A WHITE PAPER ON CYBER-PHYSICAL LEARNING

COMMEMORATING THE 2022 SINGAPORE
NATIONAL TECHNOLOGY ENHANCED LEARNING CONFERENCE

SINGAPORE UNIVERSITY OF
TECHNOLOGY AND DESIGN

> Our world of teaching and learning has changed and will continue to change rapidly. The knowledge and skills required for tomorrow will certainly be different from what we have gotten used to today, and different from what we were used to before. What we are familiar with today will soon be outdated faster than we think. So, it is important to be aware of these challenges and changes, to prepare us for the road ahead.

Mr. Chan Chun Sing
Minister for Education,
4 Aug 2022

For more on the ministerial speech, please scan the QR code

SCAN ME

Dear readers

It is a great pleasure to launch this white paper on cyber-physical learning at the Singapore's 2022 National Technology Enhanced Learning (NTEL) Conference as a commemoration.

The NTEL conference was initiated by the Singapore's Ministry of Education (MOE) in 2015. Co-organised by the six local autonomous universities (AUs), it aims to inspire teaching and learning transformation through the adoption of technology-enhanced learning strategies in higher education.

The 2022 NTEL conference is hosted by the Singapore University of Technology and Design (SUTD) in collaboration with the other AUs on 27 and 28 October 2022. The theme of the conference is "Empowering Learning in the Cyber-Physical Era".

SUTD's Office of Digital Learning (ODL) mooted the idea of this white paper to provide an overview of cyber-physical learning and explore the various approaches taken by universities around the world in cyber-physical learning. It also presents SUTD's campusX initiatives. The white paper recognizes and calls for the need for stakeholder engagement and partnerships.

I thank all the authors and contributors for this white paper and the Learning Sciences Lab of ODL for leading and producing the paper. My special thanks to the 2022 NTEL organizing and working committee members from the six AUs and our partner institutions (Tecnológico de Monterrey from Mexico, Zhejiang University from China, Institute for Adult Learning from Singapore University of Social Sciences, Singapore Polytechnic from Singapore, and SkillsFuture Singapore) for their collaborative efforts in making this possible. My colleagues and I hope that you find the white paper useful for your institutional efforts towards cyber-physical learning and we invite you to collaborate with us on our SUTD campusX initiatives and programs.

Yours sincerely
Professor Pey Kin Leong
Associate Provost, Office of Digital Learning, SUTD
27 October 2022

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Table of Contents

1. Executive Summary

The Covid-19 pandemic has disrupted our lives in many ways. Higher education is not exempted; we have seen full campus closures in many places. In returning to the physical campus and reopening to a new situation in the post-covid context, we must be prepared for both short-term and long-term challenges. We must also foresee and prepare for such situations in the future.

So, what does the future of higher education look like amid volatile economic, uncertain complex, and ambiguous (VUCA) world that is coupled with technological disruptions and changing needs of employers and employees? How can we prepare for the future today through pre-employment training (PET) in higher education and continuing education and training (CET)?

Digital transformation through online and blended learning has been valuable to address the changing needs. But is that sufficient?

What are the challenges in the present-day digital transformation of online/blended learning, and how can we address these challenges?

To this end, this white paper aims to provide an overview of the barriers/challenges in digital transformation from literature reviews, surveys, and interviews with university stakeholders, partners and collaborators on the pedagogical and technological aspects.

Possible design-centric and human-centric solutions to address these challenges from several institutions are presented as case studies. The paper provides a definition of cyber-physical learning, and outlines an approach taken by SUTD to address these challenges through the SUTD campusX initiatives and includes more detailed examples from other institutions such as Zhejiang University (China), Tecnológico de Monterrey (Mexico), Singapore Polytechnic (SP) and Institute for Adult Learning (IAL).

The analysis of the various approaches brings us to the concluding section that suggests possible next steps in moving forward on cyber-physical learning. The call is to form an international alliance/consortium on cyber-physical learning and to work together.

