes on the convergence of social, cognitive, and teaching presence to create a deep and meaningful learning experience. Imbuing a sense of social presence facilitates interaction between learners and teachers and allows learners to present themselves as 'real people' in the community of inquiry. Through sustained communication, cognitive presence refers to the degree to which participants can construct meaning for assessing critical discourse and reflection. Essentially, teaching presence facilitates cognitive and social processes with the goal of achieving meaningful, educationally meaningful outcomes for learners.

While Tan's (2023) revised instructional model for immersive learning was not intended for hybrid learning specifically, its focus on learning affordances such as interaction, immersion, presence, and learner agency provided a useful reference for IAL's conceptual development of cyber-physical learning 2.0. A desirable end state would be to enable learners to experience the flow of dynamic generation of knowledge (Csikszentmihalyi, Montijo & Mouton, 2018). A positive unintended consequence of the COVID pandemic has been the proliferation of learning technologies that support hybrid Learning, which has led to a much more affordable deployment of cyber-physical learning 2.0.

Through the integration of these two learning models, IAL aims to meet the evolving needs of adult learners while remaining grounded in future-oriented pedagogical practices. Ultimately, this integration is a step towards providing adult learners with a comprehensive educational experience.

Cyber-Physical Learning 2.0

IAL's approach to cyber-physical learning stems from the need to integrate the different learning spaces – classroom, virtual, work, and personal space – particularly for adult learners who are often juggling multiple diverse responsibilities and finding time to learn, as well as their desire to learn for work and personal development. By synthesizing the Community of Inquiry (Garrison, Anderson & Archer, 2000) with Tan's (2023) instructional model for immersive learning, IAL has designed an updated cyber-physical learning model for adult education which is being piloted in an innovative learning space). This model aims to bridge the digital and physical worlds to create a more immersive learning experience, including dimensions such as collaborative learning, active learning, and social learning (Bachir, & Abenia, 2019). As depicted in the following Figure 6e.1, this pilot project aims to gather actionable insights that will be used to inform IAL's redesign of learning spaces for future-focused cyber-physical learning.

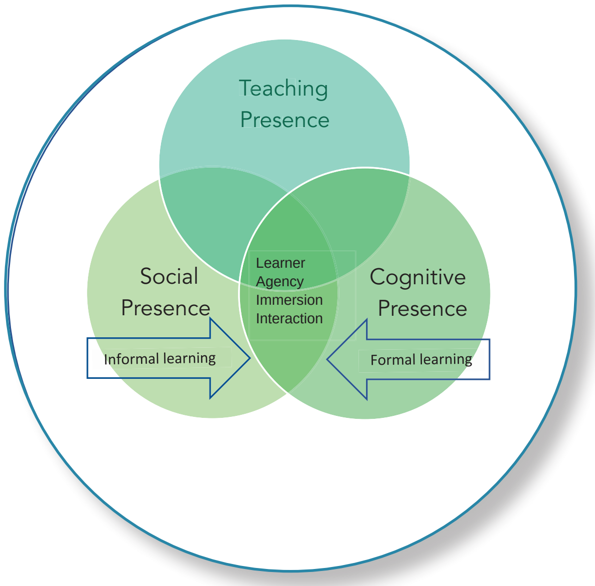


Figure 6e.1. IAL's Cyber-Physical Learning Conceptual Model 2.0

Future Development

With the rapidly changing educational landscape, specifically in the arena of generative artificial intelligence (AI), IAL continues its relentless pursuit of harnessing learning technologies to enhance adult education. As AI transforms education, it has the potential to provide personalized learning experiences based on the needs of individuals through Personalized Adaptive Learning Systems (PALS). AI can provide personalized learning experiences tailored to adult learners' individual needs (Luckin, 2018). For example, AI-driven PALS can automatically adjust the difficulty level of a lesson plan or assign learners to work on tasks specific to their individual needs. Similarly, the rapidly expanding capabilities of generative AI are already impacting the development of curriculum and assessment (Rudolph et al, 2023; Tan, 2023b). It is expected that AI will play an increasingly pivotal role in shaping IAL's cyber-physical learning framework in the future.

References

Bachir, S., & Abenia, A. (2019). Internet of everything and educational cyber physical systems for university 4.0. In *Computational Collective Intelligence: 11th International Conference, ICCCI 2019*, Hendaye, France, September 4–6, 2019, Proceedings, Part II 11 (pp. 581-591). Springer International Publishing.

Bennett, D., Knight, E., & Rowley, J. (2020). The role of hybrid learning spaces in enhancing higher education students' employability. *British Journal of Educational Technology, 51(4),* 1188-1202.

Csikszentmihalyi, M., Montijo, M. N., & Mouton, A. R. (2018). *Flow theory: optimizing elite performance in the creative realm.*

Dolasinski, M. J., & Reynolds, J. (2020). Microlearning: a new learning *model. Journal of Hospitality & Tourism Research, 44(3),* 551-561.

Garrison, D. R., Anderson, T., & Archer, W. (2000). Community of inquiry instrument *APA PsycTests.* https://doi.org/10.1037/t32875-000

Hamilton, J., Hall, D., & Hamilton, T. (2021). Microlearning in the workplace of the future. In *Microlearning in the digital age: The design and delivery of learning in snippets,* 240-263.

Luckin, R. (2018). *Machine learning and human intelligence: The future of education for the 21st Century*. UCL IOE Press. UCL Institute of Education, University of London, 20 Bedford Way, London WC1H 0AL.

Munday, D. (2022). Hybrid pedagogy and learning design influences in a higher education context. *Studies in Technology Enhanced Learning, 2*(2).

Rudolph, J., Tan, S., & Tan, S. (2023). ChatGPT: Bullshit spewer or the end of traditional assessments in higher education? *Journal of Applied Learning and Teaching, 6(1).*

Tan, S. (2023a). Harnessing immersive technologies for innovation in teaching and learning. In *Learning intelligence: innovative and digital transformative learning strategies: cultural and social engineering perspectives* (pp. 305-334). Singapore: Springer Nature Singapore.

Tan, S. (2023b). Harnessing artificial intelligence for innovation in education. In *Learning intelligence: Innovative and digital transformative learning strategies: cultural and social engineering perspectives* (pp. 335-363). Singapore: Springer Nature Singapore.

6F. STRATEGIC DEVELOPMENT OF A CYBER-PHYSICAL ECOSYSTEM AT NGEE ANN POLYTECHNIC

Shirley Williams, Philip Lau

Institution Name: Ngee Ann Polytechnic

Website address: https://www.np.edu.sg/

Programs offered: PET Diploma courses, CET, Specialised courses and workshops

Number of students: About 12,000 PET students and about 20,000 CET students (in 2022)

Number of faculty members: About 800

Ngee Ann Polytechnic (NP) adopts a strategic and holistic approach to develop its cyber-physical ecosystem for Digital Learning Transformation. NP builds infrastructure and capabilities to enable quality learning for both PET and adult CET learners, while ensuring flexibility to meet the priorities and needs of both groups. This first article looks at NP's overall considerations as well as the priorities for PET learners. The second article addresses the learning preferences of adult learners regarding online learning.

Ngee Ann Polytechnic (NP) www.np.edu.sg offers over 35 full-time diploma courses and a variety of part-time formal programmes and short courses for adult learners across many industries and professions. Since 1963, NP alumni have made their mark as entrepreneurs, engineers, corporate leaders, filmmakers, designers, researchers, healthcare professionals, and specialists in many other fields.

As one of the first polytechnics to move its vision of the IT-savvy learner, NP introduced Mobile e-learning in 1999 from vision into implementation, enabling a key shift from the then largely computer lab approach to IT for learning to a more ubiquitous environment of flexible access to learning through student-owned laptops.

Since then, the vision has gone through further transformations including the vision to inject full Remote Learning into the curriculum for all full-time students. This initiative was executed in phases starting in 2016 to ensure that every student who graduated experienced self-directed remote learning in at least 7 modules. A good proportion of NP's faculty were therefore well-placed with skills and readiness for the initial move into home-based learning during COVID-19 and were ready to see new opportunities beyond the pandemic.

From pioneering these initiatives, NP drew lessons for itself about moving "Future-Oriented Teaching and Learning", defining clear and significant change, and staging the transition for students and faculty. Our key success factors include Vision and Leadership, Systems and Structure, Capability Development, and Communication & Change Management. NP has tailored strategies for its full-time diploma courses and CET programmes.

Vision and Leadership

NP's management continues to provide Vision and Leadership to set the context for NP's holistic teaching and learning transformation to develop future and industry-ready graduates. In 2022, the current phase of transformation was summarised as "ERC" where "Experience" includes the new curricular balance of blended learning, "Relevance" emphasizes significantly re-defining a heightened presence of Industry in Curriculum and "Choice" which introduces a new framework of Personalised Learning Pathways that students may take.

In 2021, post-Covid, NP's leadership collectively envisioned the future of work and learning and the role of digitalization at the individual Course, School and Polytechnic levels to set the direction and positioning of the "Blend of Learning" at NP.

This vision was translated to form the institutional guidepost for all full-time diploma courses to iteratively review and re-design the curricula such that there is a good balance and intentional digital-enabled self-directed learning with stronger collaborative and applied in-person learning at NP.

Known internally as the 40:60 Blend of Experience, the guidepost sets the thresholds of up to 40% of the curriculum that may be delivered online fully asynchronously and 60% delivered in person (Figure 6f.1). This institutional guidepost has given significant impetus to the current phase of digital learning transformation[2].

Systems and Structures

Systems and structures include various aspects like Learning Analytics, Learning Management System, Support system, and Space.

Learning Analytics from students' progress through self-paced Online Asynchronous Learning (OAL) provides critical insights for faculty to provide appropriate support during In-Person Learning (IPL) where students clarify, deepen, and apply learning in collaboration with other learners.

NP's Learning Management System (LMS) was upgraded with Learning Analytics affordances in April 2022 and other key EdTech tools and platforms require careful planning and staging. The transition to the new LMS involved the migration of more than one thousand modules from the earlier system.

A new NP timetable format with the unambiguous presence of OAL clearly signals the importance of the roles and expected workload for students and faculty (Figure 6f.2). Every School's organisational Structure now includes the purposeful set-up of a Digital Learning Transformation (DLT) team to support and enable faculty in this transformation journey.

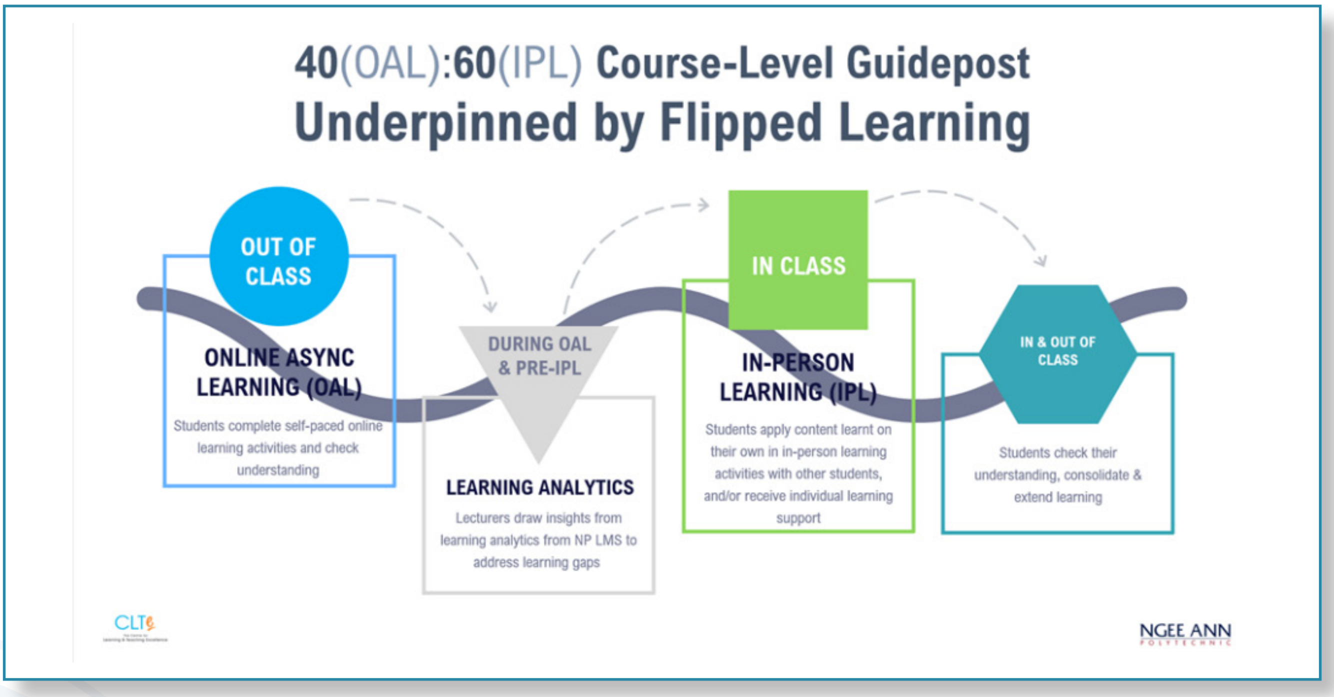


Figure 6f.1. Ngee Ann Polytechnic's 40:60 Blend of Experience

1 50%:50% (online:in person) blend is proposed as a general guidepost for CET.

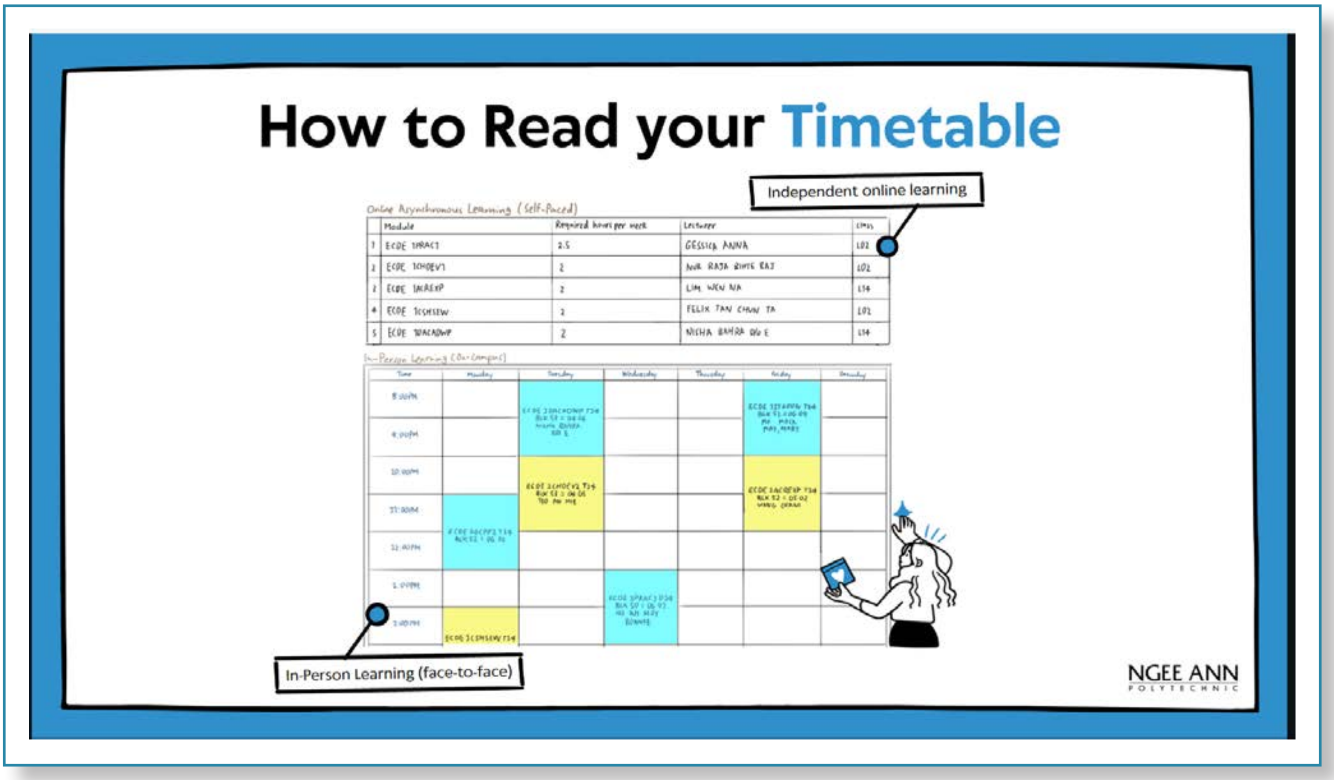


Figure 6f.2. Screenshot of Student Communication Pack

Beyond upgrading our systems, tools, and platforms that collectively form our cyber learning space, NP's physical **Spaces** are also being systematically re-imagined and re-developed in tandem. NP has started on its roadmap to progressively convert its traditional classrooms to what is known internally as "Smart Classrooms"**.** With appropriate learning design and skillful facilitation, the Smart Classroom affordances have powerful potential to enhance collaborative engagement, deepen applied learning and strengthen the dynamics of IPL. The affordances in these rooms also enable hybrid learning activities such as having industry experts as virtual guests. As more Smart Classrooms are made available, more NP modules are being timetabled and relevant faculty are being trained to design lessons that take advantage of the affordances of the Smart Classrooms (Figure 6f.3). This brings us to the next success factor.

Figure 6f.3. Active Collaboration in an NP Smart Classroom

Capability Development

Professional Development of lecturers is vital for successful Digital Learning Transformation. The Centre for Learning & Teaching Excellence (CLTE) conducts intensive train-the-trainer workshops for School DLT teams and supports them to train and coach lecturers. NP's Education Specialists at CLTE and in the Schools render ongoing support to individual staff and Schools as needed.

The train-the-trainer workshops for School DLT teams are part of capability development synchronized with NP's digital learning transformation roadmap. The workshops equip School DLT Teams to progressively train lecturers over four semesters – starting with learning the new LMS and basic OAL design, to enabling the capture and interpretation of OAL learning analytics, designing effective IPL, and improving the overall quality of flipped learning through student feedback and lesson observations.

Communication and Change Management

Another important success factor is communication and change management. A brief and student-friendly communication pack sets out the aim and focus of Flipped Learning and the importance of students' ownership of learning. Communication with faculty and the careful staging for change, bringing together Systems, Structure, Spaces, and Capability Development cannot be overemphasized.

Looking Ahead

NP's Digital Learning Transformation is an ongoing journey of checkpoints including the newly emergent need to envision how we at NP evolve as "AI-enabled educators nurturing AI-empowered learners**".** As with our earlier phases, this next phase will continue to depend on a compelling institutional vision, leadership synergy at different levels, effective and forward-looking pedagogy, appropriate resourcing, capability development, as well as clear and systematic communication and change management.

While recognizing the impact of technology on the future of work and learning, NP anchors its strategy on transformative pedagogy with a clear focus on the interests of PET and CET learners. Experience, the E in ERC that is NP's current phase of transformation, is adapted for CET learners for reasons outlined in the following article.

6G. ADULT LEARNERS PREFERENCES FOR ONLINE SYNCHRONOUS VERSUS ONLINE ASYNCHRONOUS LEARNING IN NGEE ANN POLYTECHNIC

Nasirudeen Ama, Katayon Saed

Continuing Education and Training (CET) courses at Ngee Ann Polytechnic (NP) have adopted NP's Experience, Relevance, Choice (ERC) curricular direction against the backdrop of a stock take of CET courses conducted in 2022. These changes will help improve the overall experience (E) and academic quality (R) and ensure consistent support (C) across CET courses offered by different schools/ departments in NP.

For CET courses, NP has set a guidepost of 50%:50% (online: in-person), a 'New Blend' which is underpinned by the Institute for Adult Learning (IAL)'s findings on adult learner preferences (Tan & Sheng, 2021), and NP's own research on Adult Learners' Digital Learning Readiness (NP CET Academy, 2020). IAL's findings showed a preference for online synchronous learning (OSL) by adult learners (n>1300). NP's research showed that adult learners preferred a 50:50 blended learning approach (n=313).

The 50% online components may be conducted synchronously (OSL) and/or asynchronously (OAL) and instructors were empowered to conduct the 50% online components in both synchronous and/ or asynchronous manner. The effectiveness of online learning happens when learners find comfort and motivation in engaging through communication (Yamagata-Lynch, 2014). Hence, we wanted to take an evidence-based approach through an online survey to understand adult learners' preferences for OSL versus OAL.

We also had to adhere to polytechnic requirements that due diligence must be exercised to ensure that the percentage of online delivery does not fall below the 30% online learning milestone and the interactivity level 2 for self-paced online learning, all polytechnics have achieved since 2019. At interactivity level 2, there must be some interactivity, compared with interactivity level 1 which learners have access to a repository of learning artifacts without interaction (NP Information Paper 5, 2022).

The online survey was available to all NP CET learners from May 2023 till July 2023. A total of 414 NP CET learners responded to the online survey (Figure 6g.1).