This white paper is meant for higher education and institutions/academies of continual learning, and aims to be of use to educators, educational leaders, innovators, edutech industrial partners and policy makers.

2. Introduction: Global Impact of Covid-19 Pandemic on Higher Education

An unprecedented onset of the COVID-19 pandemic in 2019 has led to a drastic impact on all aspects of our lives, with severe repercussions on higher education sector. Universities across the globe have had to shut down campuses and/or transition to online/blended learning swiftly (Sahu, 2020; The impact of coronavirus on higher education). Many aspects of higher education such as student enrolment, student-exchange programs, mode and pedagogies of teaching and learning have been affected.

According to a global survey conducted by the International Association of Universities (Marinoni, Van't Land & Jensen, 2020), almost all universities in the survey (424 institutions from 109 countries and 4 regions) indicated that their teaching and learning was affected (Figure 1). Participants also reported that the social distancing measures affected community engagement within their own universities.

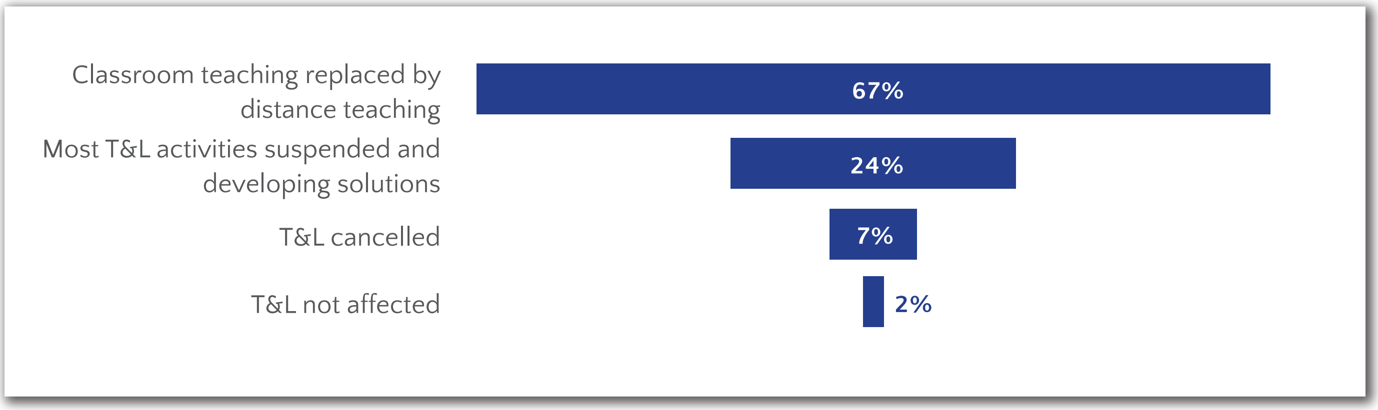


Figure 1. Impact of Covid-19 on Teaching and Learning in Universities Globally (Marinoni *et. al.*, 2020)

2. Introduction: Global Impact of Covid-19 Pandemic on Higher Education

The study reported that

- A "different" pedagogy is required for distance teaching and learning in this situation using technology.
- It is a challenge for university faculty members to shift from face-to-face to distance/online teaching and learning.
- The level of preparedness of faculty members to shift from face-to-face ranges widely; from "not prepared" to "well-prepared" and "championing innovations".
- Some institutions reported not having sufficient management structure in place to develop the teaching capacities of faculty members for them to shift towards online learning easily and this therefore often resulted in "learning by doing" approaches or attempting to imitate what would have been the face-to-face way of proceeding but using distance mode.
- Teaching of certain disciplines that require hands-on practice sessions and interaction such as clinical medicine, and veterinary studies, were negatively impacted by distance teaching and learning (Kaul *et. al.,* 2021). Also, social/team-focused learning in Arts and Humanities was also reported to be limited by this mode of teaching and learning (Boardman *et. al.,* 2021).
- Limitations in digital infrastructure and the digital divide were critical factors in responding to the emergency situation.
- Although distance/online teaching and learning using technology allows for continuing education, it may not guarantee the same level of quality compared to face-to-face education as initially planned in face-to-face teaching, Still, it is better than no teaching.
- This unprecedented situation has resulted in efforts to cope in the first instance. It is now pushing us to develop new pedagogies and new technology tools to enhance the teaching and learning experiences.

2. Introduction: Global Impact of Covid-19 Pandemic on Higher Education

The same organization, IAU, conducted a follow-on survey in 2021 (Jensen, Marinoni, & van't Land, 2022). This second survey was to monitor the situation a year after the pandemic and found that there has been an increased shift to remote teaching and learning compared to the past year (89% remote learning in the second survey versus 67% in the first survey).

More educational institutions also reported increased usage of technology tools in teaching and learning. Interestingly, capacity building of faculty members to be better prepared for online/remote teaching is still on the list one year down the road. This is probably because the first year of the pandemic primarily focused on the immediate priorities of running educational programs and initiatives to cope with the unprecedented situation. However, this is an area that would need focus now.

There was also a decline in internships and placement opportunities during the pandemic period. What is good is that despite the challenges, most of the institutions have managed to continue the lessons and conduct exams. The only thing is that the learning experience would have been different, and positive in some respects.

In summary, the two surveys have revealed the disparity of readiness in responding to the pandemic situation globally. The key take-home messages from these reports are that there may be no "one size fits all solution" and there is a need for individual institutions to self-assess their readiness to prepare for the short-term and long-term challenges ahead in digital transformation to build their cyber-physical campus. The pandemic has certainly encouraged us to reimagine the future of higher education and it is going to be a different era of higher education moving forward.

> "There is no "one size fits all solution" and there is a need for individual institutions to self-assess their readiness to prepare for the short-term and long-term challenges ahead in digital transformation."

3. Challenges of Current Online/ Blended Learning @ Tertiary Level

The Covid-19 pandemic crisis has speeded up the digital transformation of higher education and has brought about rapid educational innovations in a relatively shorter period compared to what would typically take many years because of the pressing needs and evolving managerial regulations (Strielkowski, 2020). But digital transformation is not a magical snap; there are several challenges, and it takes time and effort.

The challenges are both in the processes and outcomes of teaching and learning; from getting started in cyber-physical learning to delivering meaningful learning experiences.

A list of these challenges and difficulties in the current 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 reported (e.g., Nortvig *et. al.,* 2018; Adedoyin and Soykan, 2020; Murphy, 2020; Serhan, 2020; Arnhold *et. al.*, 2021; Amenduni *et. al.,* 2021; Neuwirth, Jović, & Mukherji, 2021) in the educational literature.

The responses from the various faculty/educational leader interviews and discussions were compiled, analysed and classified into nine challenges based on conceptual connections. The themes were also corroborated with the literature to ascertain content validity. Such challenges were found to be prevalent in not only universities but also the continual education and training industry (Meyers & Bagnall, 2017). Figure 2 shows the nine challenges. This classification is not a comprehensive list and serves as a first step.

For ease of reference, the nine challenges were further grouped into two categories as (i) operational and (ii) strategic challenges based on who could address these challenges. As the name suggests, operational-level challenges impact the individual learners, teachers, and staff members and can be dealt with more directly at the operational level. On the other hand, strategic challenges are challenges faced by the department or by the organization/institution as a higher-order entity and needs to be dealt with at an entity or system level.

We recommend that universities self-assess their learning readiness at both levels, across the nine challenges and determine if their challenges are different from what is given here. They can then ascertain to what extent the university has met the targets. For instance, one may realize that the university may lack the infrastructure, or that they may not have capacity-building initiatives. Next, it is good to identify the priorities based on the given contexts and strategize a tailored solution. Further studies can be conducted to determine the interrelation of the various challenges to address these holistically.