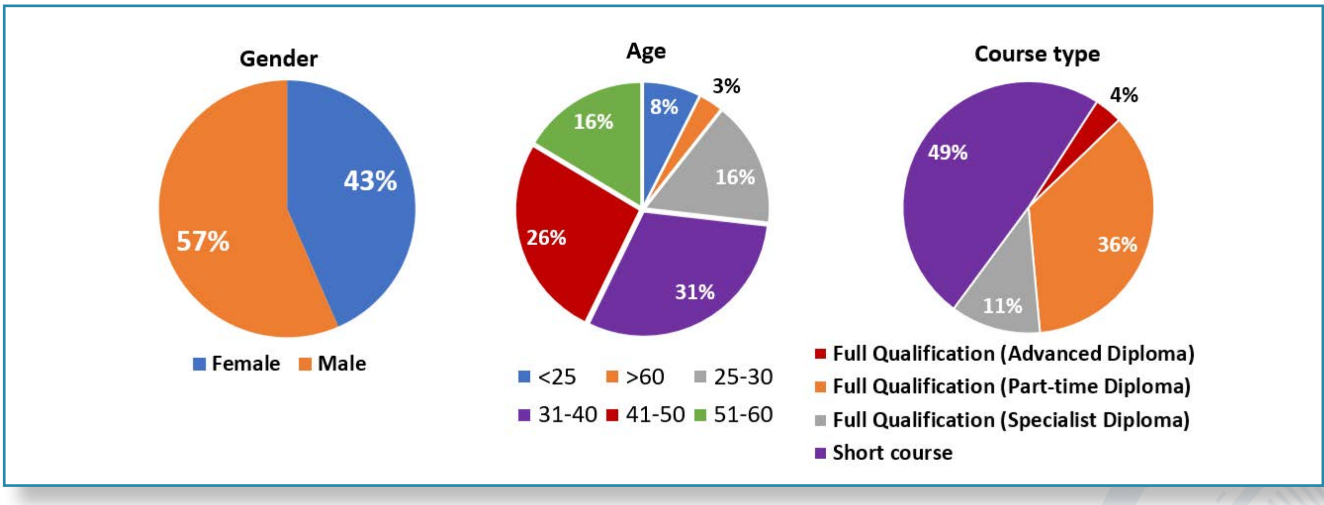


Figure 6g.1. Profile of NP CET learners who Responded to the Survey (n=414)

Adult Learner's Preferences for Modes of Online Learning

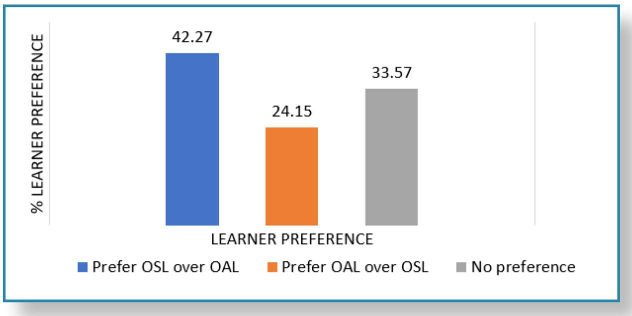


Figure 6g.2. Overall Online Learning Preference, OSL *Vs* OAL

As shown in Figure 6g.2, about 42.27% of adult learners preferred OSL compared to OAL. However, 24.15% of them preferred OAL, and 33.57% had no preference.

An estimated 52.08% of Full Qualification (Specialist Diploma) learners preferred OSL to OAL, followed by 42.86% of Short Course learners and 39.19% of Full Qualification (Part-time Diploma) learners. However, only 33.33% of Full Qualifications (Advanced Diploma) learners preferred OSL to OAL (Figure 6g.3). All learners more than 25 years old preferred OSL over OAL. However, learners less than 25 years old preferred OAL over OSL. As the age range of the learners increased from <25 years to 51-60 years, their preference to OSL over OAL increased, from 22.58% to 48.53% (Figure 3). For both female and male learners, the preference towards OSL was more than OAL. More male learners (44.44%) preferred OSL over OAL compared to female learners (39.44%) (Figure 6g.3).

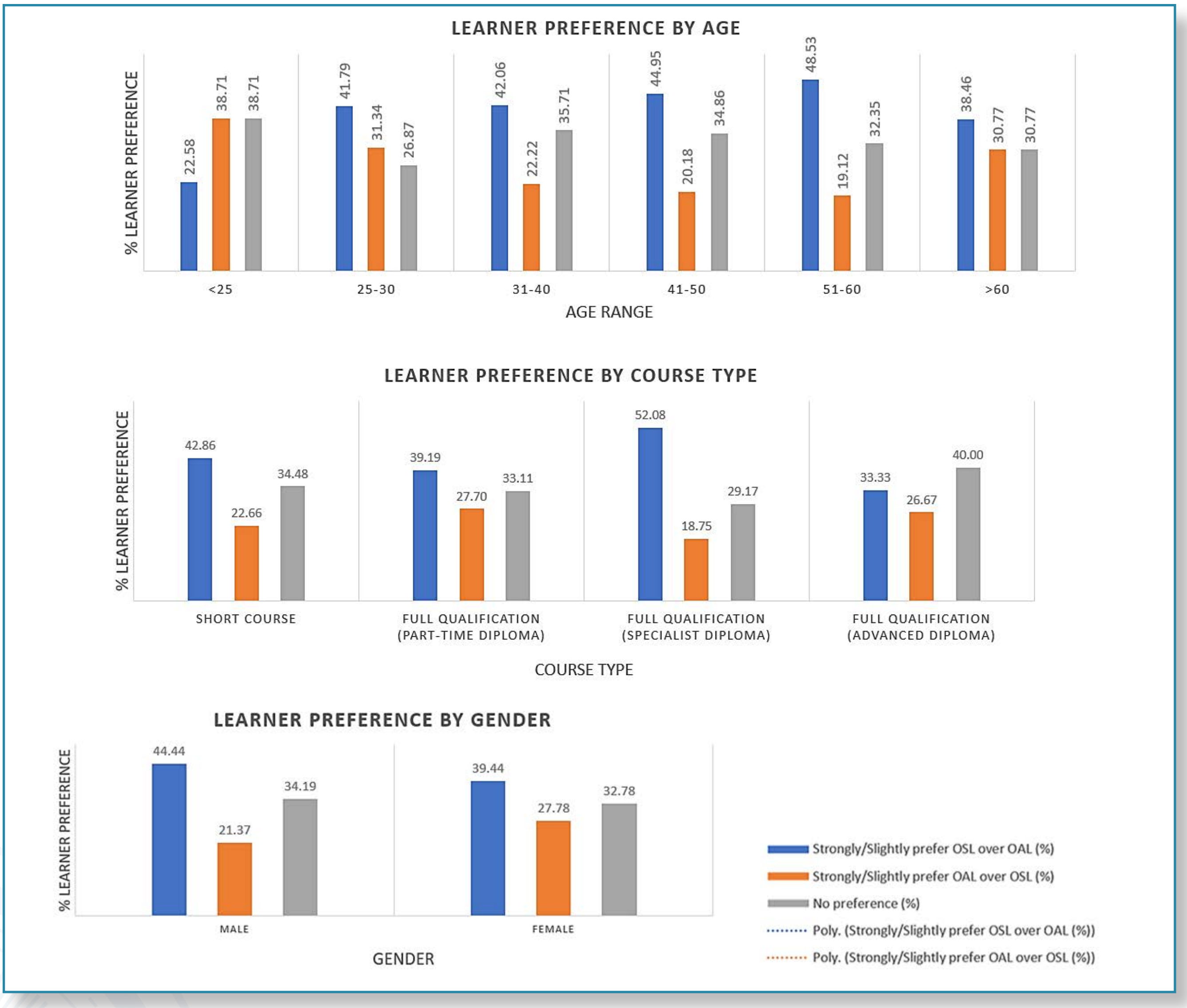


Figure 6g.3. Online Learning Preference, OSL *Vs* OAL of CET learners by Age, Course Taken and Gender

Online Synchronous Learning vs On-Campus Learning

Learners were also surveyed on how likely they would take up an option to learn synchronously online (OSL) vs on-campus lessons, if they were given the option to. Our study shows that more than 70% of adult learners would take up OSL even if on-campus lessons were offered. (Figure 6g.4).

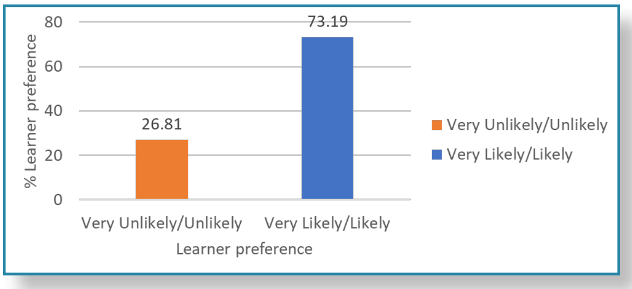


Figure 6g.4. OSL vs On-Campus Learning Preference of Adult Learners

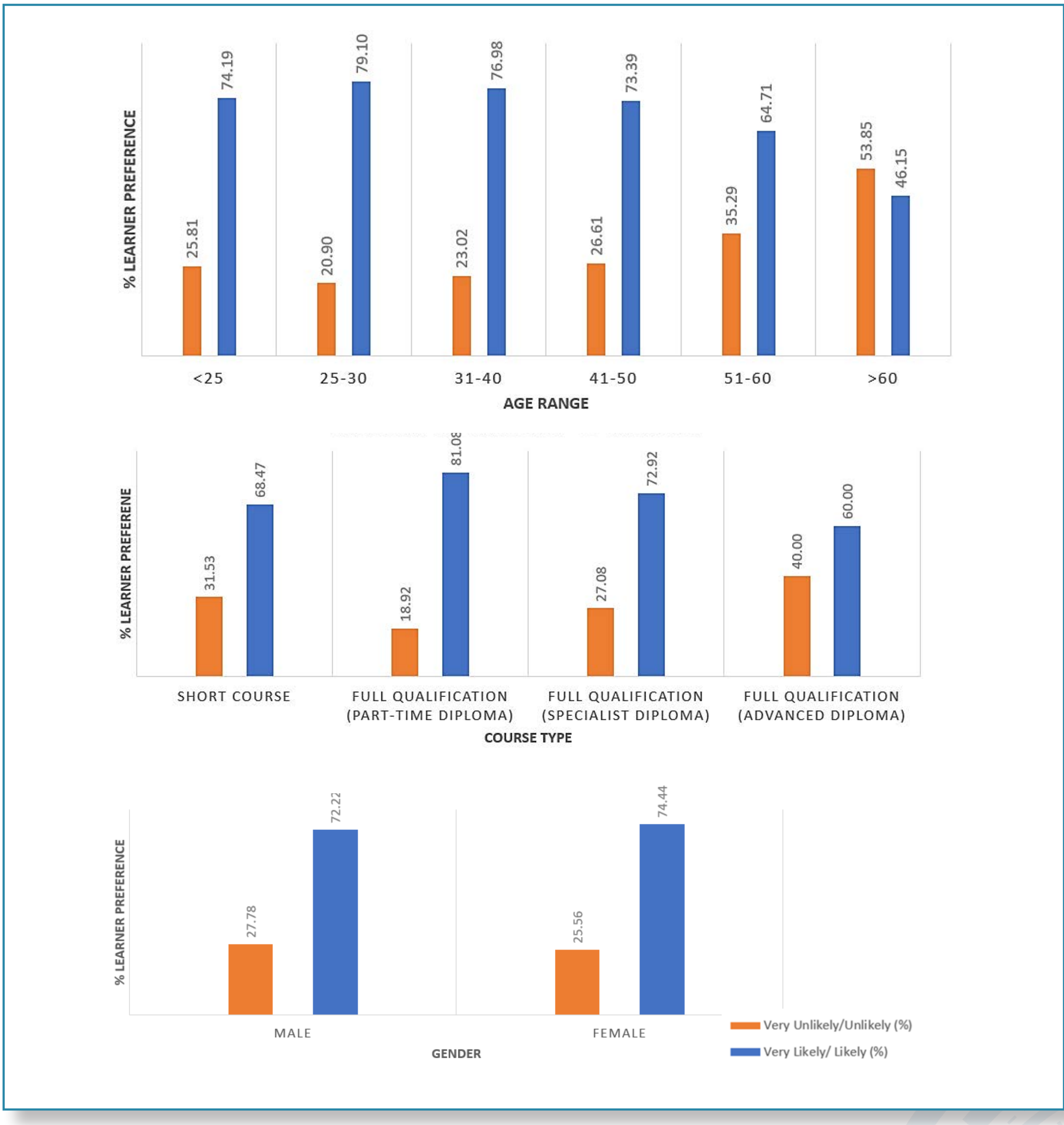


Figure 6g. 5. OSL Preference vs On-Campus Lessons of Adult Learners During Hybrid Learning by Age, Course taken and Gender

In addition to Short Courses, NP offers a range of Full Qualifications (FQ) courses including Part-time Diploma, Specialist Diploma, and Advanced Diploma. Results showed that the majority of the Part-time Diploma (81.08%) and Specialist Diploma learners (72.92%) would likely or very likely take up OSL, compared to 68.47% of Short Course and 60% of Advanced Diploma learners (Figure 6g.5). Most learners (79.10%) from the age range of 25-30 years would likely or very likely take up OSL compared to learners >60 years old (53.85%) (Figure 6g.5). Both female and male learners would likely or very likely take up OSL: 72.22% male and 74.44% female (Figure 6g.5).

Conclusion

Offering both online synchronous (OSL) and online asynchronous (OAL) learning and the option of on-campus lessons gives participants the flexibility to attend the program even if they have busy work schedules (Mavropoulos et al., 2019). This flexibility is essential for adult learners, who often must balance work, family, and other commitments with their education. A balance between synchronous and asynchronous delivery is also important for providing learners with the best possible learning experience.

When asked how likely they would take up an option to learn synchronously online (OSL) vs asynchronously online or on-campus lessons, most students indicated a strong preference for OSL. This suggests that adult learners prefer OSL to OAL or on-campus lessons. However, a significant percentage of adult learners prefer OAL and on-campus lessons to OSL.

In conclusion, the flexibility and balance offered by OSL, OAL, and on-campus lessons are essential for making online learning programs accessible and effective for adult learners. This study's findings can help NP to better meet the needs of its adult learners by designing CET courses that offer a mix of OSL and OAL delivery modes and by giving learners the option to choose between OSL and on-campus lessons.

References

Mavropoulos, A., Sipitanou, A. & Pampouri, A. (2019l. Training of adult trainers: implementation and evaluation of a higher education program in Greece. *International Review of Research in Open and Distributed Learning, 20(1)*. https://doi.org/10.19173/irrodl.v20i1.4143

NP CET Academy. (2020). NP's adult learners' digital learning readiness, CET-Adult-Learners-Report_V04_Final_14Sep2020.pdf (www.np.edu.sg)

NP Information Paper 5 (2022). *NP's Blended Learning Approach from AY2022/2023. Paper 2/2022 SM/ IP 5.*

Zhen, T. B., & Zher, S. Y. (2021). *The adult learners' perception of online learning due to COVID-19*. Institute for Adult Learning Singapore.

Yamagata-Lynch, L.C. (2014). Blending online asynchronous and synchronous learning. *The International Review of Research in Open and Distributed Learning, 15(2).*

6H. TRANSFORMING LEARNING IN WAFER FABRICATION PROCESS THROUGH SMART LEARNING SPACES:

AN EXPERIMENTAL JOURNEY AT THE SCHOOL OF ELECTRICAL AND ELECTRONIC ENGINEERING (EEE), SINGAPORE POLYTECHNIC

Lim Joo Ghee, Safura Anwar, Lim Siew Kuan, Leck Hwang Keng, Allan Wong Ann Ming, Wong Weng Yew, Julie Fan, Hequn, Tang Lian Geck, Nur Akmar Mahat

Institution name: Singapore Polytechnic

Institution website: www.sp.edu.sg

Programs offered: Diploma, Specialist Diploma and CET training

Number of students: 12,391 Full-time Diploma students, 356 Polytechnic Foundation Programme students, 3778 Part-time Diploma students and 81,994 CET training places

Number of faculty members: 1422

Enhancing student experience in lab settings with the integration of the Internet of Things (IoT), 5G capabilities, Augmented reality (AR) and Virtual Reality (VR) applications, Digital Twin technology, and other emerging technologies can significantly transform the learning process, making it more engaging, interactive, and conducive to effective knowledge retention. By integrating these technologies into the lab settings, students will be empowered to explore, experiment, and comprehend engineering concepts more effectively.

The School of Electrical and Electronic Engineering (EEE) at the Singapore Polytechnic (SP) has embarked on an experimental journey to revamp the learning experience for students enrolled in the Wafer Fabrication module. Recognizing the dynamic nature of the semiconductor industry and the need for hands-on supported by immersive learning, the School has adopted a Flipped Approach to the teaching of the Wafer Fabrication Process module.

This report outlines the transformation journey undertaken through the setup of a Smart Learning Space, comprising a smart classroom and a smart lab, at the School of EEE.

Background of School of EEE at SP

Singapore Polytechnic (SP) is known for its commitment to producing graduates who are well-prepared to meet the demands of the industry and contribute to Singapore's technological advancement. The School of Electrical and Electronic Engineering (EEE) in SP plays a leading role in Singapore to prepare students pursuing studies and careers in the fields of electrical engineering and electronics. EEE at SP is known for its comprehensive diploma programs and continuing education courses, state-of-the-art facilities, and industry-relevant curriculum. With a strong emphasis on practical knowledge and industry-relevant skills. The school has consistently strived to foster academic innovation and excellence in its students, preparing them for the challenges of the rapidly evolving technological landscape.

Flipped Approach for the Learning of Wafer Fabrication Process

Wafer Fabrication Fundamental, a module in the second year of the Diploma in Electrical and Electronics Engineering, provides students with an awareness and understanding of the processes involved in semiconductor manufacturing, which is crucial knowledge for those interested in pursuing careers in the electronics industry.

Challenges Faced by the Learners with Traditional Approach during Practical Session

Traditional approach to teaching the module involves lab-based practical sessions with lectures. Due to the high costs and large equipment footprints, one set of sophisticated and expensive equipment is used by students for each of these processes. For a typical class size of twenty students performing Wafer Fabrication processes such as Photolithography, Etching, Oxidation and Thin Fim Deposition inside a cleanroom, the students are grouped into four groups. Though this arrangement allows students to gain hands-on experience with the limited equipment available, there are challenges faced by students in this setup as the time spent acquiring the necessary hands-on skills is limited.

Group Size

- With 5-6 students per group sharing a single piece of equipment and operation under the guidance of a lecturer, students may face limitations in actively participating in the fabrication process, thereby reducing their hands-on exposure to critical procedures.
- Students may also feel apprehensive about handling such high-value equipment, leading to a cautious approach that could potentially impede their active participation and practical learning experiences.
- The larger group size may lead to decreased individual engagement, limited practical experience, and a lack of comprehensive understanding of the equipment's operation and intricacies of the processes.

Limited Learning Outside Scheduled Practical Lessons

- Students must necessarily be adequately trained in safety protocols and be confident in operating complex equipment, considering the critical nature of the clean room operations and the associated safety risks.
- Outside of the scheduled lab lessons in the cleanroom which require supervision by teaching staff, there is the challenge for students to have more hands-on learning themselves or to extend their own learning through supplementary research, practice, and experimentation, a somewhat less than optimal learning outcome, if students hope to increase their understanding and confidence of their competency in handling Wafer Fabrication equipment.

The Implementation of Smart Learning Space for Learning Wafer Fabrication Process

To address these challenges, there is a strong motivation to review student learning experiences using the traditional approach and re-design the learning space for a more interactive and immersive learning environment.

The traditional approach to teaching the intricate processes of Wafer Fabrication was reimagined through the implementation of a Flipped Learning methodology, alongside the setup of a smart learning space and the development of an Augmented Reality and Virtual Reality (AR/VR) learning package. This approach involved the pre-learning of theoretical concepts through online resources and interactive learning packages, allowing students to have interactive discussions and collaborative activities during face-to-face sessions at the smart classroom and smart lab, thereby enabling a more dynamic and engaging learning experience for students.

The module teaching team has initiated an assessment of the learning needs based on the feedback from students' dialogue sessions and also from the module survey carried out. With the review completed, the team has implemented a comprehensive strategy to encourage active participation, to promote practical skill development, and to facilitate a better understanding of the complexities associated with wafer fabrication processes within the learning environment.

A smart learning space here refers to an educational environment equipped with advanced technologies and infrastructure to support interactive and personalized learning experiences. These spaces incorporate various digital tools, interactive displays, and connectivity solutions to facilitate collaborative and engaging teaching and learning.

In response to the identified learning needs, the School of EEE established a state-of-the-art

Smart Learning Space, encompassing a smart classroom and a smart lab (Figure 6h.1). The smart classroom was equipped with interactive boards, multimedia projection capabilities, and 5G internet connectivity, enabling a collaborative and technologically integrated learning environment. The smart lab is furnished with advanced wafer fabrication equipment, augmented with AR and VR technologies, to simulate real-world scenarios and facilitate hands-on learning experiences.

The following key features were considered in the design and implementation of a smart learning space for Wafer Fabrication Process.

1. Flipped Learning Approach:
    - In line with SP's Flipped Learning methodology, students assessed the comprehensive online materials that cover theoretical concepts and fundamental procedures related to wafer fabrication using SP's Learning Management System (LMS).
    - Students are encouraged to study these materials before the hands-on lab sessions to ensure a basic understanding of the processes. In this way, face-to-face lessons can focus on interactive discussions relating to the practical applications of the concepts learned online.
2. Smart Learning Space for Conducting Tutorial and Practical Lesson for Wafer Fabrication module:
    - The learning spaces in the classroom and laboratory are equipped with smart boards and/or collaborative workstations, integrated with audio-visual system and internet connectivity to encourage student engagement and active participation during small group discussions and/or activities.
    - Data-enabled monitoring system is installed for real-time tracking of student progress and understanding, allowing teaching staff to provide timely assistance and support.
3. Augmented Reality (AR) and Virtual Reality (VR) Learning Package Development:
    - To further augment the learning experience, the school developed an innovative AR and VR learning package specifically tailored to the Wafer Fabrication processes (Figure 6h.2). This package enabled students to engage in immersive, interactive simulations, providing a comprehensive understanding of the intricacies involved in the fabrication process. The integration of AR and VR technologies allowed students to visualize complex procedures, experiment with various parameters, and receive real-time feedback, thereby enhancing their practical skills and theoretical comprehension.
    - Another benefit of having an immersive virtual environment for wafer fabrication process is to allow students to practice the

Figure 6h.1. EEE Smart Classroom with Interactive Displays, Audio-Visual Systems and Internet Connectivity

Figure 6h.2. Using AR Learning Applications to Learn Photolithography

procedures virtually before working with the actual equipment inside the cleanroom. This allows students to practise from anywhere, anytime, and provide a safe and cost-effective way to learn.

- Development and deployment of two AR and one VR applications was achieved. The AR applications allow digital information and instructions to be overlayed onto the physical equipment. This provides real-time guidance during hands-on practice sessions without supervision.
- Quizzes with instant feedback were incorporated to reinforce learning and tracking of students' progress after the hands-on learning guided by the AR and VR applications.