To get fine-grain details and understand the individual and high-level perspectives, it is useful to take an evidence-based approach and conduct surveys, focus group discussions, etc. with the learners and teachers, multiple stakeholders from the senior management, department heads, module heads, etc. The next section presents one such survey conducted at the Singapore University of Technology and Design (SUTD) with the first-year students on their readiness and views on their teaching and learning experiences online/blended during the pandemic period.

While the perceived challenges can vary for individuals and organizations, there are certainly overlaps, and we see that the solution is often achievable through multi-stakeholder participation and engagement to understand the needs and to identify blind spots, so as to design sustainable solutions. The stakeholder participation must be both bottom-up and top-down.

3. Challenges of Current Online/ Blended Learning @ Tertiary Level

Quality of learning

- Challenges in curriculum design for meaningful learning
- Challenges in impactful online activities that involve social interactions/collaboration
- Use in certain disciplines are limited
- Suitable assessments
- Intrusions-Lower engagement

Teacher and learner readiness

- Teacher readiness
- Student readiness
- Expertise in technologies
- Digital skills/competencies
- Limited experience in using new technologies
- Lack of training in terms of pedagogy and technology usage

Academic Support structures

- Limited overseas exposure/ onsite and industry expertise
- Challenges in running capstones
- Challenges in running practical laboratories
- Lack of physical/hands on skills-based experiences

Learner wellness

- Lack of socialisation aspect in online/blended learning
- Impact on peer to peer, collaborative learning, communication
- Feeling isolated/disconnected
- Mental wellness
- Tech-fatigue
- Effective personalisation of learning
- Cyber bullying

Scalability

- Different class sizes
- Different subjects
- Diversity in learners-addressing all students
- Distance learning

Resources

- Funds for additional development
- Manpower resources
- Heavy workload for faculty, administrators, and edtech/IT departments
- Extended office hours
- Time

Technology limitations

- Lack of systems for learning analytics
- Tech tools support
- Algorithm bias
- Human-Computer Interaction acceptance
- Challenges in technical aspects

Technology security and ethics

- Policies on data protection and ethics in using student data
- Cloud security
- Intrusiveness in technology
- Challenges in online assessment-proxy supervisions/cheating
- Copyright ownership of materials-Edtech/faculty

Infrastructure

- Accessibility Issues
- Digital divide-Varying socio-economic status
- Outdated technology devices
- Network bandwidth
- Changes in learning management systems
- Subscriptions to ever growing technology tools

Figure 2. Operational (Blue) and Strategic (Green) Challenges in Online/Blended Learning (Sockalingam, 2022)

4. Challenges of Blended Learning: Student Perspectives @ SUTD

A group of faculty and staff members from SUTD conducted a survey with SUTD first-year students on their experiences of blended/online learning in 2020. The survey was conducted by Assistant Professor Andrew Yee (HASS), Assistant Professor Gordon Tan (HASS), Dr. Tan Da Yang (SMT) and Dr. Nachamma Sockalingam (LSL). The survey sought to understand students' perceptions about their online/blended learning experiences during the pandemic.

The student survey was developed based on the Community of Inquiry (COI) framework, which encompasses the three factors of teaching and learning; cognitive presence, teaching presence(facilitation), and social presence (student interactions) (Figure 3). The Community of Inquiry theoretical framework (Swan *et. al.,* 2009) represents a process of creating a deep and meaningful (collaborative-constructivist) learning experience, and we have adapted this to our blended learning context. A total of 97 students participated in the survey. Some of the relevant findings from the study are reported here. Please scan the QR code for a video presentation of more detailed reporting.

The survey results (Figure 4) showed social presence to be the weakest among the three pillars of the COI framework in this study context. Students felt that online/blended learning posed limitations in interaction and collaboration with their peers in terms of emotional connection and communication.