4. Peer Teaching, Increased Collaboration and Communication achieved in Small Group Learning:

   - Active learning activities are implemented in the Smart Learning Space to encourage peer teaching within small group settings. This approach fosters collaborative learning, enables knowledge sharing, and enhances the overall learning experience through student-led discussions and interactive group activities.
   - Inside the cleanroom, each student within the small group takes turns putting on the smart glasses, and operating the equipment with the guidance from the AR learning package. The student with the smart glasses will lead group members, pace the learning, and explain every step guided by the AR learning package, ensuring all group members understand and work together to operate the equipment correctly.
   - To facilitate seamless collaboration and communication among students, group members are required to synchronise the operation steps with the help of an interactive display, showing these steps from the AR learning package, as seen by the student with the smart glasses.
   - Similarly, for the VR-based learning for one of the Wafer Fabrication processes, each student within the small group takes turns using the VR headsets to perform remote learning and operate the equipment in a virtual simulated cleanroom. The VR learning package offers step-by-step guidance and enables students to

have flexible hands-on practice from any location. This approach familiarizes students with the process and equipment, enhancing their confidence and efficiency when operating real equipment in the cleanroom.

- Inside a smart classroom, students in each group have a collaborative discussion on an assigned Wafer Fabrication topic. They will use digital interfaces such as smart displays, interactive whiteboards, and virtual collaborative tools for sharing ideas. This setup encourages active participation and teamwork among students, as well as allows them to share their experiences and knowledge, to reinforce what they have learned from online materials posted on the LMS and during their lab sessions.

5. Continuous Assessment and Feedback

- Regular assessments such as weekly quizzes to evaluate each students' understanding of theoretical concepts and practical skills are implemented in face-to-face sessions at smart classroom and smart lab.
- The Smart Learning Space is equipped with real-time monitoring and data analysis tool, which are used to provide timely insights into students' progress during the tutorial and lab sessions, enabling the lecturer to make informed instructional decisions and provide targeted support as needed.
- The lecturer will also use the performance of these weekly assessments to provide personalized feedback to help students identify areas for improvement and encourage them to take an active role in their learning journey.

These features lead to flexible and collaborative learning.

Flexible Learning in Smart Learning Space

- The smart learning space can be tailored to meet the individual learning needs of students, allowing lecturers to customize learning materials and activities based on students' learning preferences and academic abilities. By leveraging on the potential of the technologies in the smart learning space, lecturers can deliver a diverse range of multimedia resources, including interactive simulations, 3D visualizations, interactive videos, virtual field trips, and virtual laboratory tools, catering to a diverse range of learning styles and abilities. This approach offers a hands-on learning experience for students without access to physical laboratories, allowing visual learners to engage with detailed visualizations and auditory learners to grasp concepts through audio explanations.
- By allowing personalized learning approaches in this space, this helps to cater to diverse learning styles and promote student-centred learning experiences. These include adaptable furniture arrangements, versatile equipment setups, and modular learning spaces that can be easily reconfigured to support different teaching and learning activities, promoting a dynamic and versatile learning experience for the individual learner.

Collaborative Learning with Industry Experts Virtually

- The Smart Learning Space is equipped with integrated audio-visual systems for delivering presentations effectively and has 5G internet connectivity to facilitate remote learning with industry experts (both locally and overseas) in the Semiconductor industry. This industry partnership provides students with insights into the latest advancements and trends in wafer fabrication technology such as a virtual tour of the real fully automated cleanroom facilities, thereby providing an authentic learning experience beyond the classroom.

Conclusion

The journey of transforming the learning experience in the Wafer Fabrication module at the School of EEE, Singapore Polytechnic, stands as a testament to the institution's commitment to foster a culture of innovation, practical learning, and technological excellence.

In both the smart classroom and smart lab, the focus is on integrating technology to create a more engaging and effective learning environment, fostering critical thinking, collaboration, and innovation among students.

Through the establishment of a Smart Learning Space and the development of an AR and VR learning package, the school has bridged the gap between theoretical knowledge and practical application, equipping students with the necessary skills and competencies to thrive in the ever-evolving landscape of the semiconductor industry.

The learning in Wafer Fabrication Process through Smart Learning Spaces is still a work in progress. The experimental classroom and lab will be deployed with the participation of about 160 students and three lecturers in Oct 2023. We will be conducting a focus group discussion with these participants to study if this cyber-physical learning initiative provides a meaningful and effective learning experience for our learners.

Future Plans

The school hopes to further improve the learning experience of the students through exploiting the use of technology in the smart learning space. With the maturity of technologies like advanced AI tools and 5G connectivity, such measures enhance the quality of interaction amongst learners with voice and face recognition, and enabling remote control of lab equipment may positively further impact the student learning experience.

1. **Voice and Face Recognition and Analysis**
    - Personalized Learning: Voice and face recognition technology can identify individual learners and analyze their facial expressions and vocal tones to gauge their emotional state, level of engagement, and understanding. This information can be used to personalize learning experiences, tailoring content to the needs and preferences of each student.
    - Feedback and Assessment: Real-time analysis of student interactions can provide valuable insights to educators. For example, if a student appears confused during an online class, the system can alert the instructor, allowing them to provide immediate support. It can also help in assessing the effectiveness of online teaching methods.
    - Inclusive Learning: Recognizing and accommodating diverse communication styles and needs is crucial for creating an inclusive learning environment. These technologies can ensure that students with various abilities and communication preferences are equally engaged and included in class discussions.
2. **Remote Control of Equipment Inside the Lab**
    - Virtual Hands-on Learning: Remote control capabilities allow students to operate laboratory equipment from a remote location, enabling them to engage in practical experiments and hands-on learning activities without being physically present in the lab.
    - Flexibility and Self-Paced Learning: Remote control capabilities offer flexibility, allowing students to access lab equipment and experiments at their convenience. This self-paced learning approach can accommodate different learning speeds and schedules. providing them with the opportunity to explore and deepen their understanding of complex concepts and procedures in a self-directed manner.
    - Safety and Accessibility: Remote control minimizes the risks associated with physical lab work, ensuring student safety. It also makes educational resources more accessible to students who may have physical limitations or other barriers to accessing a traditional lab environment.

When combined these elements in the Smart Learning Space, it can create a holistic and technology-enhanced learning environment that not only promotes engagement and interactivity, but also supports individualized learning experiences. As technology continues to advance, the potential for improving the quality of education through voice and face recognition, and remote control of equipment inside the learning space is boundless.

61. LASALLE COLLEGE OF THE ARTS, UNIVERSITY OF ARTS SINGAPORE: MERGING DIGITAL AND PHYSICAL ARTS EDUCATION

Wolfgang Muench, Damaris Carlisle

Institution name: University of Arts Singapore, LASALLE College of the Arts

Institution website: https://www.lasalle.edu.sg/

Programs offered: Diploma, BA and MA level courses in arts subjects including design and performing arts

Number of students: 2500

Number of faculty members: 110 full-time academic staff and over 350 part-time lecturers

Located in the heart of Singapore, LASALLE College of the Arts is a founding member of the University of Arts Singapore. The institution represents a unique melding of contemporary artistic fields with the fast-paced advancements of digital technology. Their official website, lasalle.edu.sg, provides an in-depth view of their comprehensive range of academic programmes, spanning diplomas to masters degrees. These programmes encompass areas as varied as design to the lively realm of performing arts.

The college has the responsibility of fostering the educational growth of its diverse student body, which currently numbers approximately 2,500 of which 37% are international students from more than 20 different countries. This task is undertaken by three faculties: the Faculty of Fine Arts, Media and Creative Industries, Faculty of Design, and Faculty of Performing Arts. The three faculties house eight schools offering a total of 35 undergraduate and postgraduate programmes.

The impact of the COVID-19 pandemic on LASALLE, especially in the transition to digital learning, was immense. Prior to the pandemic, LASALLE's pedagogy primarily centred around practice-based learning, which heavily emphasized research and studio work. However, when the global pandemic necessitated a shift to remote and digital education, LASALLE had to swiftly adapt its approach.

During the pandemic, the institution faced the challenge of maintaining the immersive and hands-on nature of arts education while ensuring the safety and well-being of students and faculty. To achieve this, LASALLE introduced innovative strategies, including virtual studio sessions, online critique platforms, and collaborative digital projects. These initiatives allowed students to continue their creative journeys, albeit in a virtual space.

Moreover, LASALLE's faculty underwent extensive upskilling in the use of digital pedagogy to effectively engage students in a remote learning environment. This included the adoption of new digital tools, methods for providing constructive feedback, and the creation of virtual galleries and showcases to display students' work.

While LASALLE has now largely returned to campus as the world navigates the 'new normal,' the experience of adapting to digital learning during the pandemic has left a lasting impact. It has broadened the institution's perspective on how technology can enhance arts education, and some digital elements have been integrated into the regular curriculum to provide students with more diverse and flexible learning opportunities.

In summary, although the discussion had been ongoing for a number of years, the COVID-19 pandemic prompted LASALLE to pivot towards digital learning, challenging the institution to find innovative ways to maintain the practice-based nature of its pedagogy. This experience has not only enabled the institution to adapt to the challenges of the pandemic but has also enriched its teaching and learning framework by incorporating valuable digital elements that enhance the overall educational experience.

Institutional Framework

LASALLE prides itself on its distinctive teaching and learning framework, acknowledging that in the field of arts education, a one-size-fits-all approach is neither practical nor conducive to nurturing creativity. The institution places a strong emphasis on granting faculty members the autonomy to choose the most appropriate pedagogical practices for their specific disciplines. This approach recognizes the unique nature of each art form and the diverse needs of students across its various programmes.

In terms of technology integration, LASALLE acknowledges the evolving landscape of education, and the significant role technology plays in the arts. While the institution doesn't impose a uniform directive on the use of technology, it actively encourages a blended learning approach in selected units and departments. This approach is especially prevalent in areas where technology enhances artistic expression, such as digital arts and design, fostering an environment in which students are encouraged to explore new media and digital platforms as part of their creative processes.

The underpinning framework of LASALLE's teaching and learning philosophy is rooted in the belief that artistic education should foster creativity, critical thinking, and self-expression and embraces the values of collaboration, excellence, courage, agility and engagement. The institution recognizes that the arts are inherently dynamic and evolving, and thus, faculty members are encouraged to adapt and experiment with their teaching methods to best engage students in this ever-changing landscape. This flexibility ensures that LASALLE remains at the forefront of arts education, equipping students with the skills and mindset needed to excel in both traditional and emerging art forms. Overall, LASALLE stands as an institution that champions the uniqueness of artistic expression, leveraging technology and flexible teaching practices to prepare students for the challenges and opportunities presented by the digital age.

Technological Integration in Arts Education

In the curriculum, LASALLE incorporates digital tools such as the Learning Management System (LMS) through Moodle, the Google Suite, and the Adobe Suite to support and enrich students' learning experiences. These tools are integrated into coursework to facilitate collaboration, research, and creative expression. Moreover, the inclusion of physical technologies like sewing machines, potters' wheels, cameras and 3D printers extends the scope of artistic exploration, enabling students to bridge the gap between traditional and digital art forms.

Student development at LASALLE goes beyond technical skills. The institution places a strong emphasis on nurturing critical thinking and emotional intelligence. Through a combination of technology-enabled learning and experiential opportunities, students are encouraged to reflect on the 'why' of their education, fostering a deeper understanding of their artistic journey.

Faculty development also plays a pivotal role in this framework. LASALLE supports its educators in adapting to evolving pedagogical methods and technology integration. Workshops, training programs, and ongoing professional development opportunities ensure that faculty members are well-equipped to guide students through the ever-changing landscape of arts education.

In essence, LASALLE's commitment to technological integration is not a standalone endeavour but an integral part of a holistic approach to education. It seeks to empower students with the skills and mindset needed to navigate the digital age while retaining a strong focus on the core values of creativity, experiential learning and critical thinking. This comprehensive approach is deeply ingrained in the institution's ethos and permeates every aspect of its teaching and learning framework.

Innovative Initiatives at LASALLE

LASALLE's ethos of innovation is encapsulated in several initiatives. A notable example is the Collaborative Online International Learning (COIL) programme. In a unique partnership with UAntwerp, during the global pandemic, this initiative provided a platform to explore the multi-dimensional aspects of space in art, especially in the context of a world reshaped by the global pandemic. São Paolo, Brazil, served as the backdrop for this digital collaboration, offering students and faculty an opportunity to engage with themes of cultural interaction, physical and emotional distancing, and the changing dynamics of public and private spaces.

Shared Campus

Shared Campus is a collaborative platform dedicated to international education formats and research networks, forged through the collective efforts of 13 prominent international arts universities, schools, and colleges.

In an increasingly interconnected world, the future belongs to professionals who thrive in a global context by engaging in communication, exchange of ideas, constructive debates, and critical reflection. Shared Campus plays a pivotal role in establishing connections that yield tangible benefits for students, educators, researchers, and professionals alike, facilitating the seamless sharing of knowledge and competencies.

The platform has been meticulously designed to revolve around themes of international significance, with a pronounced emphasis on transcultural issues and cross-disciplinary collaboration. Within the framework of five core thematic pillars, Shared Campus offers a diverse array of educational, research, and cultural activities. These encompass semester programs, summer schools, specialized courses, immersive workshops, dynamic networking events, enlightening symposia, vibrant festivals, insightful publications, and an interactive collaborative learning platform.

One notable project undertaken during the global pandemic was Teleprovisation (Figure 6i.1). This project created an entirely new experiential digital online mobile environment (DOME) for musicians and actors. It achieved this by leveraging specialized software to enable real-time online interaction capabilities. Additionally, Teleprovisation encompassed the development of Collaborative Online International Learning (COIL) environments. These COIL environments provided students with international learning experiences through 'virtual mobility.' This innovative approach facilitated the development of intercultural competences and digital skills as students collaborated on subject-specific learning tasks and activities.

Figure 6i.1. Shared Campus (Credit: Teleprovisation 2021)

Hybrid Teaching

LASALLE's exploration into **hybrid teaching methods**, as exemplified by the BA (Hons) Fashion Designs and Textiles program, effectively blends local pedagogies with a global perspective (Figure 61.2). This endeavour explores the hybrid instructional model's implementation, with a particular focus on cross-border collaboration between the United Kingdom and Singapore. This approach seamlessly integrates online and in-person teaching, emphasizing transparent communication and a cohesive instructional team. Notably, it showcases the successful integration of an industry-specific expert into the program, illustrating the potential for leveraging specialized knowledge without the logistical challenges of physical relocation. Key considerations encompass the necessity of an experienced program manager, tailored curriculum content, and strategies for overcoming technology-related obstacles. Conversely, the hybrid model presents promising opportunities, including the development of a transferable educational framework and potential collaboration in a Global Campus model with other institutions. This exploration acknowledges challenges such as technological constraints and the initial workload associated with the hybrid approach while recognizing the broader potential and challenges within this evolving educational landscape.

Figure 6i.2. Student Output from Hybrid Delivery (Image of FDT Graduate Collection (2022-2023) using CLO3D Fashion Design Software, (Credit: Varsha Venkatesan)

Generative AI in Modern Arts Education

In the rapidly evolving educational landscape, Generative AI (GenAI) described as a technological disruptor, has immense potential. LASALLE is keenly aware of its implications. Instead of viewing it merely as a tool or a technological novelty, the institution sees GenAI as a valuable adjunct, one that can operate in tandem with human creativity. The introduction of GenAI into the curriculum hasn't been without challenges. Intellectual property concerns, potential academic integrity breaches, and even logistical issues loom large. Yet, LASALLE's approach is one of proactive problem-solving. Through constructive dialogue, innovative technological solutions, and constantly referencing best practices from global counterparts, the institution is poised to navigate these challenges with grace and foresight.

ai.land.nation

Many programmes have started integrating GenAI into their curricula, with a notable example being the Diploma in Design for Communication and Experiences. (Figure 61.3) The project ai.land.nation, initially emerged as a proposal for Singapore Design Week, with a primary focus on exploring potential future scenarios for Singapore in the year 2050. Within this initiative, students actively engaged with prompts that encouraged creative and imaginative thinking while using AI tools to visualize their concepts. The project underscored the significance of exploring diverse solutions and potential outcomes, harnessing AI for activities such as brainstorming, mind mapping, and generating visual content. The overarching objective was to immerse students in the realm of speculative design thinking, enabling them to effectively integrate AI tools. This project fostered an environment in which students enthusiastically embraced the boundless capabilities of AI, stimulating their involvement in future thinking across various domains, including fashion, retail, and technology. As they explored the speculative and imaginative facets of design, students not only harnessed AI's potential but also adapted to the evolving landscape of content creation, acknowledging the increasing prevalence of AI-generated content in contemporary society.

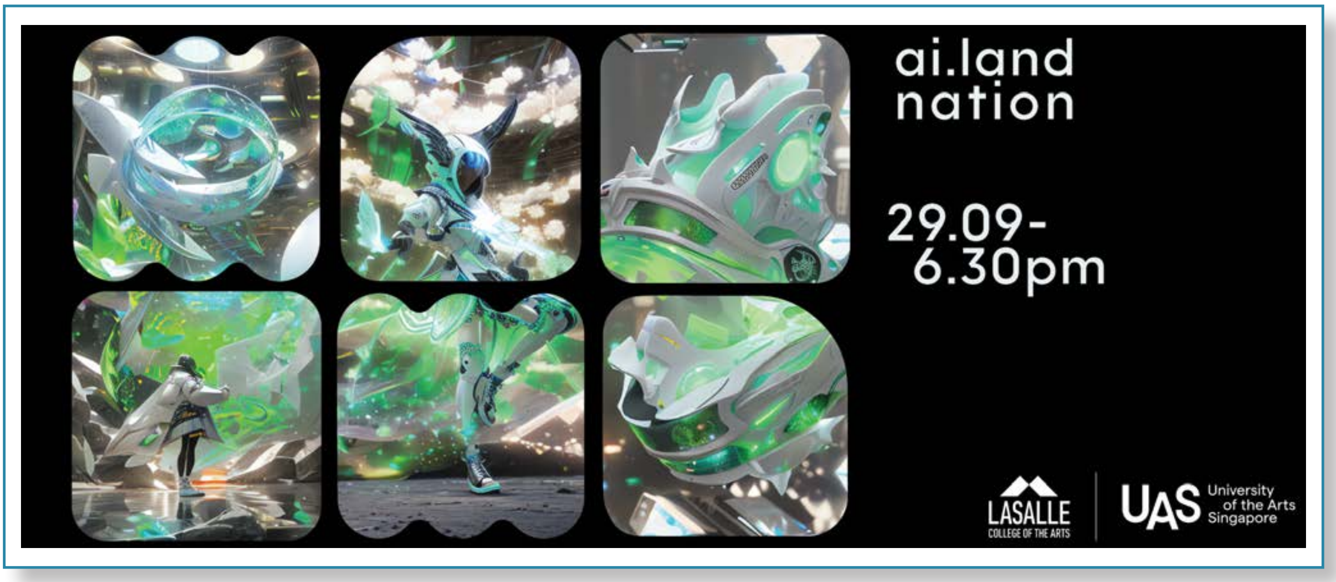


Figure 6i.3. Diploma in Design for Communication and Experiences, LASALLE College of the Arts. (Credit: Jaygo Bloom, Programme Leader)

Conclusion

As the arts education sector undergoes transformative changes, LASALLE is positioning itself as not just a passive observer, but an active participant and thought leader. The strategic integration of traditional methodologies with cutting-edge digital tools paints a picture of an institution that's both rooted in tradition and eagerly looking toward the future. In a rapidly changing world, LASALLE's approach to arts education offers a beacon of adaptability, innovation, and unwavering commitment to excellence.

7. A PRIMER ON THE ETHICS OF CYBER-PHYSICAL LEARNING

Jeffrey Chan, Kenneth Lo, Jacob Chen, Nachamma Sockalingam

Sectors such as transportation, manufacturing, healthcare, energy, and agriculture rely on cyber-physical systems (CPS) today. CPS are engineered to seamlessly integrate computational algorithms and physical components (The National Academy of Sciences, 2016). In higher education, COVID-19 disruptions have shown the potential of CPS in the form of cyber-physical learning (CPL) (Sockalingam *et. al*, 2022). Because CPL can bridge the physical classroom and different cyberworlds by leveraging on their respective advantages, students not only are able to learn 'anywhere and anytime', but they also can collaborate with others across different geographies while personalizing their own learning experience. CPL therefore offers a valuable mix of accessibility, inclusivity, and personalization unlikely to be found in either a physical or the virtual classroom alone. In a world increasingly vulnerable to volatility, ambiguity, complexity, and uncertainty in the form of climate-triggered risk cascades (Kemp et al., 2022), conflict, extreme weather events, resource scarcities, and diseases, among others—CPL can offer an invaluable source of resilience for higher education moving forward.

Despite these benefits, CPL, like all CPS, introduces new risks (The National Academy of Sciences, 2016). An early study conducted by the Scientific Foresight

Unit (STOA) of the European Parliamentary Research Service (EPRS) describes the potential lack of safeguards, privacy lapses, and robotic substitution in workplaces as areas of likely ethical fracture in CPS (STOA, 2016). More recently, a UNESCO (2023) report suggests that an exclusive focus on online learning technologies may structurally render education less accessible, less effective, and less engaging (i.e., entrenching a mode of learning that privileges parties that can afford costly digital technologies). Contextualizing Zwetsloot and Dafoe's (2019) threefold characterization of risk in CPL, there are at least: (i) risks of unintended and negative consequences of intended use of CPL; (ii) risks of harmful unintended use (or misuse and abuse); (iii) structural risks of CPL. This general characterization of risk in CPS should constitute the beginning of an account of ethics in CPL.

But there are also novel risks peculiar to CPL. At SUTD, early applications of CPL are telepresence learning systems for both remote/cyber students and face-to-face physically present students, augmented reality modules teaching projectile motions, and gamified metaverse with skill-based learning. Given that CPL exploits the boundary-spanning potential between the real world and interconnected virtual worlds (or the metaverse) for educational gains, it can also be expected to introduce unique "dual world" risks (Benjamins, Vinuela & Alonso, 2023). For instance, acts that are considered inappropriate in the real-world classroom may not be similarly perceived in the metaverse, while participants can 'carry-over' the traumas experienced in the metaverse to the real world.

Ethics, which centers on questions of how one should live and act, what kind of person one should be in relation to the well-being of others, and how one should make decisions about right and wrong acts (Keane, 2015), become important when social norms and regulatory standards lag behind fast-moving CPL development. Ethics can provide guidance on how one should preempt or avoid certain risks in CPL. When these risks are unavoidable, ethics can recommend responses that are more appropriate or accountable. Formulated as a code, ethics becomes actionable knowledge that can help participants identify inappropriate or unacceptable behaviors in advance, recall important values and ideals in higher education when in doubt, and suggest more accountable responses or solutions under conditions of uncertainty. Because of rapid innovations in CPL, this code of ethics is likely to require regular updating. This 'living' code then presents an additional opportunity for CPL participants to collaborate, foreground risks and ethical challenges, and discuss how to address them together. These moments of social learning build trust (Light & Akama, 2019).

The aim of this chapter is twofold. First, this chapter will explain why ethics is an indispensable aspect of CPL. Second, this chapter will describe the co-creation process of a code of ethics for CPL in the Singapore University of Technology and Design (SUTD), which to the best of the authors' knowledge, is the first of its kind in the world.

The Ethics of CPL Goes Deeper: A Brief Moral History of Cybernetics

To better understand this connection between ethics and CPL, revisiting the history of cybernetics briefly is necessary.

The term 'cyber-physical systems' was coined by Helen Gill at the National Science Foundation (USA) in 2006 (Lee & Seshia, 2017). The prefix, 'cyber', however dates back further in history. Lee and Seshia (2017) suggest that 'cyber' can be traced back to 'cybernetics', which is the science of control and communication by machines or humans (Wiener, 2019). Concisely stated, cybernetics posits that the control of certain physical processes can be computed by measuring some aspect of the physical world, which when converted to data through a feedback mechanism, drives further actions that permit this system to attain predefined goals. Cyber-physical systems, which involve constant feedback between their respective physical, data and decision components in order to attain a predefined outcome (Nardelli, 2022), can be directly traced back to the ground-breaking science of cybernetics.

An early application of cybernetics was demonstrated by Wiener's 'antiaircraft (AA) predictor' used in World War II. This technology could characterize an enemy's pilot's zigzagging flight path, anticipate its future position and then launch a more accurate counterattack instead of second-guessing by human judgment (Galison, 1994). After the war, Wiener (1964) thought that it was necessary to consider ethical safeguards when powerful, intelligent and learning machines—unaligned to human values and sufficiently autonomous to evade human control (see Russell, 2019)—are used in cyber-physical systems. The controversial debate on AI agents as powerful actuators to be used in defence, infrastructure, and everyday routines today (Metz & Weise, 2023), can be traced back to Wiener's ideas nearly six decades ago.

A Conceptual Model for CPL: Three Primary Layers of a CPS

Similar to all CPS, a CPL in operation is dynamic, fast, and complex. It also comprises a human and social dimension that tend to render further interactions indeterminate and their respective output somewhat uncertain (Elster, 2007). A conceptual model that can break a complex CPS down into distinct and separate layers at least for the purpose of analysis is invaluable. Nardelli (2022) proposes one such model that can help to anticipate where and how ethical issues may emerge in CPL. In turn, knowing where possible ethical fractures may occur focuses awareness and attention in the right direction.

According to Nardelli (2022), CPS is constituted by at least three primary layers interleaved by three different cross-layer processes (i.e., sensing, informing, and acting respectively). The primary layers are namely, the physical, the data, and the decision layer. The physical layer entails the material system of the CPS and the physical world, which are specified by design and constrained by physical laws. Sensors relay what is being measured in this physical layer to the data layer. The data layer is constituted by data, data processes and logical relations, unbounded but still subjected to energy and information limits. This layer provides data that informs the decision layer. Finally, the decision layer is constituted by decision-making processes, either by algorithms, humans, or a combination of both. The decision layer produces action, which impacts and alters the physical layer again (see Figure 7.1). For the purpose of this chapter, examining each layer then provides an anticipatory visual of where and how ethical risks and challenges might arise, and where applicable, working ideas on how to preempt them.

The Physical Layer

The physical layer is everything that occurs and exists in the real world constrained by physical relations and laws. This includes events of chance, or natural factors, which can still turn out to be morally significant. But for the purpose of this article, only the intentional actions that impact the physical layer will be considered.

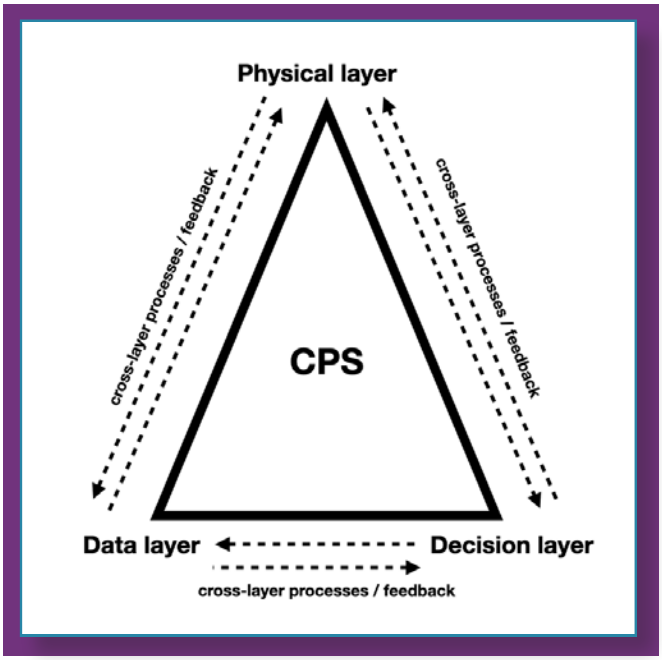


Figure 7.1. Visualizing a dynamic CPS (derived from, Nardelli, 2022), (Credit: Jefferey K.H. Chan)

Two design questions are therefore in order: How might one design the 'physical layer' of CPL to create affordance that can result in a more ethical outcome? Or conversely, how might one 'design away' physical sources of risk and hazard? In thinking about these questions, the design choices concerning technological specifications, classroom configuration and pedagogical setup—and how all of them come together—become paramount. Drawing from the design theory of affordance, choices about physical structures shape behaviors and actions even though they do not determine them (Davis, 2020). Designing the physical layer to preclude errors, conflicts, misunderstandings and hazards, or conversely, to encourage communication, cooperation and collaboration, is a powerful tactic aligned with the goals of ethics.

Consider four simple examples here. Configuring the seating plan of the classroom such that every participant can be captured by a mounted camera reduces the probability of transmitting inaccurate data that will in turn risk an inappropriate outcome at the decision layer. Anticipating the number of robots that can be equitably shared by both physical and remote participants such that there is little chance of any antagonistic conflict is another straightforward design of the physical layer. Implementing a protocol where students who have to step out of the physical or virtual classroom leave a visible sign that informs their absence to computer vision will reduce the probability of misunderstanding in CPL. Finally, robots in the physical setting controlled by remote participants who do not share the same embodied knowledge of the physical classroom have to be secured or else closely monitored to ensure safety.

These suggestions may appear trivial; they also do not capture all the possible choices concerning the design of a physical layer in CPL. Nevertheless, they underscore the observation that the physical layer is the source of many unnecessary risks, which can be preempted by careful design. The modified adage, 'prevention by design is better than cure', guides further thinking on the configuration of the physical layer.

In sum, the physical layer may be the most amenable category for foresight-driven design thinking. Nearly all aspects of this layer, at least within a CPL classroom, fall under the designers' (i.e., the stakeholders of CPL) purview. Further improvements made on this layer may well eliminate unnecessary sources of risks, especially when certain physical configurations of CPL can produce unintended and negative consequences (see Zwetsloot and Dafoe, 2019).

The Data Layer

The data layer refers to the symbolic domain constrained only by energy and information limits. It is also a vast layer encapsulating everything from the algorithmic design of the CPS to data processes, privacy and cybersecurity, and importantly for CPL, the virtual selves (avatars) and experiences that occur in different virtual reality worlds. This article will only examine the most salient risk areas of the data layer in CPL.

The first area concerns privacy (STOA, 2016). Especially when CPL enables communication between physical and virtual worlds, monitors participants in real-time and collecting vast amounts of data in this process, the routine operation of this system already guarantees a minefield of privacy risk issues. For example, the data collected on the performance of the participants is vital to instructors who are monitoring their learning progress; but this data is also valuable to third-party edutech developers. How might this data be stored and used such that the privacy risk is reduced as much as possible? And how should one manage data on the participants' social behaviors or interactions, which are captured alongside academically relevant content but may prove to be embarrassing or awkward (see, for example, Suwa (2023).

Privacy is also connected to values such as equality and security paramount in CPL. Participants of CPL come from different cultures and socioeconomic backgrounds, and it is important to ensure that CPL narrows, rather than widens, any equity gap. It is generally recognized that marginalized individuals or groups often require stronger data privacy than those belonging to entrenched majorities because the former may not have the necessary resources to resist undue conformance pressures and exploitative advances (Waldman, 2019). Contextualized in CPL, this may mean that participants that are chronically under-performing may require a greater sensitivity on their academic data, and in tandem, may also necessitate greater data privacy than those doing better. On the other hand, trust conditions are most fragile when participants do not know how their private data is being collected, used and stored. But participants who feel (and are actually) secured because of robust and transparent privacy safeguards will exhibit greater trust (Camp, 2015). And trust is paramount for sustained participation in CPL.

In considering these issues, the model of 'privacy by design' has become *the* default legal practice in many places (Waldman, 2019). 'Privacy by design' typically refers to the class of proactive and deliberate ex ante approaches of protecting privacy instead of managing privacy harms ex post (Hartzog, 2018). Drawing from Waldman (2019) for CPL, this can mean abiding by a set of privacy principles above and beyond those legislated (e.g., Singapore's PDPA), encoding these principles into the architecture of CPL technologies, or mandating a form of value-sensitive design where respecting an individual's privacy is considered from the ground up at every stage when designing CPL. Design plays an indispensable role in safeguarding privacy (Hartzog, 2018).

The second area is the metaverse. The metaverse is an immersive and constant virtual three-dimensional world where participants interact through avatars specifically created for this world (EPRS, 2022). Possibly a unique feature of CPL, the metaverse exists entirely on the digital layer yet with participants interacting with others as though they were present on the physical layer. In education, the metaverse can support learning for people with disabilities and may even render certain physiological constraints irrelevant (EPRS, 2022). Yet the metaverse is a source of many risks. The issue of "blurred roles" stands out for education. In the metaverse, interactions between avatars occur in ways that do not always conform to norms that can be expected in the real world, which complicates the determination of responsibilities and liabilities. Furthermore, what is perceived to be inappropriate behaviors in the real world may not be similarly appraised in the metaverse, where participants lack an overall embodied awareness of knowing what is more or less appropriate because of the absence of social cues and body language.

Closely related is the issue of digital personas (IEEE, 2019). In the metaverse, the choice of adopting any one specific digital persona or avatar is consequential for the decorum and civility of the CPL session. For example, should every participant take on a 'human-like' avatar, and if so, to what extent should they vary in appearances, race or gender, if any? Are certain participants allowed to take on different forms (e.g., an animal form) and should these forms then come with their corresponding capabilities of the real world (i.e., a bird can fly) in the metaverse? Might the appearance of certain digital personas constitute a form of harassment or trauma for participants of CPL, who cannot be assumed to share similar cultural or moral beliefs with the data processor (or the convenor) of this metaverse?

The metaverse presents far more questions than there are answers in the novel space of CPL. There are many more risks of the metaverse that exceed the explicative scope of this article, for example, risks of technology addiction, compulsive use of the metaverse to escape the stress of the physical world, and virtual reality 'hangovers' or cybersickness (Benjamins, Vinuela & Alonso, 2023). Despite the absence of answers or concrete research evidence at this point, it is almost certain that the metaverse will constitute one key area of risk and many ethical conundrums in CPL.

In sum, the data layer presents a gamut of profound issues important for an ethically aligned CPL. Only the primary issues of privacy and metaverse have been discussed, and other equally critical issues await further research.

The Decision Layer

The decision layer is constituted by decision-making processes about actions concerning possible interventions in all three layers and cross-layer processes (Nardelli, 2022: 135). These decision-making processes can be carried out by algorithms, robots or human agents. Subsequently, these processes result in actions, which shape physical layer. While AI is increasingly making decisions on behalf of humans—for instance, by recommending certain learning modules and in turn, participants trust and follow this recommendation by AI—humans are nonetheless assumed to maintain agency in this layer in the foreseeable future.

Therefore, this human-centric aspect of the decision layer in CPL renders ethics salient. People are rarely rational decision-makers; they commit recall errors, and they cannot accurately anticipate the outcomes of their actions. Just as likely, they do not know many important factors and parameters that impinge on their decision-making. People rely on simplifying shortcuts of intuitive thinking, or biases, when making decisions under uncertainty (Kahneman, 2011). In turn, evidence suggests that biases can inhibit people's ability to make ethical decisions (Watts et al., 2020).

Biases present a significant source of practical and moral risks in this layer. In one direction, biases undermine effective learning outcomes. For example, teachers can often over-trust their workable pedagogies by sticking to default practices, otherwise also known as the 'default bias', even when CPL may offer experimental but more effective approaches. Anyone who has taught using Zoom understands that conventional classroom approaches of establishing eye contact or else looking out for bodily cues for participation will not work, and novel approaches are required to stage a convivial virtual classroom.

In another direction, biases complicate ethical decision-making. Ethical problems are often ambiguous, ill-defined, high-stakes and cognitively demanding, where there is likely no one right answer (Watts et al., 2020)—even though there are certainly unacceptable ones (Whitbeck, 2011). Participants who exhibit 'selective attention bias' will focus on their preferred train of thought while ignoring other possibilities, which will undermine lateral thinking key to ethical reasoning. A CPL lesson that has already made certain learning choices more salient based on reinforcement machine learning can further entrench this nature bias (i.e., primarily only showing content that aligns with participants' interest and thereby arresting their attention).

In sum, if biases are an invariant reality in the decision layer, then they can skew, distort, or even polarize decision-making, which together, render unethical situations more likely in CPL.

Co-Creating a Living Code of Ethics

To address these ethical issues and challenges, a code of ethics is proposed. A three-pronged approach is used to co-create a code of ethics for CPL. First, we examined existing and emerging literature on CPS. This literature also includes existing codes of conduct and other relevant internal documents in SUTD. By analyzing this literature, we draw out key historiographies, concepts, issues and questions concerning ethics in CPL. Importantly, this literature review establishes important categories and concepts used in this co-creation process.

Second, we engaged various stakeholders of CPL in SUTD to identify key aspiration and risk areas of CPL. We discovered that their inputs elucidated, and also corroborated, key categories, concepts and issues gleaned from the literature review. Third, a draft code of ethics that can encapsulate the key aspirations and address different cautionary concerns of these stakeholders was drawn up.

Subsequently, these stakeholders were again invited to provide feedback to this draft. This approach exemplifies a collaborative co-creation (and co-design) approach that involves the key stakeholders to participate and collectively identify values, standards and principles deemed paramount in an ethically aligned CPL system. The resultant code of ethics is anticipated to be a 'living document', which means that it is likely to be modified in subsequent iterations reflecting a dynamically evolving CPL in SUTD. In taking this approach, our approach eschews an abstract framing of ethics and instead encompasses a co-design approach of formulating ethical standards and principles in the situation with the community of CPL developers and practitioners (see Light & Akami, 2019).

In responding to these anticipated ethical issues and challenges, the first draft of a code of ethics for CPL has been drawn up. Paraphrasing Kahneman (2011), a code of ethics should be seen as a cognitive tool: it improves one's ability to identify and understand potential errors of judgment and choice; helps people to recognize signs of a moral minefield; recalls important values and ideals in this situation, and importantly, to slow down, deliberate, and assess a problem scenario with the knowledge resources embedded in the code. When widely used, a code of ethics also builds trust among users of this code.

The Code of Ethics for CPL is summarized here:

1. **Uphold integrity and respect**

   Integrity, which implies 'intactness' or 'wholeness', is a foundational ethical value. Commitment to integrity means that participants of CPL should practice intellectual honesty and fair dealings, and should not use this technology to fabricate or falsify data, to harass, deceive or impersonate another participant. In the same vein, participants collaborating with others who do not share similar values should respect and not discriminate them based on any personal, ethnic, religious, or political beliefs, either in their actual or virtual selves.

2. **Prioritize safety and well-being**

   CPL can introduce new risks and harms. To counteract these negative impacts, the safety and well-being of participants must be prioritized. Establishing a culture of safety and well-being is key.

3. **Safeguard privacy**

   The Personal Data Protection Act 2012 (PDPA) in Singapore, revised in 2020, stipulates that individuals have a right to protect their personal data and organizations can only collect, use and disclose personal data for appropriate purposes. This Act foregrounds the need to safeguard privacy especially when data collection and processing are integral to CPL.

4. **Advance equity**

   Participants of CPL come from dissimilar and often unequal settings. To improve this status quo, there is a need to commit to the advancement of equity. Especially when CPL technologies often come with powerful specifications that limit access, or expensive subscription costs that foreclose access to certain socioeconomic groups, advancing equity is vital.

5. **Work toward sustainability**

   The lifecycle of CPL technologies imposes heavy impacts on the environment—from the non-renewable energy and minerals required to manufacture and operate them, to the environmental cost of their disposal later on. Taking care of these technologies and optimizing their use for as long as possible are practical steps to meeting SDG 12 (ensure sustainable consumption and production patterns) and 13 (take urgent action to combat climate change and its impacts).

Acknowledgements

The authors are indebted to all the developers and designers of campusX in SUTD, who have generously shared their expertise and knowledge of cyber-physical learning, as well as members of the Ethics Taskforce, who have shaped this living code of ethics. Some examples of use cases in CPL described in this article are attributed to these developers, designers and members mentioned above.

References

Benjamins, R., Vinuela, Y.R., & Alonso, C. (2023). Social and ethical challenges of the metaverse: opening the debate. *AI and ethics.* https://doi.org/10.1007/s43681-023-00278-5

Camp, L.J. (2015). Designing for trust. In J. Savirimuthu (ed.), *Security and privacy. Volume III*. New York, NY: Routledge, pp. 3-17.

Davis, J.L. (2020). *How artifacts afford: The power and politics of everyday things.* Cambridge, MA: MIT Press.

European parliamentary research Service. (2022). *Metaverse—opportunities, risks and policy implications.* Retrieved from: https://www.europarl.europa.eu/thinktank/en/document/EPRS_BRI(2022)733557

Galison, P. (1994). The ontology of the enemy: Norbert Wiener and the cybernetic vision. *Critical Inquiry, 21(1)*, 228-266.

Hartzog, W. (2018). *Privacy's blueprint: The battle to control the design of new technologies.* Cambridge, MA: Harvard University Press.

Keane, W. (2015). Varieties of ethical stance. In M. Lambek, V. Das, D. Fassin & W. Keane (eds.), *Four lectures on ethics: anthropological perspectives*. Chicago, IL: HAU Books, pp. 127-173.

Kemp et al. (2022). Climate endgame: Exploring catastrophic climate change scenarios. *Proceedings of the National Academy of Sciences, 119(34).*

Lee, E.A. & Seshia, S.A. (2017). *Introduction to embedded systems: A cyber-physical systems approach*. Second edition. Cambridge, MA: MIT Press.

Light, A. & Akama, Y. (2019). The nature of 'obligation' in doing design with communities: Participation, politics and care. In T. Fisher & L. Gamman (eds.), *Tricky design: The ethics of things.* New York, NY: Bloomsbury, pp. 131-142.

Metz, C. & Weise, K. (2023). *How 'A.I. Agents' that roam the Internet could one day replace workers.* The New York Times, October 16, 2023. Retrieved from: https://www.nytimes.com/2023/10/16/technology/ai-agents-workers-replace.html

Nardelli, P.H.J. (2022). *Cyber-physical systems: Theory, methodology, and applications.* Piscataway, NJ: IEEE Press.

Russell, S. (2019). *Human compatible: Artificial intelligence and the problem of control*. New York, NY: Viking.

STOA. (2016). *Ethical aspects of cyber-physical systems*. PE 563.501. Retrieved from: https://www.europarl.europa.eu/RegData/etudes/STUD/2016/563501/EPRS_STU%282016%29563501_EN.pdf

Sockalingam, N., Lo, K., Kurniawan, O., Herremans, D., Raghunath, N., Cancion, H. G, C., Kejun, H., Leong, H., Tan, J., Nizharzharudin, K., & Pey, K. L. (2022). *A white paper on cyber-physical learning*. Singapore University of Technology and Design. Retrieved from: https://www.sutd.edu.sg/SUTD/media/SUTD/LSL_WhitePaper_Cyber-physical-Campus-Higher-Education.pdf

Suwa, K. (2023). *AI system developed that detects students sleeping in class*. The Asahi Shimbun, September 6, 2023. Retrieved from: https://www.asahi.com/ajw/articles/14976774

The National Academy of Sciences. (2016). *A 21st century cyber-physical systems education*. Washington, D.C.: The National Academies Press.

UNESCO. (2023). *An ed-tech tragedy? Educational technologies and school closures in the time of COVID-19*. Paris: UNESCO.

Waldman, A.E. (2019). *Privacy's law of design*. UC Irvine Law Review, 9(5), 1239-1288.

Watts et al. (2020). Decision biases in the context of ethics: initial scale development and validation. *Personality and Individual Differences, 153*, 109609.

Whitbeck, C. (2011). *Ethics in engineering practice and research*. New York, NY: Cambridge University Press.

Wiener, N. (2019). *Cybernetics: or control and communication in the animal and the machine*. Reissue of the 1961 second edition. Cambridge, MA: MIT Press.

Zwetsloot, R. & Dafoe, A. (2019). *Thinking about risks from AI: Accidents, misuse and structure*. Lawfare, February 11, 2019. Retrieved from: https://www.lawfaremedia.org/article/thinking-about-risks-ai-accidents-misuse-and-structure

8. BUILDING CYBER-PHYSICAL LEARNING THROUGH PARTNERSHIPS AND COLLABORATIONS

Kenneth Lo, Wendy Loh, Amanda Lee

As SUTD looks into the future of education with Cyber-Physical Learning (CPL), there are endless possibilities and potential to incorporate the new and emerging technologies to meet educational needs. Whilst SUTD seeks to achieve important learning outcomes through conducting various minimum viable products (MVPs) and innovation and development (I&D) projects, we recognise that SUTD does not have all the expertise across the various disciplines. Therefore, as part of the strategic direction to further advance CPL, campusX has been reaching out to various academic institutions and organisations to jointly collaborate and innovate.