4. Challenges of Blended Learning: Student Perspectives @ SUTD

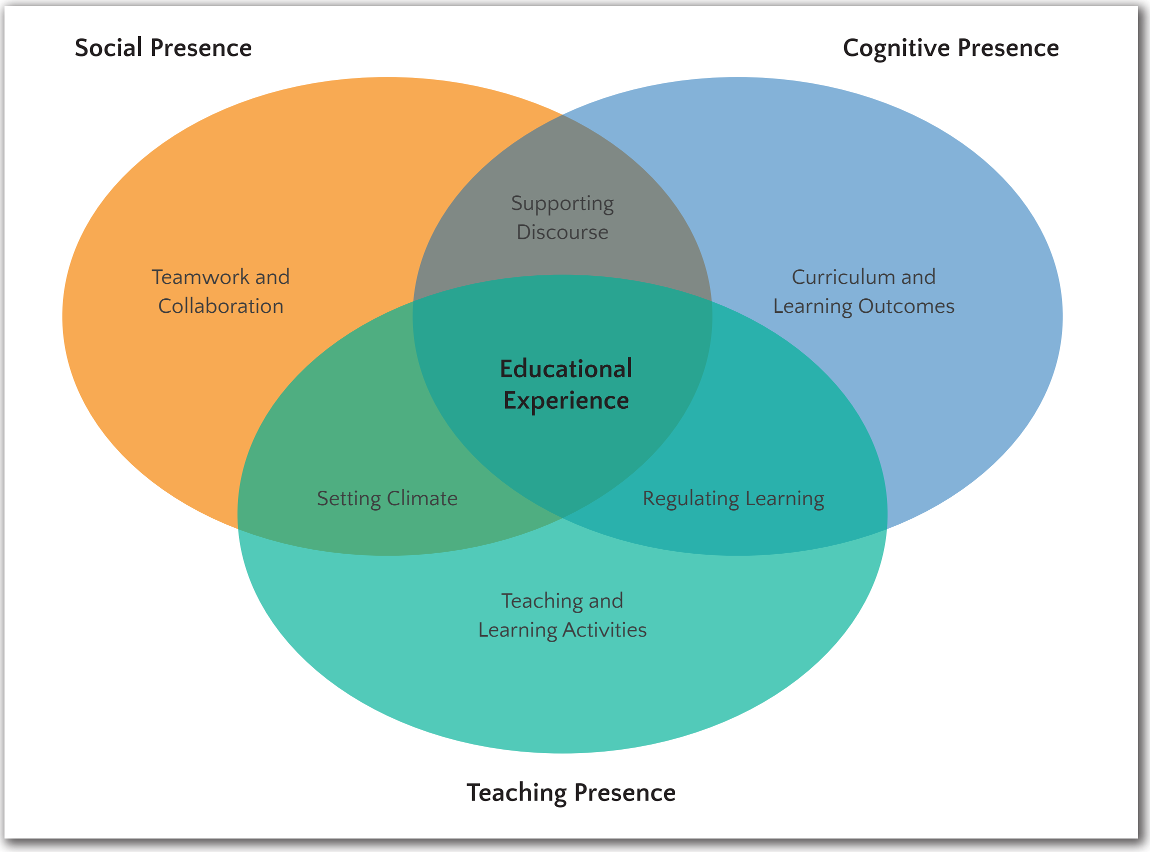


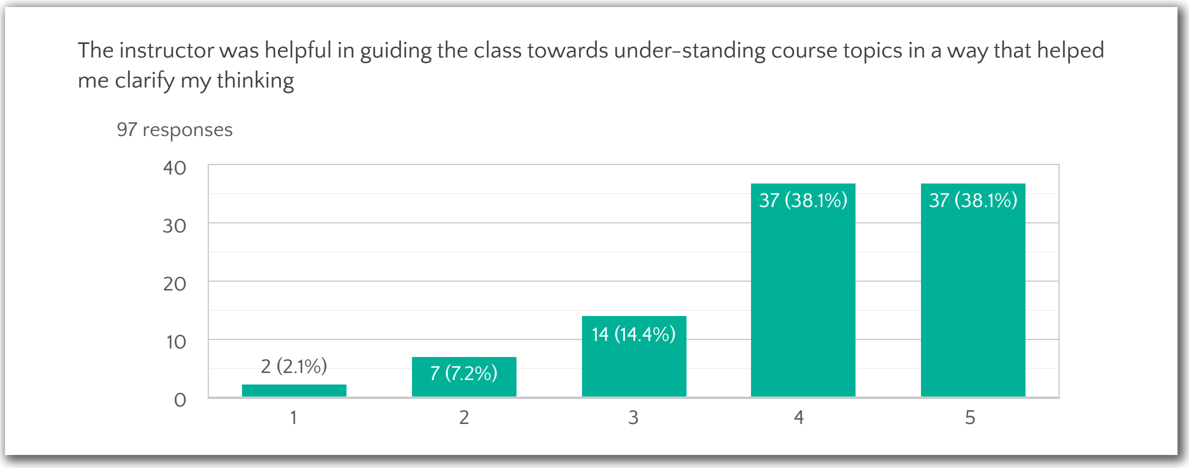
Figure 3. Community of Inquiry Framework (Swan *et. al.*, 2009)

As for teaching presence, students opined that their instructors/ faculty members were competent to facilitate online classes in terms of being able to question and engage students in discussion during the online lessons. They also felt that the instructors were able to design a curriculum suitable for online learning. This was encouraging to note. However, more can still be done to improve teaching presence to help enhance social and cognitive presence through teaching presence.