In the post-covid era where institutions and companies alike are forced to pivot to incorporate digital means, there are many potential collaborators that could be involved. However, not all of them necessarily have similar vision and outlook to dream how the education sector could look vastly different with the implementation of these technologies. Therefore, it is important to be able to gather like-minded institutions and industry partners so that collectively, we can multiply the efforts put into research and development to achieve greater results when expertise is being shared.

For SUTD campusX, this meant that partnerships also go beyond geographical boundaries to include both a Singapore-based alliance and an international-based alliance consisting of institutions and organisations with diverse learner audiences (undergraduates, postgraduates, adult learners) and encompassing various countries (China, Finland, Hong Kong, Mexico). Thus, by reaching out and collaborating with Institutes of Higher Learning (IHLs) and Continuing Education and Training (CET) centres, SUTD campusX reflects an inclusive lifelong tertiary learning educational approach.

This chapter covers the formation of Cyber-Physical Alliance in Singapore and internationally sharing the existing progress as well as future developments. Another key sector would be collaboration with other Institutes of Higher Learning (IHL) where more in-depth research work could take place. SUTD is also planning on engaging partners in the CET centres and K-12 schools based on the developments and progress with the existing work with IHLs.

Cyber-Physical Learning Alliance (International and Singapore)

SUTD has been building the CPL Alliance since 2022 (Figure 8.1).

On 17th January 2023, SUTD and Tecnológico de Monterrey Mexico (TEC) jointly organized a fringe workshop titled "Future Education on Cyber-Physical Learning" as part of the 2023 International Conference on Education Innovation (CIIE) (Figure 8.2). The workshop aimed to discuss the future trajectories of CPL and establish an international alliance to promote the advancement of CPL through joint collaborative efforts, innovation projects, and knowledge sharing among institutes of higher learning.

The workshop brought together representatives from SUTD, TEC, Aalto University, Zhejiang University (ZJU), and Hong Kong University of Science and Technology (HKUST), both physically and through online participation. All five universities expressed strong interest in pursuing CPL and engaged in insightful discussions regarding future developments in this field. A consensus was reached among all universities to form an international alliance to facilitate mutual learning and collaboration on cyber-physical learning. The Rector of TEC (Professor Juan Pablo Murra Lascurain) also

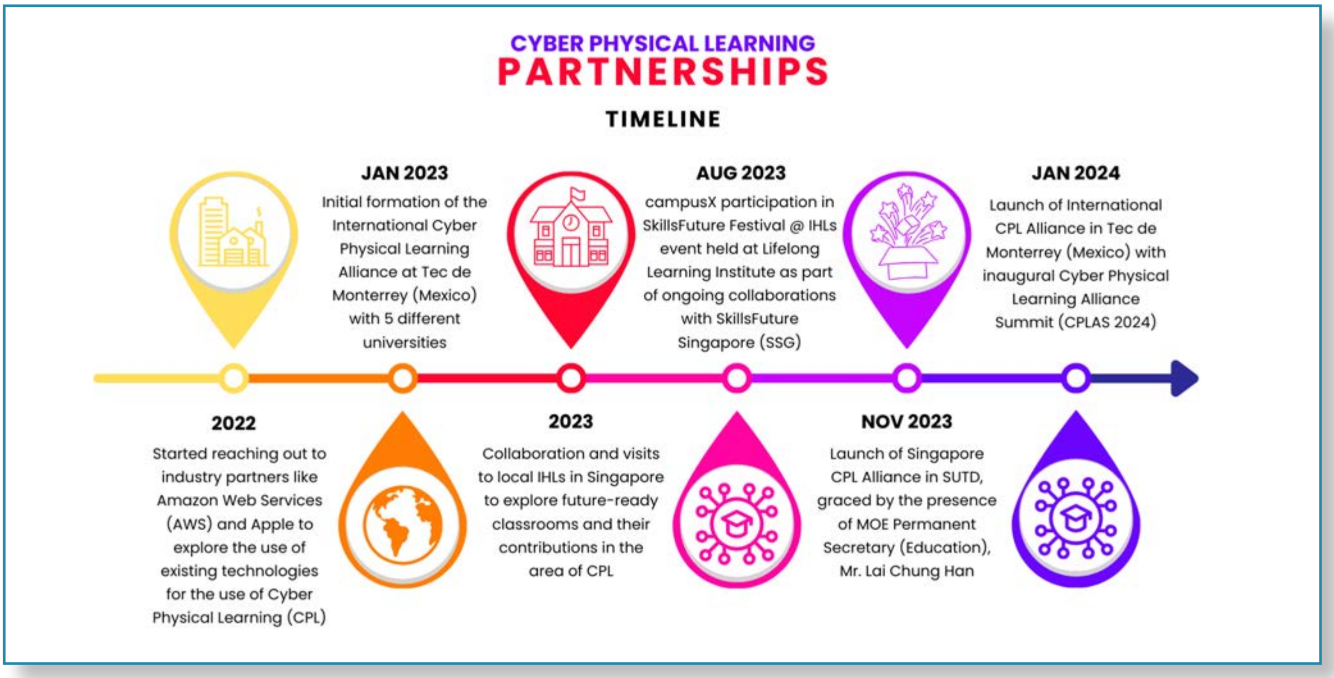


Figure 8.1. Timeline of CPL Initiatives at SUTD

Figure 8.2. Workshop to Kickstart Discussions on Cyber-Physical Learning Alliance

Figure 8.3. Support from TEC's Rector, Professor Juan Pablo Mura

lent his strong endorsement for the formation of the International Cyber-Physical Learning Alliance (CPLA) (Figure 8.3).

Since the formation of the alliance at CIIE, the international alliance has also agreed on specific innovation workstreams to generate forward-looking projects and initiatives. These workstreams encompass various areas, such as (i) CPL White papers/Trend reports such as this, (ii) CPLA alliance website, iii) CPL Journal , CPL AI for future CPL education, CPL hackathons, CPLA fellowship/ certification, CPL educational models, and CPL learning analytics. Alliance members would then share and present findings and reports emerging from these workstreams to jointly advance the field of CPL.

The international alliance is going to be officially launched at the first I Cyber-Physical Learning Alliance Summit (CPLAS) at Mexico, in January, 2024. This would be an event that brings together researchers, faculty members, industry professionals, and decision makers from around the world to explore the diverse approaches employed by universities in implementing cyber-physical learning scenarios. This summit aims to promote international collaboration, share best practices, and advance the field of CPL, focusing on topics from the alliance's workstreams. Figure 8.4 shows the international alliance.

Seeing the potential and successes of an international alliance, SUTD campusX saw the need to form partnerships with like-minded organizations within Singapore as well. A Cyber-Physical Learning Alliance (CPLA) consisting of Singapore partners has been formed and the local alliance (i.e. SG CPLA) had its launch on 29th November 2023 (Figure 8.6). Key partners include 3 Polytechnics (Ngee Ann Polytechnic, Singapore Polytechnic, Temasek Polytechnic), 3 Universities (Singapore Institute of Technology, Singapore University of Social Sciences, University of the Arts Singapore (LASALLE, NASA), 1 Private University (SIM University), and education-related agencies (Institute for Adult Learning, BCA Academy, Singapore Institute of Manufacturing Technology) with Ministry of Education as observer. Besides Pre-Employment Training (PET) for under- and post-graduates, the SG CPLA will have an additional focus on CET learning. See Figure 8.5 for Singapore-based CPLA partners.

Figure 8.4. International CPLA Partners

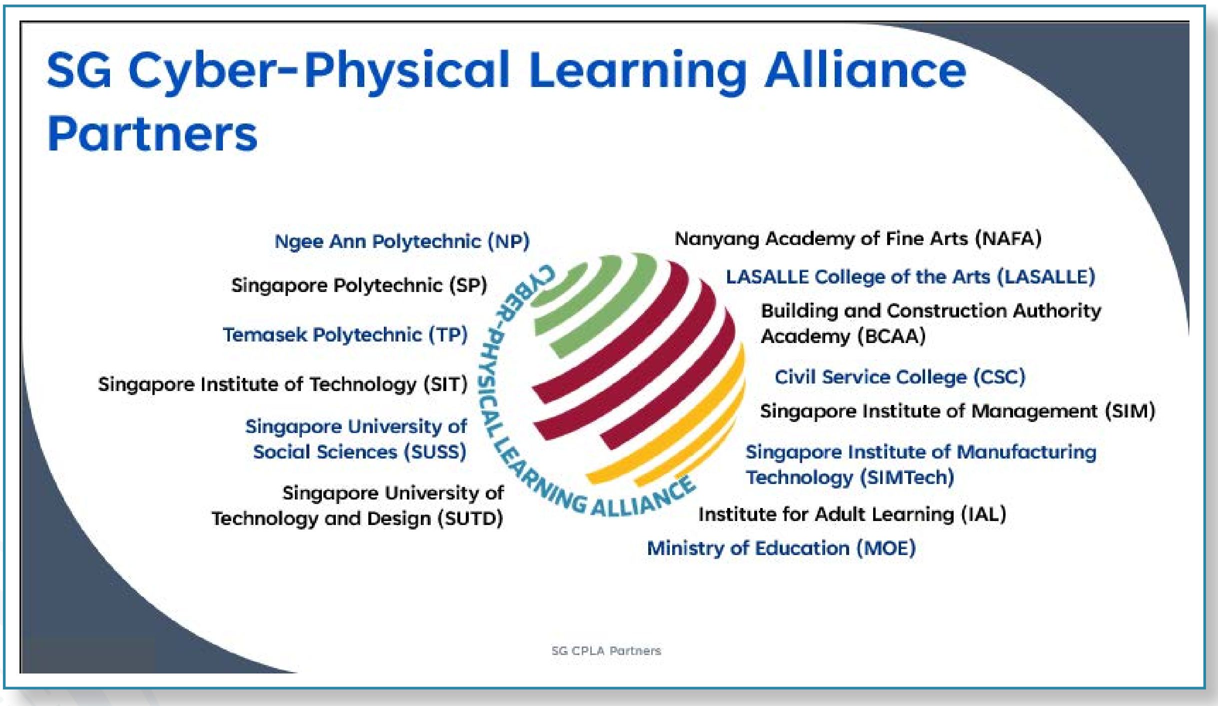


Figure 8.5. Singapore-based CPLA Partners

Figure 8.6. Discussions with Singapore CPLA

Singapore's Ministry of Education Permanent Secretary, Mr. Lai Chung Han, graced the SG CPLA launch event with his presence as Guest-of-Honour. The event featured a keynote talk by SUTD Assistant Professor Jeffrey Chan on the topic "A Primer on the Ethics of Cyber-Physical Learning (See Chapter 7), and an insightful panel discussion on "Borderless Learning with Cyber-Physical Technologies and Pedagogies". The keynote presentation and panel discussion provided insights into the purpose and significance of the event and also motivated attendees to embrace the spirit of CPL. The launch event also provided an excellent platform for attendees to network and connect with like-minded individuals.

SUTD plans to eventually harmonize both the Singapore and International alliances and build a "bridge" so that all partners can jointly contribute to and leverage on a collective expertise hub to advance cyber-physical learning and meet the needs of their future education strategies.

Collaboration with other Institutes of Higher Learning

In November 2022, TEC signed a collaboration agreement with SUTD to improve student learning outcomes and develop technology for CPL through initiatives like user trials.

In a follow-up meeting in Jan 2023, SUTD demonstrated the usability of one of the campusX minimum viable products, the Telepresence Learning System, to the researchers at TEC. The telepresence robot was positioned in Singapore with the audience at TEC acting as remote cyber students (Figure 8.7).

Figure 8.7. Demonstration of SUTD's TLS to TEC

This session served to showcase the technology and systems developed by campusX. TEC was impressed by the demonstration of the TLS and gained a hands-on experience of CPL. The session was engaging and interactive, with TEC collaborators sharing new ideas on further improving the TLS and discussing next steps to advance research collaboration. Upcoming plans include having one of TEC researchers to visit SUTD as part of the exchanges in collaborative research projects to further research and share expertise with each other.

Locally in Singapore, the CPL space has also been a keen area that IHLs are looking at. One of the key interest areas is creating the next future-ready classrooms that are equipped with technologies capable of engaging both physical and cyber students at the same time, which has become a priority for many institutions. As more local institutions are developing such classrooms, the campusX team visited various academic institutions (e.g., SIM, Ngee Ann Polytechnic, Singapore Polytechnic, Temasek Polytechnic, Singapore University of Social Sciences) to learn and observe their experiences in creating such a classroom (Figure 8.8).

There were also other areas of interest to collaborate amongst IHLs, including the Continuing Education and Training level, where the consensus of institutions is that setups for CPL would greatly aid the CET learners. It would improve the quality and accessibility of CET education and further enhance the learning experiences of adult learners who are unable to attend courses physically as they often must juggle multiple diverse responsibilities while balancing their need or interest to learn for work and personal growth.

Engaging Continuing Education and Training (CET) Centres and K-12

Learning does not take place just in schools or IHLs. Continuous and lifelong reskilling and upskilling are needed to remain competitive and relevant and thus, SkillsFuture Singapore (SSG) established CET centres to deliver quality adult training.

CET Centres play a crucial role in providing lifelong learning opportunities to individuals, helping them acquire new skills and stay competitive in a rapidly changing job market. By staying up to date with technology trends and continuously evaluating their effectiveness, CET centres aim to remain competitive and meet the evolving needs of learners and industries. The leverage on technology enables them to offer more dynamic and effective educational experiences that require hands-on training and interaction between cyber and physical environments.

Figure 8.8. Pictures of Visits to Other IHLs in Singapore by SUTD campusX Team

To reach out to adult learners, campusX participated in the SkillsFuture Festival@IHLs event held at Lifelong Learning Institute on 3rd August 2023 (Figure 8.9). The SkillsFuture Festival is an annual event organised by SSG that celebrates lifelong learning and skills development. It brings together individuals, industries, and organisations to showcase the transformative power of continuous education.

The TLS System was set up at the booth for the audience to have first-hand experience in CPL. Dr Kenneth Lo also conducted a talk on "Future of CET Education" by addressing how CPL can revolutionize teaching methods, making CET education more interactive and personalized. The talk fostered a sense of curiosity among the attendees, sparking discussions on the potential of this innovative approach to reshape the future of adult learning.

During the recent visits from SSG, Institute for Adult Learning (IAL), Singapore Institute of Manufacturing Technology (SIMTech), Civil Service College, and NTUC Learning Hub, the campusX team shared possible ways on how CET centres can harness technology for cyber-physical learning. For example, how Augmented Reality (AR) and Virtual Reality (VR) simulations can be used to create realistic immersive learning experiences for learners (Figure 8.10). Specifically, these CET partners saw the benefits of the TLS, Skill-Based Learning Pathway Mobile App, and SUTD Living Labs 2 and 3, in enabling and supporting implementation in CET centres to further enhance their educational offerings and provide an engaging learning experience for adult learners.

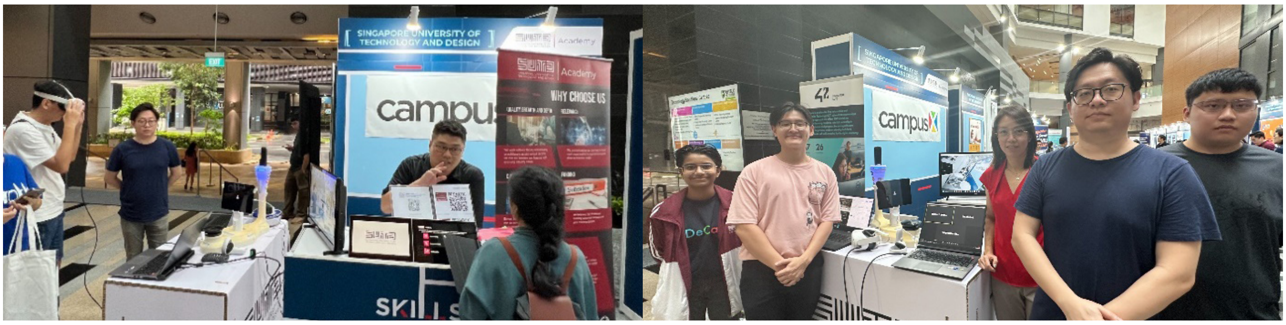


Figure 8.9. SUTD campusX Booth at SkillsFuture Festival@IHL Event

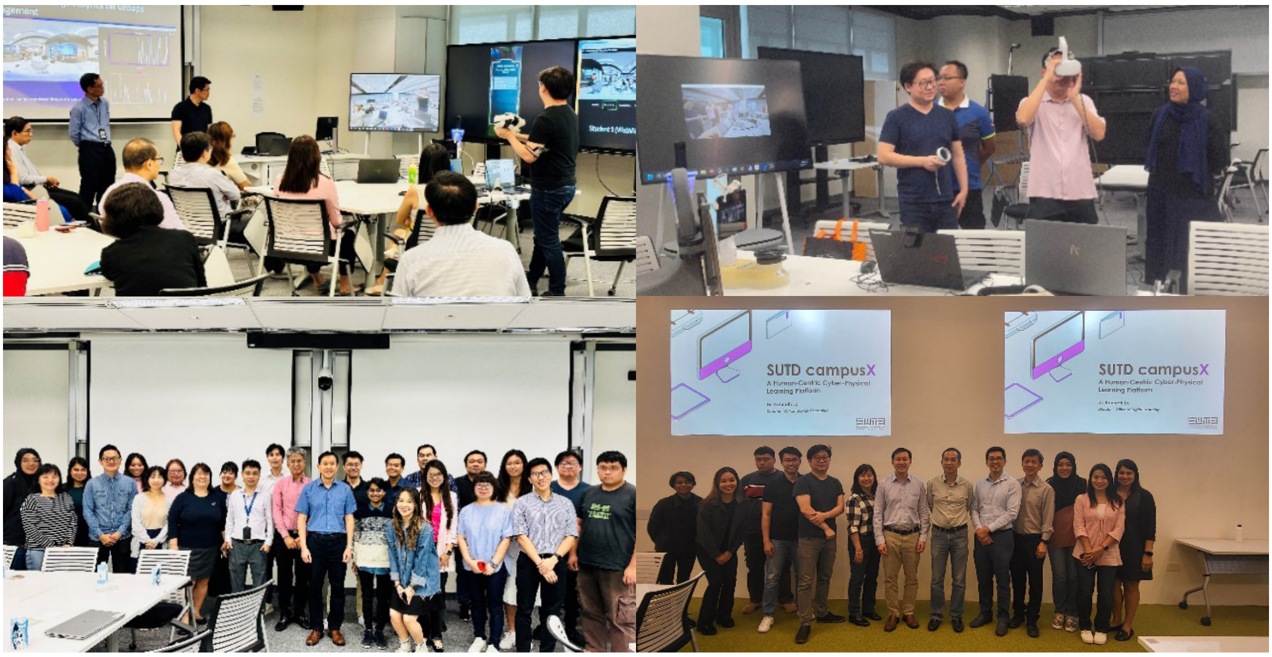


Figure 8.10. Visit from IAL, SIMTech, Civil Service College and NTUC Learning Hub

Thought Leadership on Cyber-Physical Learning

The campusX team participated in the 2023 International Conference on Education Innovation (CIIE) [attended by around 4,000 participants and organized by TEC where Prof. Pey Kin Leong gave a special session talk to introduce the concept of campusX CPL to the Latin American audience, attracting a sizable audience (Pey, 2023; Sockalingam, Lo, and Pey, 2023). See Figure 8.11.

Dr. Kenneth Lo of Office of Digital Learning gave a presentation on campusX at the Higher Education Planning in Asia (HEPA) Forum 2023 (hepaforum.hepa-association.org), University of the Sunshine Coast, Australia from 13th to 14th April 2023. The presentation focused on how CPL and campusX was able to contribute to a more sustainable future education under the theme "Mapping Sustainable Solutions for Future Education". See. Figure 8.12.

Professor Pey Kin Leong and Dr. Kenneth Lo co-chaired an interactive session on "Future Skills Outside Classroom for Sustainable Higher Education" during which a project (under development by campusX) on personalized skill-trees for learners to navigate and map their acquired skills was shared.

Apart from the overseas visits, campusX also hosted visitors at SUTD to share with our international counterparts the motivations and visions of CPL. This includes visits from MIT , Minerva University, and National Taiwan University. These events and sharing held in Mexico, Australia and Singapore brings campusX to a global audience and opens opportunities to invite interested collaborators to partner with us. See Figure 8.13.

Engaging with Industry

In the era of rapid technological advancement within the educational ecosystem, SUTD campusX recognizes that it is important to engage with industry to tap into the latest technological trends and developments. To leverage on industry's expertise, campusX has been actively engaging various companies to gain knowledge and skills through workshops and project collaborations. Such a collaborative approach helps campusX leverage on the latest and best-practice technologies in

Figure 8.11. SUTD campusX Presentation at CIIE 2023, Mexico

Figure 8. 12. SUTD campusX Presentation at HEPA Forum 2023, Australia

Figure 8.13. International Visitors to SUTD campusX

Figure 8.14. Apple AR Workshop at SUTD

learning analytics, gamification, robotics, artificial intelligence, augmented reality, and virtual reality to further advance cyber-physical learning and facilitate personalized and interactive learning experiences for all learners.

As an example, AWS has conducted several workshops with campusX to explain developments and trends of cloud infrastructure. In the virtual reality space, Apple shared about features of apps that would aid in the creation of Augmented Reality content. Workshops were also conducted by Apple to explore the possible usage of these technologies (Figure 8.14).

SUTD campusX is also in discussion with Lenovo on collaborations for CPL in areas such as telepresence and metaverse learning. The campusX team has also reached out to NVIDIA to discuss and exchange ideas and thoughts on digital twins. In addition, campusX is collaborating with SIMTech to develop improved versions of the Telepresence Learning System, tapping into the industrial design, and manufacturing expertise of SIMTech Innovation Factory.

The SG CPLA is setting up work streams to jointly develop best practices in the areas of CPL Technology (ToCPL), CPL Educational Models (SoCPL), Ethics of CPL (EoCPL), Learning Analytics of CPL and AIGC for CPL education. Through joint projects in these disciplines, and in conjunction with innovation activities to develop Minimum-Viable-Products, campusX aims to enable rapid prototyping and rapid translation of campusX technology into practices to build up sectoral capabilities within our partners.

References

Sockalingam, N., Lo, K., & Pey, K. L. (2023). SUTD campusX: An institutional digital transformation approach to higher education, presented at the *World Engineering Education Forum (WEEF) and Global Engineering Dean´s Council (GEDC) 2023*, Mexico, October 2023.

9. PERSPECTIVES OF THE FUTURE OF LEARNING

In this section, educational leaders of various institutions were asked on their perspectives of the future of learning. Their responses follow. The Future of Learning is going to be built on developments of today's technologies and practices, some are marginal changes and some others are radical and transformative.

Professor Pey Kin Leong

Associate Provost (Digital Learning)
Singapore University of Technology and Design

With the disruptive digital learning technologies, the landscape of the future of learning will be transformative. For example, blended *online* learning powered by AI Instructors and peers, and AI-assisted personalised learning machine, group-based and experiential learning can be taken place almost anywhere and anytime in a fun, fulfilling and secure environment. Such new form of learning removes many physical constraints and restrictions, and yet provides opportunity for genuine peer-to-peer and instructor-to-peer *synchronous* interaction despite the peers and instructors could be AI-trained humanistic machines. While in physical classes, authentic learning with good learning outcomes of both cyber and physical students are expected via the proposed cyber-physical learning environment.

Such complementary learning approaches using blended online learning and Cyber-Physical Learning is synergetic and is well suited for **bite-size and stackable modules** that require a lot of group-based activities. Leaners can **learn on-the-go and on portable devices**. Coupled with well-designed and structured pedagogy, it will make learners more self-driven and directed to sustain their learning passion and interest, embracing continuous lifelong learning for prolonged horizon.

We need to note that learning technologies will keep rapidly evolving and hence one needs to be mindful that educational technology is just a means. Sustainability of lifelong learning should be self-directed and driven by each learning needs. Hopefully with the evolving learning technologies and pedagogy/andragogy, the **future of learning can be more individualised, designed and customised for each individual's needs, truly embracing self-driven personalized learning**. This also opens the doors to all **regardless of their social status**.

Dr Luis F. Morán-Mirabal

Living Lab Coordinator, Living Lab & Data Hub, Institute for the Future of Education, Tecnologico de Monterrey Mexico

The future of work has been outlined by 5 disruptions:

1. Advances on technology, automation and digitalisation,
2. Globalisation and Localisation,

3. the shifting on demographics,
4. a greater longevity on which people develop multiple careers, and
5. the global pandemic of COVID-19.

In consequence, the new paradigm that Tecnologico de Monterrey envision for Education is defined by:

  i. flexibility for selecting multiple pathways for learning,
  ii. the integration of work and study,
  iii. empowering individuals,
  iv. the timely identification of priority and emerging skills, and
  v. being front-loaded to life-long learning.

We think Education should be FAIR:

- **Fit for purpose** - Pedagogical and technological approaches that lead to effective learning.
- **Accessible** - Cater to different learners needs and contexts.
- **Inclusive** - Higher Education and Lifelong learning opportunities for all segments of the population (universal access).
- **Relevant/Responsive** - Meet the dynamic changing needs of industries and society.

The Institute for the Future of Education is addressing five grand challenges to improve quality, relevance, access/inclusion and efficiency of education:

1. **Elevate learning outcomes** by transforming teaching & learning to be engaging and motivating.
2. **Design effective competency-based education** and lifelong learning systems to elevate learning outcomes.
3. **Skills development** to support worker job mobility and companies' business transformation.
4. **Scale up quality** higher education and lifelong learning opportunities for all segments of the population.
5. **Make education affordable and convenient** to different learner segments.

Dr Sean McMinn

Director, Center for Education Innovation,
The Hong Kong University of Science and Technology, Hong Kong

The Future of Learning will involve a shift towards **value-based and skills-based education**. Knowledge will still be important; however, there will be a heavier emphasis on the **need to develop students' competencies in abilities and skills, such as creativity, critical thinking, and attitudes and values, such as adaptability, grit, and growth mindset.** One reason is the rise of the AI-era, where knowledge acquisition and dissemination can be automated. In this example, it is increasingly important for students to be able to navigate complex systems, synthesize disparate pieces of information, and engage in lifelong learning. With AI systems capable of handling routine tasks and even specialized knowledge-based roles, the unique value humans bring lies in their ability to ask meaningful questions, solve open-ended problems, and adapt to rapidly changing circumstances.

In relation to this, the future of learning will not be an either-or scenario between human teachers and AI educators but **a synergistic relationship where the strengths of one complement the weaknesses of the other**. Students will benefit from a hybrid educational model that combines the adaptability, creativity, and emotional intelligence of human educators with the data-driven, personalized approaches that AI systems can provide.

Human/AI Collaboration in Problem-Solving

In this model, **human thinking will be augmented by machine intelligence** to tackle complex, real-world problems. Imagine a classroom scenario where students collaborate with AI agents to solve a climate change simulation. Here, AI can process large datasets to forecast trends, while students apply critical thinking to evaluate solutions, consider ethical implications, and make decisions. Such collaborative problem-solving can be a powerful teaching opportunity, emphasizing the blend of technical and soft skills that future professionals will need.

Emergence of AR, VR, and AI Technologies

As technologies in Augmented Reality (AR), Virtual Reality (VR), and AI continue to advance, they will become more accessible and affordable. We can **expect a proliferation of AI agents embedded in AR/VR simulations,** creating more immersive, interactive learning experiences. These technologies offer unique advantages:

- **Reinforced Learning:** AR/VR simulations with embedded AI can offer immediate, contextual feedback, reinforcing learning in real-time.
- **Distance Learning:** These technologies can break down geographical barriers, allowing for rich, interactive experiences that come close to traditional classroom settings.
- **Active Learning:** Students can engage in experiential learning scenarios that require them to apply knowledge, analyze situations, and make decisions, thereby promoting active learning.
- **Personalized Learning:** AI can adapt AR/VR experiences to individual learning styles and paces, offering a more personalized education.
- **Feedback Opportunities:** Real-time analytics from these platforms can offer insights into student performance and engagement, providing valuable feedback for both educators and learners.

Implications for Education

Emphasizing human skills and leveraging AI: The convergence of these technologies not only amplifies the potential for human/AI collaboration but also necessitates a shift in educational priorities. As AI takes over more routine cognitive tasks, the educational focus will shift towards **nurturing skills and attitudes that are uniquely human but can be significantly enhanced when augmented by technology.**

Ethical and Social Responsibility: As AI systems gain more decision-making capabilities, integrating ethical and social considerations into problem-solving will become critical. Students need to learn how to collaborate with AI responsibly.

Digital Literacy: As AI and AR/VR become integral to daily life, digital literacy will be non-negotiable. Students will need to know not just how to use these technologies but also how to do so effectively and ethically.

Interdisciplinary Education: The complexities of modern problems will require interdisciplinary solutions. Educational programs will need to blend science, technology, arts, and social sciences to prepare students for the challenges ahead.

Associate Professor Karin Avnit

Deputy Director, SIT Teaching and Learning Academy, Singapore Institute of Technology, Singapore

We see the future of learning is characterised by a convergence of technological advancements and a reimagining of the educator's role.

Educator's Evolving Role:

Educators are no longer just disseminators of information; their focus **shifts towards facilitating learning** and nurturing holistic student development. They become coaches and facilitators, tailoring education to individual needs and strengths. They add value beyond what technology can provide, offering mentorship, critical thinking skills, and emotional support.

Self-Paced, Personalized, and Adaptive Learning:

Learning experiences become highly tailored to individual students. Technology enables self-paced learning, allowing students to progress at their own speed. **Adaptive learning systems leverage AI and data analytics to provide customized content and assessments, ensuring engagement and motivation.** This approach prepares students with a solid foundation of knowledge and skills for more interactive sessions.

Blended and Flipped Pedagogies:

Traditional classroom settings evolve into **blended and flipped models**. Pre-recorded lectures and interactive digital content become pre-requisites, setting the stage for dynamic live sessions. Educators leverage in-person or virtual environments for high-level thinking activities, such as facilitated discussions, collaborative problem-solving, and real-world applications of knowledge through peer learning, group discussions, and hands-on exercises in authentic settings. The emphasis is on applying knowledge in meaningful ways.

Technology provides a web of communication tools that support students on their independent learning journeys. These channels foster a sense of connection and community, allowing students to seek help, engage in discussions, and collaborate outside of formal sessions. This asynchronous support system enhances the overall learning experience.

Adaptive Learning Spaces:

Learning environments, both physical and virtual, are purposefully designed to align with the pedagogical approach. They are equipped with cutting-edge technology, flexible furniture, and resources that facilitate active learning, collaboration, and exploration. **These spaces are dynamic, responsive, and conducive to a variety of learning activities.**

Industry Collaboration and Curriculum Integration:

The **curriculum is enriched through dynamic collaboration with industry experts.** This integration takes various forms, from internships and co-op programs to industry-sponsored projects and guest lectures. Industry insights shape the curriculum, ensuring that students graduate with relevant skills and knowledge that align with real-world demands.

In this envisioned future, education transcends traditional boundaries, embracing the potential of technology while recognizing the irreplaceable value of human interaction and mentorship. The learning experience becomes highly personalized and engaging.

Associate Professor Rebekah Wei Ying Lim

Deputy Dean, College of Interdisciplinary and Experiential Learning
Director, Teaching and Learning Centre.

1. We consider the following aspects, though not exhaustive, to be important for the future of learning:
   a. **Technology innovation and integration.** With continuous technological advancements, technology will play increasingly important roles in the future of learning. This encompasses the **use of AI for personalized learning, the use of immersive technology for experiential learning experiences,** and the integration of other cutting-edge digital tools to enhance the learning process.
   b. **Big data and learning analytics**. As we leverage technology to enhance the teaching and learning process, it simultaneously generates a wealth of data. When harnessed for the development of learning analytics, these **data can empower both instructors and learners to make informed decisions** regarding their teaching and learning experiences.
   c. **Ethical consideration in using technology.** With the ongoing evolution of technology and its increasingly important role in education, ethical considerations, including those related to privacy, security, accessibility, and digital well-being, will continue to be important issues in the future of learning.
   d. **Interdisciplinary learning.** The complexity of real-world challenges increasingly demands interdisciplinary solutions, and this trend will become even more obvious in the future. To better prepare our students for the challenges ahead and foster their critical thinking and creative problem-solving abilities, it is imperative to promote interdisciplinary learning. Through interdisciplinary education, we can empower students with the adaptability required to navigate the ever-evolving landscape of industries and circumstances in the future. It can also equip them with diverse perspectives and enable them to obtain a holistic understanding of complex issues, which are essential for addressing complex real-world problems in life.
   e. **Lifelong learning**. With the changing job landscape, lifelong learning will be a norm in the future. Our education should address this emerging need and better equip them with the skills, mindset, and knowledge needed to become lifelong learners.

Ms Shirley Williams

Director, Centre for Learning & Teaching Excellence, Ngee Ann Polytechnic, Singapore

Mr Philip Lau,

Senior Academic Fellow, Centre for Learning & Teaching Excellence, Ngee Ann Polytechnic, Singapore

- Digital and AI-First: Learning to be digital & AI-powered, with online tools as key enabler.
- Gen AI Integration: Gen AI enhances personalised learning and streamlines tasks.
- Hybrid Models: Blending of virtual and in-person learning for flexibility.
- Industry Collaboration: Strong ties with industry for real-world skills.
- Lifelong Learning: Continuous skill growth is vital as industries evolve.
- Interdisciplinary: Promoting versatile skills through cross-disciplinary learning.
- Life Skills: Recognising the importance of life/soft skills in the future workplace.

Dr Lim Joo Ghee
Director, School of Electrical & Electronic Engineering, Singapore Polytechnic, Singapore

Ms Leck Hwang Keng
Assistant Director, School of Electrical & Electronic Engineering, Singapore Polytechnic, Singapore

- Focusing on empowering students to take ownership of their learning and tapping on intrinsic motivation
- Providing an environment which is flexible, innovative and challenging and which will foster students who are capable of making formative decisions based on accessing the facts
- Technology based
- Micro credentials (Lifelong learning)

Our aim is not to predict the future but to build up our strength so that we are resilient and persevering even amid adversity and unforeseen circumstances such as the pandemic COVID-19, and that starts without readiness to continually learn, improve and develop the new future of learning together.

How is your institute getting ready for the Future of Learning?
Come, join us at the CPLA Network to build the Future of Learning

10. AN OVERVIEW OF CYBER-PHYSICAL LEARNING

Nachamma Sockalingam

This Trends and Foresight paper on Cyber-Physical Learning (CPL) presents the concept of CPL and elaborates using case studies from various institutions, particularly from Asia and Mexico. This report is likely to be the first of its kind and novel. This final overview chapter attempts to weave together the lessons learned from the various institutions and distill the take-home message for our readers.

Concept of Cyber-Physical Learning

Cyber-Physical Learning is a new term innovated at SUTD (Sockalingam *et. al.*, 2022). to refer to seamless and synchronous hybrid learning, where both remote cyber students and face-to-face physical students can learn and interact effectively, seamlessly, and synchronously in the same lesson, by using technologies such as immersive technologies (e.g., Augmented Reality (AR)/ Virtual Reality (VR)/ Mixed Reality (MR), metaverse learning, gamification), telepresence robotics, learning analytics, and personalized learning.

As seen in our literature search for the term "Cyber-Physical Learning" in the Web of Science or other databases (Chapter 4), CPL is a relatively new terminology in the literature and there is a need for more research and documentation on CPL. This Trends and Foresight report aims to address that. We have invited various institutions to be part of the CPL Alliance network and contribute examples of CPL at their institutions. These case studies are from

i. **SUTD:** Singapore University of Technology and Design
ii. **IFE@TEC:** The Institute for the Future of Education (IFE) Experiential Classroom Project at Tecnologico de Monterrey
iii. **HKUST:** Hongkong University of Science and Technology
iv. **SIT:** Singapore Institute of Technology
v. **SUSS:** Singapore University of Social Sciences
vi. **IAL:** Institute for Adult Learning
vii. **NP:** Ngee Ann Polytechnic
viii. **EEE@SP:** School of Electrical and Electronic Engineering, Singapore Polytechnic
ix. **LASALLE:** LASALLE College of the Arts, University of Arts Singapore: Merging Digital and Physical Arts Education
x. **NAFA:** Nanyang Academy of Fine Arts

We can see from the case studies in this report that COVID-19 has indeed played an important role in catalyzing digital transformation in these higher education institutions. The impact of COVID-19 on the digital transformation of higher education is supported by various other studies globally (e.g., Adedoyin, & Soykan, E. 2023; Salas-Pilco, Yang, and Zhang, 2022; Isoherranen, V., & Kääriäinen, 2021). Our literature search in Web of Science also indicates a spike in published articles on digital learning during and post-COVID period. This resonates with a bibliometric study by Zhang et. al., (2022) on online learning that examined 1061 documents from 105 countries. They found that there was an unprecedented rise in pandemic-imposed online learning in higher education. These are strong indications that hybrid/blended digital learning and CPL are the way forward.

The various case studies presented in the earlier chapters provide detailed information on CPL implementation in these institutions. To gather more insights, key representatives from these institutions were asked to participate in a written interview to share their strategies and plans on various aspects of CPL, their technology of choice, and the challenges in implementing CPL. The next sections provide information on the educational context of the participating institutions, compare the triggers, initiatives, types, and approaches of CPL in the various institutions in Table 10.1. Following that is a summary of the CPL strategy at the various institutions in Figure 10.2. This chapter provides an additional dimension to the earlier chapters of case studies and draws insights from the various chapters.

About the Participating Institutions

A total of ten institutions from the CPL Alliance network participated in this study.

i. Out of the 10 participating institutions, 8 are Singapore-based. We have 2 from overseas, of which one is from Hong Kong and the other from Mexico.
ii. We have institutions of various sizes, starting from departments/schools to entire institutions. The smallest caters to 60 faculty members, and 800 students, and the largest caters to 87,000+ students in 26 campuses in Mexico with 11115 faculty members.
iii. Participants include various types of higher educational institutions such as polytechnics, universities, and institutes for adult learning. Most institutions cater to both undergraduate and graduate students and offer specialized programmes for continual learning
iv. These institutions specialize in a wide range of topics, including art, and science.
v. The institutions have had ongoing Learning initiatives and are seen to be transforming to the changing needs of curriculum and technology.

Benchmarking of CPL at various institutions

Table 10.1 presents an overview of the various educational triggers of CPL and their approach to solving those challenging situations from the earlier chapters. Given that CPL is a new concept, and that there are very few publications, we hope that these case studies will be useful references for our readers.

Institution	Triggers	Solution		
		Initiative	Type	Approach
SUTD	• COVID-19 • SUTD's Experiential and project-based learning needs to be better supported by the existing technologies for these activities to be conducted online.	SUTD campusX program	An institution-wide parallel program to existing blended/online learning. Also, bottom-up	Uses an agile product development approach in partnership with educational stakeholders. Focus on • People-centric learning and design • Immersive realities learning • Metaverse and blockchain for learning • Socially interactive educational robotics • Advanced learning analytics, especially real-time analytics • Enhanced learning through innovative technology

Institution	Triggers	Solution		
		Initiative	Type	Approach
IFE@TEC	• COVID-19 • Need to understand current educational models, pedagogical approaches, and technologies such as digital learning platforms, video conference systems, virtual and mixed reality headsets, mobile devices, and portable computer devices for in-person, remote, or hybrid participants	Living Lab	Institution-wide, parallel program	Specialize in enabling research projects that involve experimentation with educational technologies in user-centered real-context learning environments
HKUST	• COVID-19 • Need to continue adopting and exploring appropriate technology and innovative pedagogy that provides high-quality course design, student-centered pedagogy, and flexibility of delivery and access to learning.	HKUST Digital Learning	Institution-wide, all courses to have a parallel digital footprint	Strategic priorities include • Learning environments • Innovative pedagogy • Assessment design and practices • Quality assurance • Faculty development
SIT	• COVID-19 • To address the needs of applied learning	Blended Applied Learning	Institution-wide	Focus on • Educator • Faculty development • Flipped Learning pedagogy • Learning environment

Institution	Triggers	Solution		
		Initiative	Type	Approach
SUSS	• COVID_19 • Addressing the needs of adult learners, especially for part-time learners	SUSS Digital Learning	Institution-wide and bottom-up projects	Focus on • Learning Sciences • Faculty development • Adaptive Learning System • ADLes Learning Model • Flipped Learning
IAL	• COVID-19 • Need to integrate learning spaces more effectively to raise the quality of adult education	Cyber-Physical Learning 2.0: In.lab	Institution-wide	Aim to create a learning environment that is conducive to collaboration and critical thinking, to engage students in self-directed learning.
NP	• COVID-19 • Future-oriented teaching and learning	Digital Transformation: Experience, Relevance, Curriculum (ERC)	Institution-wide 40 Online Asynchronous learning (OAL):60 In-person Learning (IPL) for Diploma courses, and 50% OAL: 50%IPL for CET	Key success factors include • Vision and Leadership • Systems and Structure • Capability Development • Communication and Change management • Evidence-based
EEE@SP	• COVID-19 • The dynamic nature of semi-conductor industry and the need for hands-on immersive, flexible and collaborative learning	Learning space for a more interactive and immersive learning environment	School and course-based	Key features of implementation include • Learning Space • Flipped Learning • Augmented Reality and Virtual Reality Learning Package Development • Collaborative teaching and learning • Continuous assessment and feedback

Institution	Triggers	Solution		
		Initiative	Type	Approach
LASALLE	• COVID-19 • Practice-based learning in Arts	Digital Pedagogy	• Institutional Framework • Innovative initiatives	• Due to the diversity of subjects, it is not possible to have one-size-fits-all approach. • Institutional Framework • Technological integration • Faculty development • Shared Campus • Hybrid Teaching

Table 10.1. A Comparison of CPL at CPL Alliance Institutions

CPL Strategy at Various Institutions

In the first white paper on CPL, SUTD had proposed its CPL strategy (Figure 10.1). The participating institutions were asked to suggest where they envision their immediate priorities star in terms of this CPL strategy which proposes that CPL constitutes of Science of CPL, Technology of CPL, and Ethics of Learning. Figure 10.1 shows SUTD's position. Figure 10.2 presents that of the various institutions. Although the various institutions may not use the same terminologies (such as CPL, Science of CPL), they were asked to suggest their alignment based on conceptual meaning. For instance, Learning Sciences would map to Science of CPL.