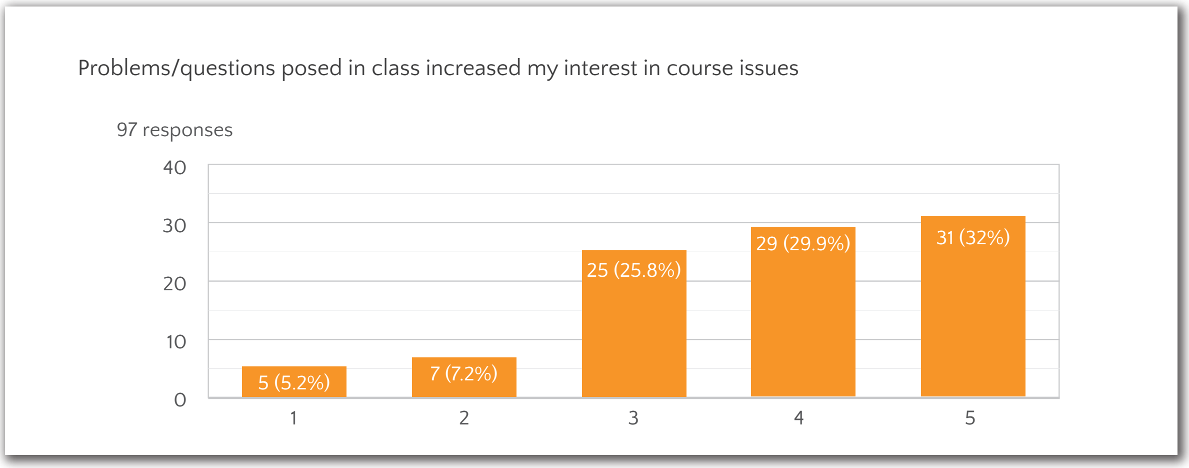
For the cognitive presence component, students reported that they were able to learn effectively in online learning with the ability to synthesize and acquire knowledge. Students reported that idea of brainstorming for answers as well as finding relevant information to address the questions that were asked in the online course enabled them to understand the topic well. Effective cognitive presence in online learning depends on instructional design and delivery and this can also impact the social presence.

4. Challenges of Blended Learning: Student Perspectives @ SUTD

Teacher Presence



Cognitive Presence



Social Presence

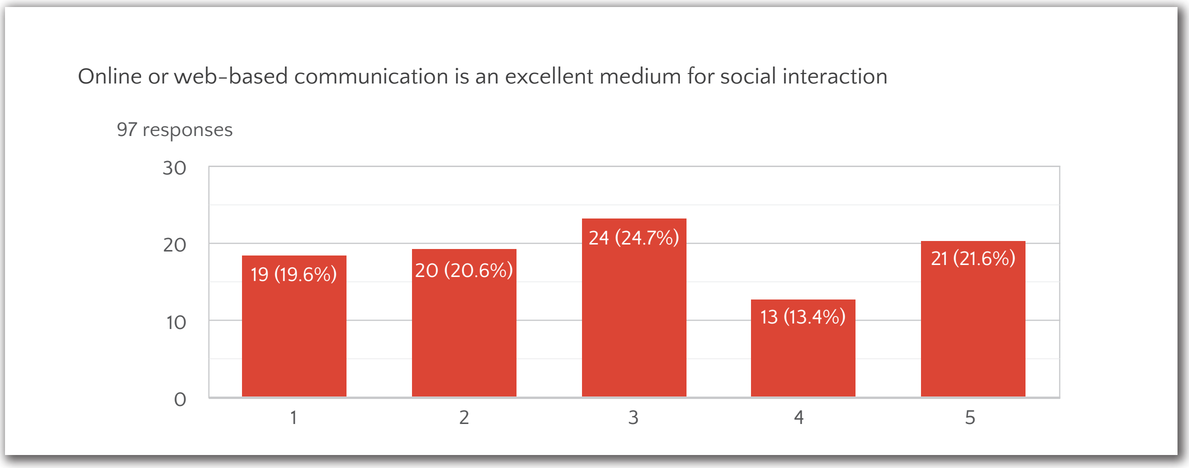


Figure 4. SUTD Student Perspectives on Challenges in Blended/Online Learning Based on the COI Framework (Yee, Tan. G., Tan, D.Y, & Sockalingam, 2021)

4. Challenges of Blended Learning: Student Perspectives @ SUTD

When asked if they would prefer a blended learning or completely online or face-to-face model, interestingly, most of the participants indicated a preference for a blended learning mode (Figure 5). It looks like students still wanted face-to-face interaction even though online learning offered convenience. This emphasizes the value placed on human-human social connection and interaction.