SUTD

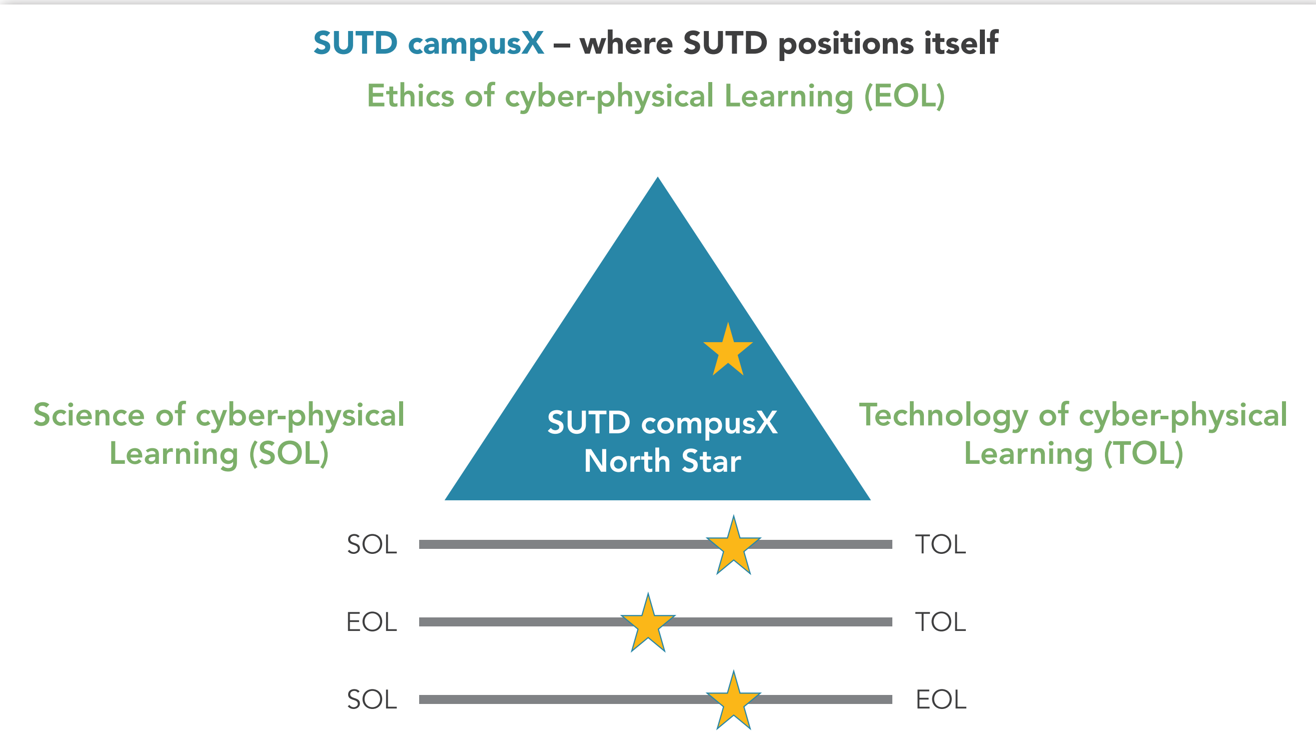
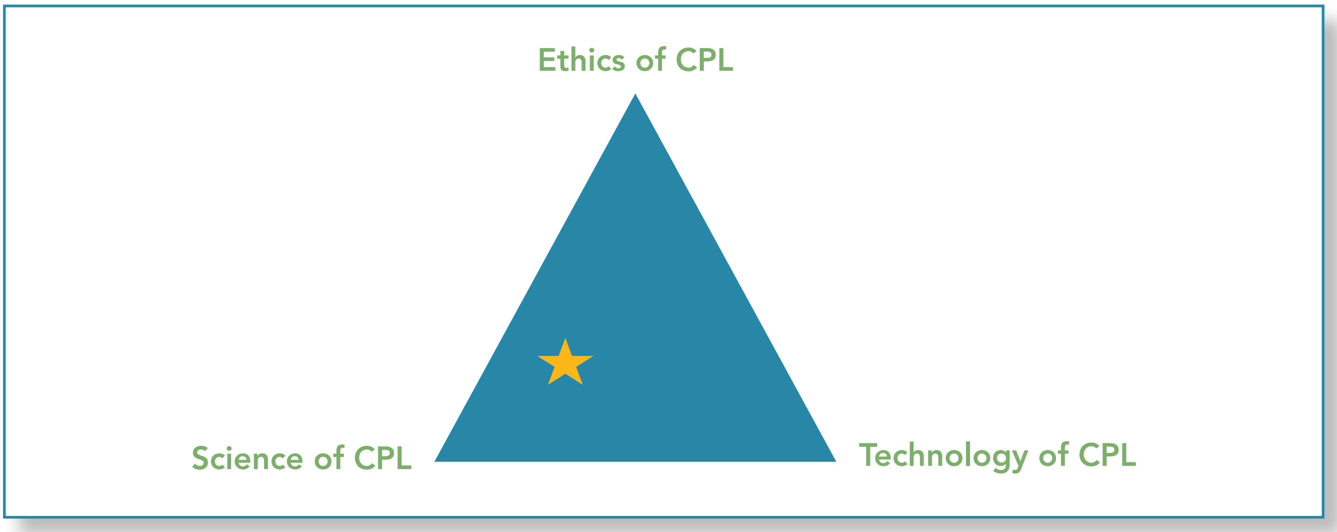
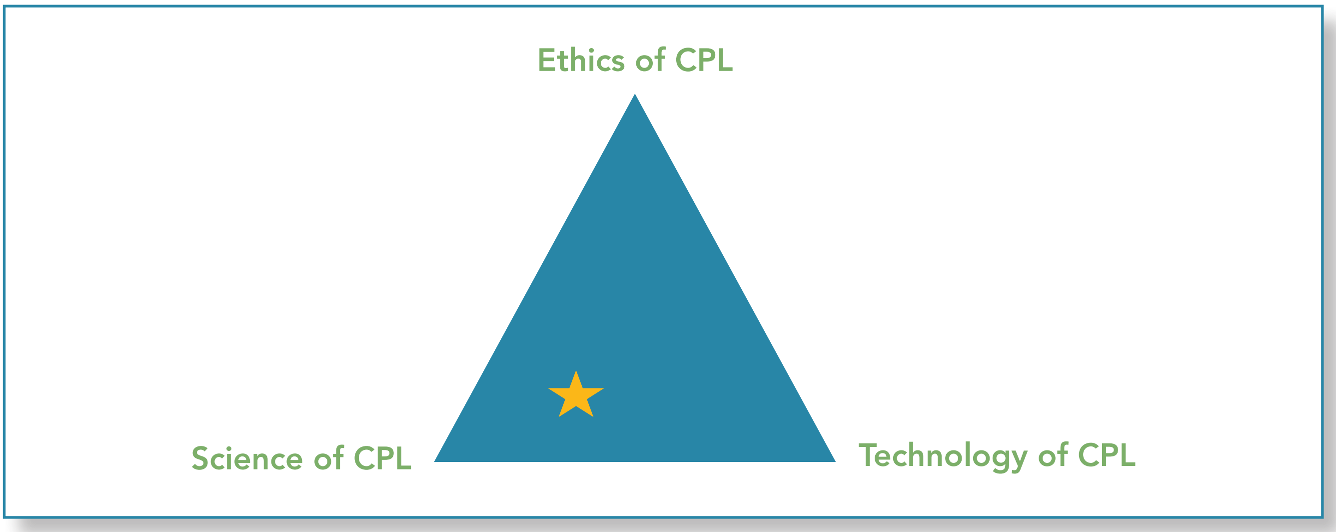


Figure 10.1. CPL Strategy at SUTD (Credit: Kenneth Lo, Judy Teo, Pey Kin Leong, 2022).

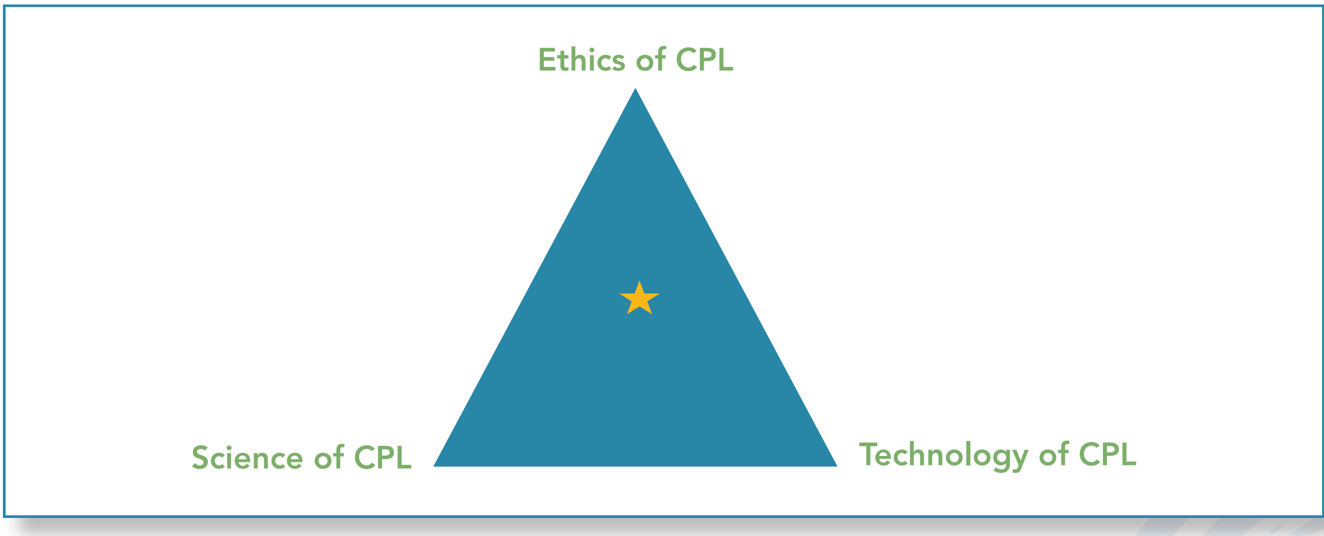
IEE@TEC



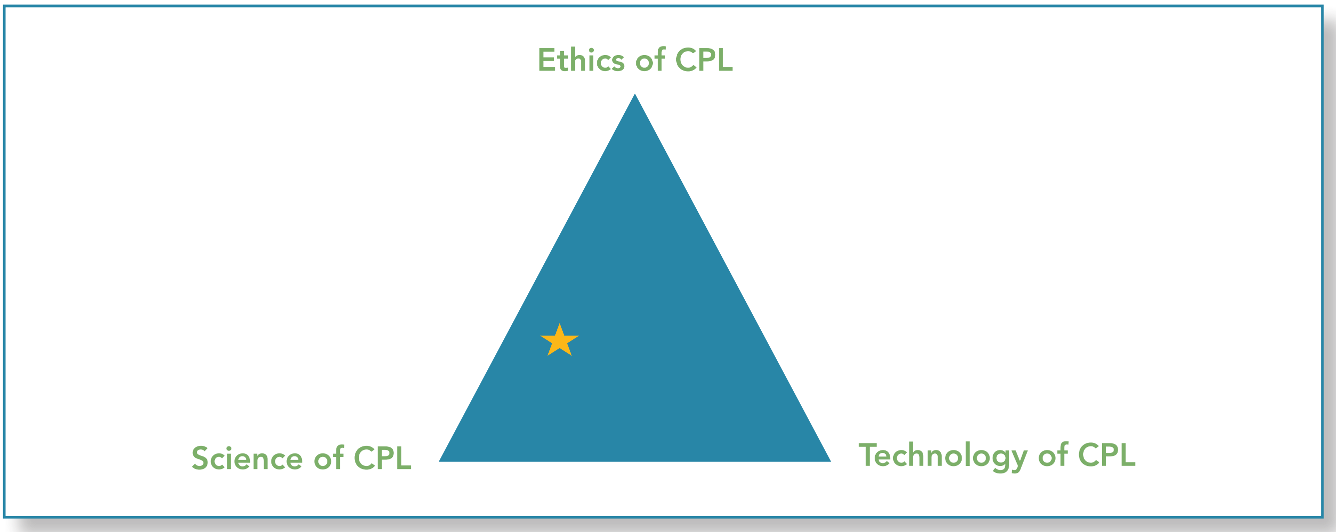
HKUST



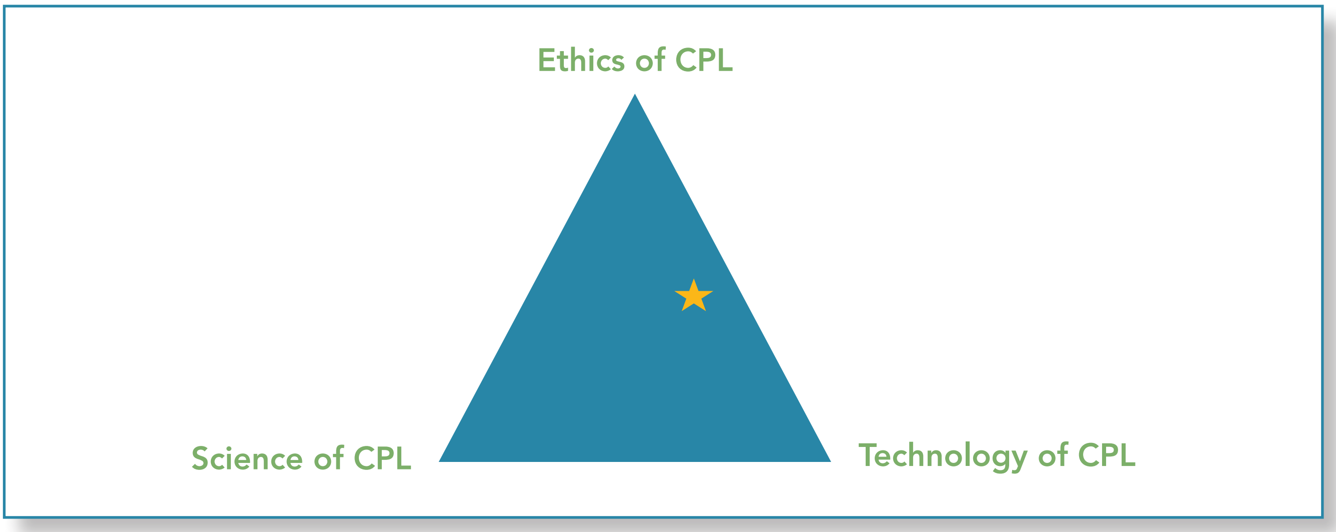
SIT



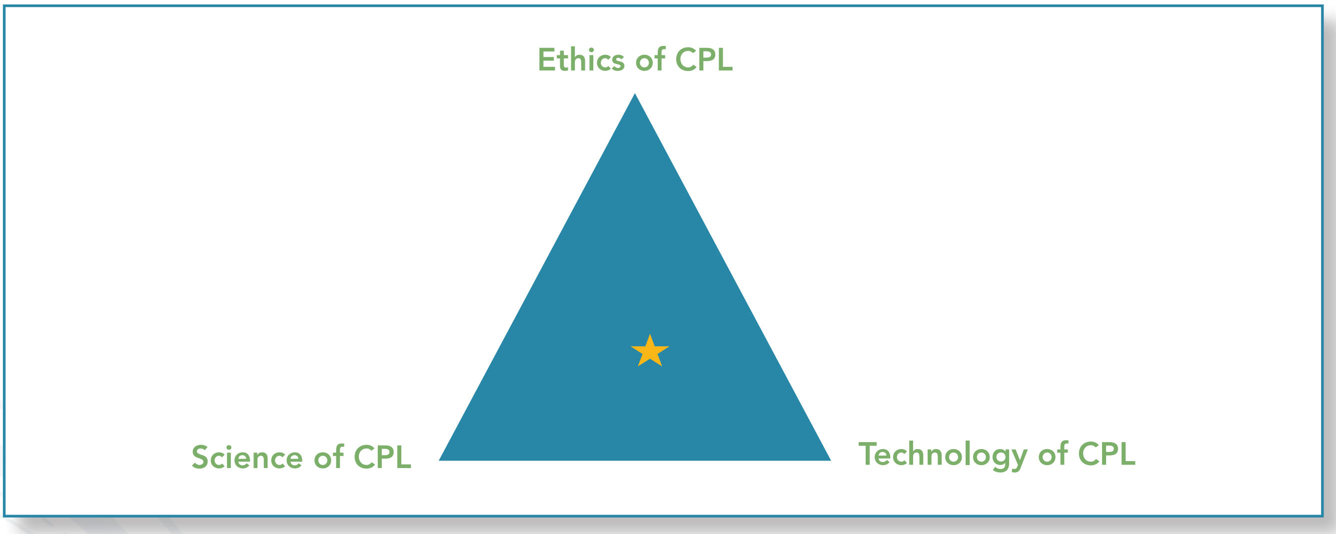
SUSS



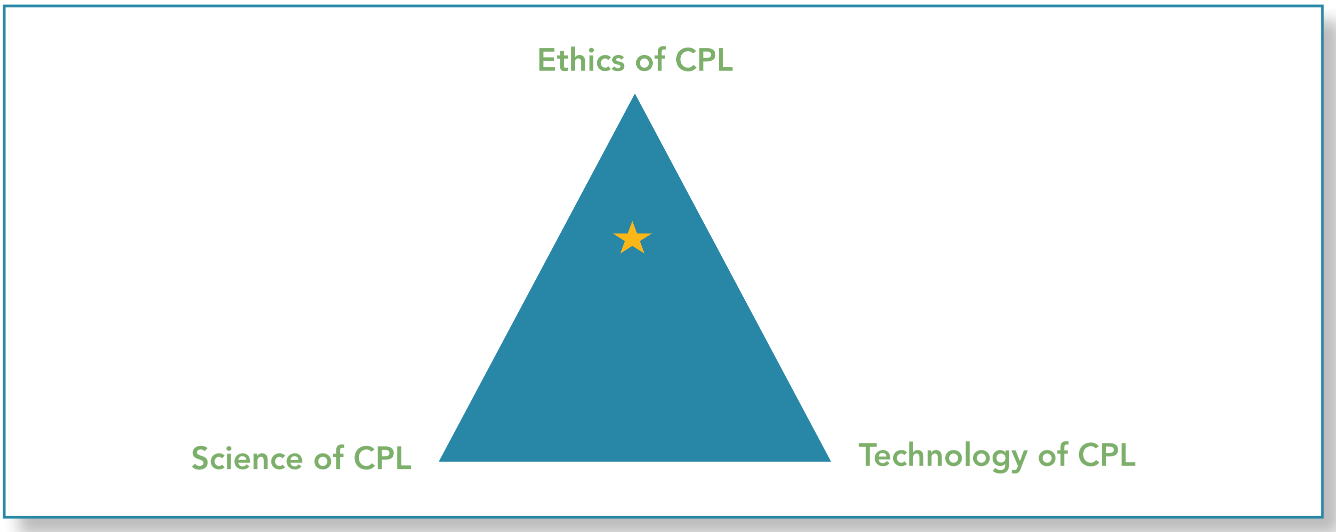
NP



EEE@SP



LASALLE



NAFA

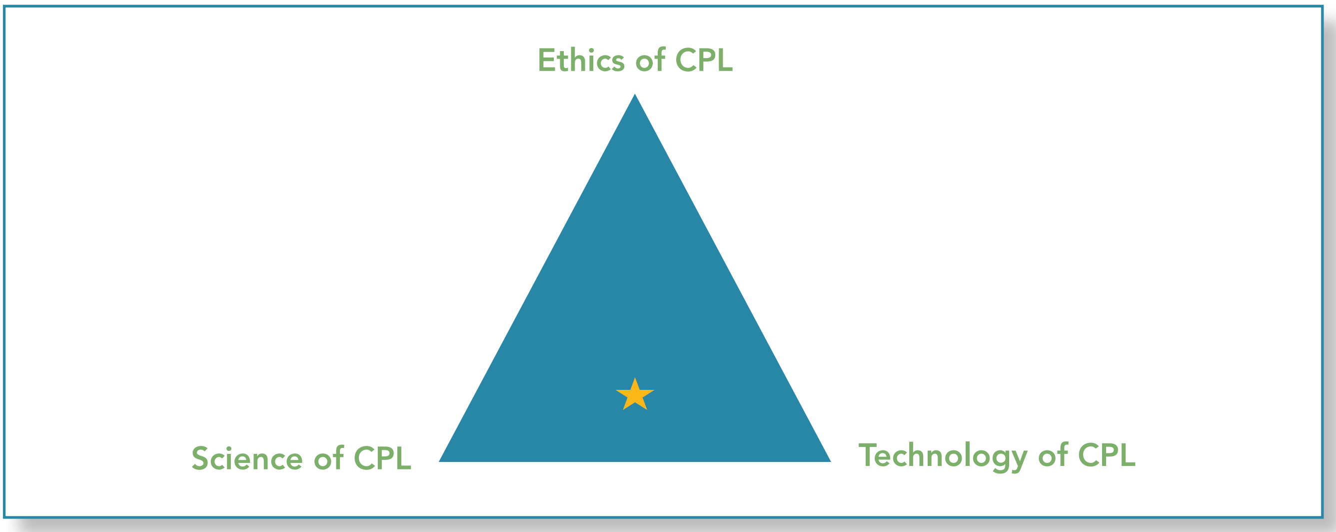


Figure 10.2. CPL Strategies at the Reported CPL Alliance Institutions

Technology of Choice

Participating institutions were referred to the Horizon Report (Pelletier, *et. al.*, 2023) and asked to identify technologies used in their institution and rank them by their prevalence at their institution and importance, with one being top-ranking. Horizon Report is an annual report that gets an expert panel to identify the technologies in higher education. For the year 2023, the expert panel identified the following six items as potential technologies and practices:

1. AI-Enabled Applications for Predictive, Personal Learning
2. Generative AI
3. Blurring the Boundaries between Learning Modalities
4. HyFlex (i.e., students enrolled in a course can participate on-site, synchronously online, or asynchronously online as preferred)
5. Micro-credentials
6. Supporting Students' Sense of Belonging and Connectedness

All the institutions agreed that all six technologies applied to them. Table 10.2 presents their responses.

Institution	Prevalence	Importance
SUTD	1. Blurring Learning Modalities boundaries 2. Hyflex 3. Other technologies	1. Hyflex 2. Learning environment/Immersive learning 3. Generative AI
IFF@TEC	1. Micro-credentials 2. Supporting student connection 3. Hyflex	1. Micro-credentials 2. AI-enabled applications 3. Generative AI
HKUST	1. Learning Management Systems (e.g., Canvas) 2. Video Conferencing Software (e.g., Zoom, Microsoft Teams) 3. Generative AI	1. Video Conferencing Software (e.g., Zoom, Microsoft Teams) 2. Generative AI 3. Virtual Labs and Simulations (AR/VR)
SIT	1. Generative AI 2. AI-enabled applications for predictive personalized learning 3. Micro-credentials Each of the technologies listed plays a significant role in enhancing our educational offerings and experiences for both faculty and students. Regarding prevalence, the adoption and implementation of these technologies vary across different faculty and programmes. Factors such as disciplinary requirements and pedagogical approaches can influence their utilization. We have not measured their prevalence in the university. In terms of importance, each of these technologies addresses distinct facets of our educational mission. They contribute to our institution's commitment to fostering an inclusive, innovative, and adaptable learning environment.	
SUSS	1. AI-enabled applications for predictive, personal learning 2. Hyflex, 3. Generative AI	1. AI-enabled applications for predictive, personal learning 2. Hyflex, 3. Generative AI
NP	1. Blurring learning modality boundaries 2. Supporting Students' sense of belonging and connectedness 3. Generative AI	1. Generative AI 2. AI-enabled applications for predictive, personal learning 3. Supporting Students' sense of belonging and connectedness
EEE@SP	1. AI-Enabled Applications for Predictive, Personal Learning 2. Generative AI 3. Supporting Students' Sense of Belonging and Connectedness	1. AI-Enabled Applications for Predictive, Personal Learning 2. Blurring the Boundaries between Learning Modalities 3. Supporting Students' Sense of Belonging and Connectedness
LASALLE	This is difficult to answer as the use of technology is subject-specific	This is difficult to answer as the use of technology is subject-specific
NAFA	1. Supporting students' sense of belonging and connectedness 2. Blurring learning modalities boundaries 3. AI-enabled applications for predictive personal learning	1. Supporting students' sense of belonging and connectedness 2. Blurring learning modalities boundaries 3. Generative AI

Table 10.2. Choice of Technologies at the Reported CPL Alliance Institutions

Challenges in CPL

Practicing CPL is not without its challenges. In the very first white paper on CPL, a list of these challenges and difficulties in the implementation of online/blended learning was gathered from multiple sources such as (i) Interviews with stakeholders/ educational leaders in and outside of the Singapore University of Technology and Design (SUTD), (ii) Discussions with SUTD campusX members, and (iii) Literature survey of various studies (Sockalingam *et. al.*, 2022). These challenges were classified as strategic (Green) and operational (Blue) (Sockalingam, 2022). Figure 10.3 shows the classified challenges. We wanted to know if this list of challenges still holds, if there are any additional challenges faced by the institutions, what they perceive as their top 5 challenges, what challenges/s they see as the hardest to solve, and how they are overcoming the challenges in general. These data are presented in Table 10.3.

Figure 10.3. Strategic and Operational Challenges in Online and Blended Learning (Credit: Nachamma Sockalingam, 2022)

Institution	Additional Challenges	Top 5 Challenges	Hardest to solve Challenge	Overcoming Challenges
IFE@TEC	1. Use of ChatGPT by students 2. Classroom availability	1. Learner Wellness (Mental wellness, Lack of socialization aspect in online/blended learning) 2. Resources (Heavy workload for faculty) 3. Technology limitations (Lack of systems for learning analytics) 4. Technology security and ethics (Use of ChatGPT by students) 5. Infrastructure (Classroom Availability)	1. Learner Wellness (Mental wellness, Lack of socialization aspect in online/blended learning) 2. Technology security and ethics (Use of ChatGPT by students) 3. Infrastructure (Classroom Availability)	1. Mentors to address students' mental wellness 2. Learning Analytics applications 3. Responsible use of Generative AI
HKUST		1. Teacher readiness 2. Scalability (Classroom design, classroom size) 3. Suitable assessments 4. Lack of systems for learning analytics. 5. Human-Computer Interaction acceptance	1. The hardest to solve is scalability, particularly in relation to the number and design of classrooms and class sizes. For example, class size is constrained by a lack of available land and buildings.	1. Comprehensive programs to foster faculty's pedagogical and technological skills. 2. HKUST encourages faculty to explore and adopt assessment methods that are not only suitable for online and blended environments but also aligned with the pedagogical objectives of each course 3. Redesign current classrooms to accommodate faculty's preferences
SIT		1. Manpower resources: heavy workload for faculty, administrators, and edtech/IT departments	1. Resources	1. Strategic planning and resource allocation. 2. Continuous adaptation of teaching methods, curriculum design, and support services.

Institution	Additional Challenges	Top 5 Challenges	Hardest to solve Challenge	Overcoming Challenges
SIT (continued)		2. Scalability: diversity of learners - addressing all learners 3. Learner wellness: effective personalization of learning		3. Leveraging technology for adaptive learning, and providing comprehensive support services for mental and emotional well-being
SUSS		1. Diverse and multifaceted needs of our learners 2. To provide them with a learning environment characterized by flexibility, accessibility, and industry relevance	1. Diverse and multifaceted needs of our learners	1. AdLeS---to support personalized and self-directed learning 2. To provide industry-relevant experience for students, we offer work-study degree programmes, and we also utilize emerging technology such as VR to support experiential learning
NP	As outlined above. No additional challenges	1. Continually refreshing the campus ed technology infrastructure 2. Ensuring compliance with cloud security and data protection standards 3. Enhancing the quality of design, facilitation, and assessment practices for effective digital learning experience across all courses and staff 4. Efficiently handling procurement, contractual obligations, and adapting to changes in edtech platforms 5. Managing the complexities of fragmented tools and platforms for digital content delivery, communication and engagement	1. Addressing challenges related to frequent changes in data protection policies	1. Streamlined EdTech Ecosystem: Focus on identifying, procuring and implementing T&L critical suite of compatible tools that seamlessly integrate with our core LMS (Brightspace) to create a unified learning environment. 2. Data Protection Policies: Collaborate closely with our IT security and risk assessment teams to ensure that digital learning platforms comply with data protection regulations. Seek innovative yet sufficiently secure solutions that align with these policies, learning from counterpart institutions.

Institution	Additional Challenges	Top 5 Challenges	Hardest to solve Challenge	Overcoming Challenges
EEE@SP	Infrastructure-Cyber security	1. Teacher and learner readiness (Digital and Technology Transformation) 2. Academic Support Structures (Sophisticated and expensive equipment, thus students faced challenges in acquiring sufficient knowledge to be reinforced by the hands-on experience limited equipment) 3. Resources (Time and manpower) 4. Technology Limitations (Technical and tools support) 5. Infrastructure (Cybersecurity, backend pipeline and integration)	1. Infrastructure (Cybersecurity, backend pipeline and integration)	1. Training 2. Sharing (Physical and virtual) 3. Gathering feedback and improvement
LASALLE	1. Use of Generative AI	1. Unlearning the process of learning - the acquisition of knowledge and skills through embodied learning 2. Intellectual property issues for staff and students (plagiarism) 3. Assessment security 4. Academic quality assurance 5. Inability to do anything if there is a power outage	1. Unlearning the process of learning 2. Inability to do anything if there is a power outage	1. Education and discussion 2. Use of technology 3. Benchmarking
NAFA	1. Technology limitations	1. Resources, 2. Scalability, 3. Teacher and Learner Readiness, 4. Technology limitations, 5. Quality of learning	1. Resources and technology limitations are quite hard to solve if we do not have sufficient budget.	1. Increased funding and resourcing are difficult. We plan to find different means of increasing our income/budgets.

Table 10.3. Challenges in CPL

Learnings about CPL from Participating Institutions

1

In general, the CPLA institutions are taking concerted, well-planned, comprehensive, and strategic steps. They are recognizing the value and potential of technology in higher education.

2

We see that the institutions are generally taking institution-wide approaches based on sound strategies, and visions that are underpinned by educational frameworks and theories while embracing ground-up innovative initiatives at the same time. In other words, the efforts are both "top-down" and "bottom-up". This finding is similar to what Kashada, Li, and Koshadah, (2018) found. They recommend that "Mediating the top management support between adoption of a digital learning technology and user awareness, perceived usefulness, and perceived ease of use provides clear and crucial evidence to support the effective adoption of a digital learning technology."

3

Commonly used educational pedagogy includes flipped learning, blended and hybrid learning, and is based on the needs of the institution on whether they are offering courses for working adults, or for practice-based learning, etc. and these institutions are tailoring their programmes to their needs. When the range of courses within an institution is diversified (e.g., LASALLE, HKUST, and SUTD), the choice of exact pedagogy and technology is often left to the faculty members to select to some extent although flipped learning is the most common.

4

Institutional priorities and focus seem to be varied at this time point; Some are focused primarily on pedagogy and curriculum (e.g., TEC, HKUST, and SUSS), others on technology (b), and some others on the learning space and learning environment (TEC, and SP). Institutions are also beginning to consider the ethics of learning (SUTD) and more recent emergent technologies such as Generative AI. Although all factors, such as technology, pedagogy, ethics, and learning environments/space seem to be considered, the CPLA institutions tend to prioritize specific aspects depending on their immediate priorities, needs, and developmental stage. These priorities and focus are expected to change over time.

5

The various institution's approach to supporting digital transformation is also diversified. Some institutions such as SIT, SUSS, and NP emphasize faculty and student development, whilst institutions such as SUTD and TEC take a more product development approach (SUTD), and experimental approach (TEC, and NP) to CPL (See Figure 10. 4). A single institution may undertake a multi-pronged approach.

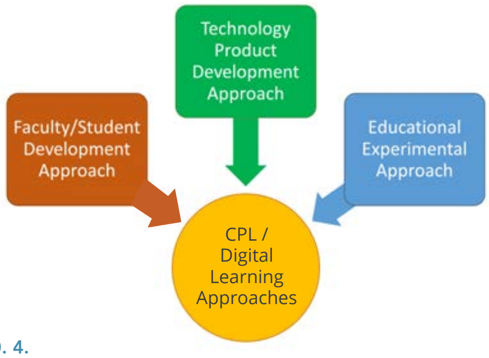


Figure 10. 4.
Cyber-Physical Learning/ Digital Learning Approaches of Adoption in Higher Education and Beyond (Credit: Nachamma Sockalingam, 2023)

6

It can also be seen that when taking an experimental or product development approach, institutions tend to do this as a parallel initiative to ongoing university-wide technology-enhanced learning efforts so that student learning is not impacted negatively, and yet offer a way to learn about how students are learning in the CPL environment.

7 Almost all institutions emphasize redesigning the learning environment and space to create "Smart digital learning spaces" (e.g., HKUST, Tec, SIT, SUSS, SUTD, NP, SP, and LASELLE)

8 "Prevalent" technologies in Table 10.2 refer to currently used technologies in institutions while "Important" technologies refer to futuristic or newly emerging technologies. Examples of the latter include Generative AI. Blurring modalities of learning, and the use of various technologies such as video technologies and augmented/ virtual reality are commonly cited as prevalent technologies. From our literature search on Web of Science, we identified augmented/virtual reality to be the most published as well, supporting this.

9 Various institutions are starting to explore the use of Generative AI and AI-enabled applications in their educational models for assessment and feedback to afford personalized learning (Mao, Chen, and Liu, 2023). This ranked as one of the important technologies of the future.

10 The use of learning analytics is also taking prominence in several institutions (e.g., SUTD, SUSS, and NP)

11 We can also see certain topics like Micro-credentials as an area to monitor, and may potentially be useful, particularly in continual learning such as for IAL or SUTD Academy etc.

12 Supporting Students' Sense of Belonging and Connectedness also seems to be an important aspect to look out for moving forward. Given the search result from our literature search and identification of "internet addiction" as a consistently top listed topic of interest, we can infer that this may indeed an area worth investing in. This can also be addressed using Generative AI and AI-enabled applications.

13 From the participants' responses, it can be seen that the identified operational and strategic challenges of digital learning (Sockalingam, 2022) still hold. Additionally, we can include the use of emergent technologies such as Generative AI and AI-assisted learning.

14 Technology limitations and Resources/Support for implementation were the top-cited prevalent challenges. This was followed by Infrastructure, Teacher and learner readiness, and Security issues with digital assessments. Pedagogical considerations and scalability of digital assessments mattered next. Ethical considerations regarding plagiarism and the use of Generative AIs were also of concern. These resonate with various other reports (García-Morales, 2021).

15 The hardest reported challenge to solve was infrastructure and resources related. It can be inferred that this is possibly due to budget constraints, and the limitations of resources.

16

Participating institutions cited various approaches to mitigating the challenges, which again resonate with several other reports (García-Morales, 2021). These include

a. Formulating strategic visions, frameworks, and guidelines for digital transformation
b. Employing strategic planning for resources
c. Providing faculty development and student support
d. Leveraging prevalent and emergent technologies to aid the future of learning.
e. Providing support and guidelines on the use of Generative AIs, plagiarism, and such ethics-related topics
f. Exploring alternative ways to support digital transformation cost.

17

From Table 10.3, we can see that Ethics in teaching and learning seems to be a relatively novel aspect. Given the age of big data, generative AI, and learning analytics, institutions need to address the need for frameworks, and guidelines on ethical practices in data usage (Andrews et. al., 2021).

18

This report did not observe mention of topics like "digital divide" and "Inclusivity" in general. This shows that Asian universities may need to consider the Asian context in the digital transformation journey, while exploring practices in the Western context and evaluate if applicable to them.

Discussion

Cyber-Physical Learning and Digital Blended Learning are the Future of Learning. We are at a crossroads to redefine teaching and learning in higher education. While the traditional theories and approaches to teaching and learning such as lecturing are still valuable, we cannot ignore the potential and need to embrace emergent technologies.

Technologies such as Augmented/Virtual Reality (AR/VR) (e.g., Kaur, *et. al.* 2022), and Generative AIs (e.g., Baidoo-Anu, and Ansah, 2023). afford new possibilities that could not be possible without the use of such technologies. For instance, it is now possible to use digital simulations in AR/VR without impacting personal safety to learn concepts through trial and error/immersive learning (Shrivastava, Kurniawan, and Sockalingam, 2022). Generative AIs encourage creativity beyond imagination, for instance, in creating digital art (Hutson and Lang, 2023).

We can also envision a new concept of higher education beyond physical to digital/hybrid learning spaces that Ball and Savin-Baden (2022) describe as fluid liminal spaces. Students can pick and choose modular courses from various institutions in the world, while staying in Singapore, learning in an immersive context. Learning is also becoming lifelong, requiring each individual learner to continue learning throughout their lifetime from undergraduate studies. As such, higher education needs a bold and daring approach to teaching and learning, while retaining the best of traditional approaches (Rasli *et. al.*, 2022).

Higher education needs a bold and daring approach to teaching and learning, while retaining the best of traditional approaches.

Many institutions are recognizing this and are cognizant that they need to review their teaching and learning philosophies, upgrade their infrastructure and technology, and empower instructors, learners, and support staff members (Zhang *et. al.*, 2022; Rasli *et., al.*, 2022; García-Morales *et. al.*, 2021).

All CPL Alliance institutions interviewed in this study stated that they are evolving their teaching and learning practices and were taking institutional approaches. Even though many instructors may have been practicing blended and digital learning even before the pandemic, it is no longer just up to the instructors to champion technology-enhanced teaching and learning. It is becoming necessary to take a systemic and holistic institution-wide approach.

It is expected that there will be a leap and jump in the extent of digital learning moving forward, as already observed in our literature searches, and earlier chapters of case studies. While many of the reviews and reports on online/digital learning post-COVID focus on the challenges, technologies, and pedagogies, there is a lack of reports on the approaches taken by the institutions, particularly in the Asian context. This report adds to the educational literature in this aspect.

This report is also the first to identify various adoption approaches to digital learning such as the (i) faculty and student development approach, (ii) experimental approach, and (iii) product development approach. This classification of CPL / Digital Learning adoption approaches has not been cited in the literature before, and this report adds to that. This classification helps to identify and evaluate institutional adoptions.

This report also helps to identify the technologies of choice and recommends that there is no one-size-fits-all approach and that institutions will have to consider their educational context and adopt suitable approaches. The technology of choice will also rapidly evolve with the swift technological advancements, and institutions need to be resilient in terms of infrastructure, curriculum, and teaching and learning practices.

It can also be seen that teaching and learning are no longer limited to the instructors and learners. Various support staff members such as faculty developers, library staff members, maker space teams and educational technologists are needed. Additionally, specialists such as AR/VR developers and data scientists are needed. One of the most cited challenges by the CPLA institutions (Table 10.3) is the limitations of present-day technology. For instance, although learning management systems have been prevalent in higher education for over two decades, we realize that the various database systems, content, and learning management systems have been largely disconnected and operable on their own. Hence, there is a need to integrate the various systems such that we can relate the various systems together coherently to help our instructors and learners.

Another example is that it would be useful to identify and alert high-stakes students who need help based on their pre-university data and identify their strengths so that they can be supported in their personalized learning journey in the university. We can also help the students to be self-aware of their learning journey using Skill tree-like metaverse platform that allows them to plan and track progress while getting support. Systems like the Telepresence Learning System can aid CPL in physical as well as cyber learning spaces. This is an example of how not just the people, but also how the various CPL projects can and need to be interconnected. Such collaborations and partnerships within the university and with the industry is the way forward (García-Morales *et. al.*, 2021).

This also calls for educators to come out of their comfort zones to collaborate with technologists to even co-develop some of these educational technologies, as what SUTD and the other institutions are aspiring to. In doing so, the regular track of teaching and learning must not be impacted too much. This is to avoid the risk of non-acceptance, and non-adoption. Several of the institutions such as SUTD and TEC are taking a parallel approach, where new centres are set up to champion experimental studies on developing and evaluating emerging technologies. This evidence-based, experimental approach adds to our understanding of the new ways of teaching and learning. This is indeed an unprecedented approach to EdTech development. This requires us to forge stronger collaboration with not just the educational partners, but also the industrial partners. For instance, SUTD is collaborating with SIMTECH to codesign and develop the Telepresence Learning System.

In sum, this study strongly supports the need to integrate the new CPL with the traditional teaching and learning practices meaningfully. It also proposes that we take a holistic, multi-pronged approach to forge relationships and partnerships with educational and industrial communities to co-design, develop, implement, and evaluate the impact of the techno-pedagogies on teaching and learning experiences and outcomes. The report also suggests that it is important to conduct periodical literature surveys, and user/market studies as the pace of technological innovation is fleeting. It is also important to use explorative approaches to find the needs of instructors, learners, and even other stakeholders, and eventually evaluate the impact on teaching and learning. This also needs to be shared with a wider audience so that we can share and learn and identify potential areas for improvement and collaboration. Given the pace of technological development, it is no longer possible for individual institutions to work on their own. We can work together in alliance to hasten our progress and development together. This is the purpose of this trends and foresight report to provide a platform for sharing and learning.

Through this report, we can identify areas of special interest and expertise amongst the CPLA and collaborate to travel unchartered waters and define the future of learning together. This Trends and Foresight report will therefore be of use to policy makers, senior management and administrative leaders, instructors and even students on adopting cyber-physical learning. We need to be resilient to the external evolving social, political, economic and technological changes in the world of higher education by being self-aware through audits, market searches, and benchmarking studies on educational practices, and be prepared for potential challenges and changes in teaching and learning using technology.

While this report focuses largely on the teaching and learning aspects, readers are encouraged to extend this search to other aspects of education such as student wellness, etc. For instance, readers could explore how technology can be used to support students get out of internet/game addictions and build social connectivity, engagement and interaction.

Overall, we need to undertake strategic, suitable, systemic, comprehensive, adaptive, scalable, and sustainable Cyber-Physical Learning

References

Adedoyin, O. B., & Soykan, E. (2023). Covid-19 pandemic and online learning: the challenges and opportunities. *Interactive Learning Environments, 31(2)*, 863-875.

Andrews, D., Leitner, P., Schön, S., & Ebner, M. (2022). Developing a professional profile of a digital ethics officer in an educational technology unit in higher education. In: Zaphiris, P., Ioannou, A. (eds) *Learning and collaboration technologies. designing the learner and teacher experience. HCII 2022. Lecture Notes in Computer Science*, vol 13328. Springer, Cham.

Baidoo-Anu, D., & Ansah, L. O. (2023). Education in the era of generative artificial intelligence (AI): understanding the potential of ChatGPT in promoting teaching and learning. *Journal of Artificial Intelligence, 7(1)*, 52-62.

Ball, J., & Savin-Baden, M. (2022). Post-digital learning for a changing higher education. *Post-digital Science and Education, 4(3)*, 753-771.

García-Morales, V. J., Garrido-Moreno, A., & Martín-Rojas, R. (2021). The transformation of higher education after the COVID disruption: emerging challenges in an online learning scenario. *Frontiers in Psychology, 12*, 616059.

Hutson, J., & Lang, M. (2023). Content creation or interpolation: AI, generative Art in the classroom. *Metaverse, 4(1).*

Isoherranen, V., & Kääriäinen, J. (2021). Engineering students' experiences of digital remote learning during COVID-19 pandemic in *IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)*, Singapore, Singapore, 2021, pp. 1476-1479, doi: 10.1109/IEEM50564.2021.9672926.

Kashada, A., Li, H. G., & Koshadah, O. (2018). Analysis approach to identify factors that influence digital learning technology adoption and utilization in developing countries. *International Journal of Emergent Technologies in Learning. 13(2)*, 48-59.

Kaur, D. P., Kumar, A., Dutta, R., & Malhotra, S. (2022). The role of interactive and immersive technologies in higher education: a survey. *Journal of Engineering Education Transformations, 36(2).*

Mao, J., Chen, B., & Liu, J. C. (2023). Generative artificial intelligence in education and its implications for assessment. *TechTrends,* 1-9.

Pelletier, K., Robert, J., Muscanell, N., McCormack, M., Reeves, J., Arbino, N., Grajek, S., Birdwell, T., Liu, D., Mandernach, J., Moore, A., Porcaro, A., Rutledge, R., & Zimmern, J., *2023 EDUCAUSE Horizon Report, Teaching and learning edition*. (Boulder, CO: EDUCAUSE, 2023).

Rasli, A., Tee, M., Lai, Y. L., Tiu, Z. C., & Soon, E. H. (2022). Post-COVID-19 strategies for higher education institutions in dealing with unknown and uncertainties. In *Frontiers in Education* (Vol. 7, p. 992063). Frontiers.

Salas-Pilco, S. Z., Yang, Y., & Zhang, Z. (2022). Student engagement in online learning in latin american higher education during the COVID-19 pandemic: A systematic review. *British Journal of Educational Technology, 53*(3), 593-619.

Shrivastava, S., Kurniawan, O., & Sockalingam, N. (2022). Extended reality for enhanced learning beyond the classroom: three pandemic-proof prototypes. *In Proceedings of the International Conference on Best Innovative Teaching Strategies (ICON-BITS 2021).*

Sockalingam, N., Lo, K., Kurniawan, O., Herremans, D., Raghunath, N., Cancion, H. G, C., Kejun, H., Leong, H., Tan, J., Nizharzharudin, K., & Pey, K. L. (2022). *A white paper on cyber-physical learning*. Singapore University of Technology and Design. Retrieved from: https://www.sutd.edu.sg/SUTD/media/SUTD/LSL_WhitePaper_Cyber-physical-Campus-Higher-Education.pdf

Zhang, L., Carter Jr, R. A., Qian, X., Yang, S., Rujimora, J., & Wen, S. (2022). Academia's responses to crisis: A bibliometric analysis of literature on online learning in higher education during COVID-19. *British Journal of Educational Technology, 53*(3), 620-646.

Acknowledgement

We would like to acknowledge and thank all participants from the CPLA institutions for contributing to this chapter.

SINGAPORE UNIVERSITY OF TECHNOLOGY AND DESIGN

8 Somapah Road
Singapore 487372
Email: enquiry@sutd.edu.sg
Phone: +65 6303 6600