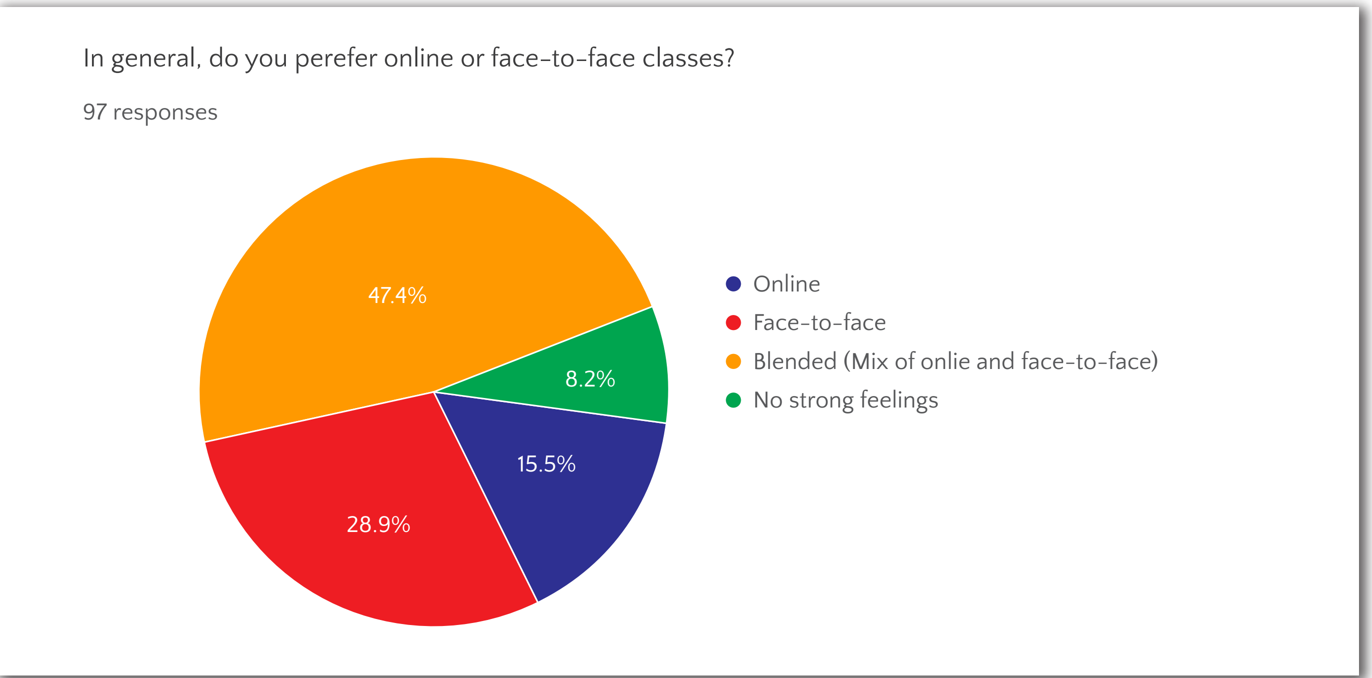


Figure 5. SUTD Students' Preference of Learning Mode (Yee, Tan. G., Tan, D.Y, & Sockalingam, 2021)

This result is similar to findings by Professor Stephen Billet and his team (2022) with adult learners in Singapore on online continuing education. In a survey with 258 adult learners, he found that CET learners prefer blended (a mix of online and face-to-face) learning over completely online or completely face-to-face learning.

Overall, SUTD students seemed to be open and receptive to blended learning; and their responses suggest that more efforts need to be channeled into enhancing social presence in online/blended learning. Other studies have also reported the same concern regarding social presence in digital learning (e.g., Oztok and Brett, 2011, Sung and Mayer, 2012). While students seemed to rate teaching and cognitive presence to be high, further studies need to be done to understand the impact of teaching and cognitive presence on social presence (and vice versa).

The lower rating for social presence suggests that there is a need to ensure that this aspect needs more scaffolding. For instance, we need to consider how students can learn from each other via teamwork or collaborative learning in fostering a positive online learning environment. This is critical in educational contexts that use learner-centric pedagogies such as that by SUTD (Sockalingam *et. al*. 2021) since we adopt project-based learning where students must work in teams to solve real-world problems and complete authentic projects.

4. Challenges of Blended Learning: Student Perspectives @ SUTD

An added challenge is that the existing technology tools are somewhat limited in fostering collaborative learning online. We need to be creative in our instructional design and innovate pedagogies as well as technologies to foster collaborative, social learning in the cyber-physical environment. Since understanding the students' needs can be non-intuitive, one solution is to take a consultative approach with students as they are the end users of new technological solutions.

Studies such as the one conducted at SUTD to understand the students'/teachers' needs will be the first step in that. Next, teachers can take a consultative approach to co-design solutions with students. Following that we can conduct evaluative studies to investigate the impact of emerging technologies/cyber-physical learning or educational interventions on student motivation, achievement, and learning. Such evidence-based studies will help faculty and management to develop and support new pedagogical innovations for meaningful l learning (Figure 6).

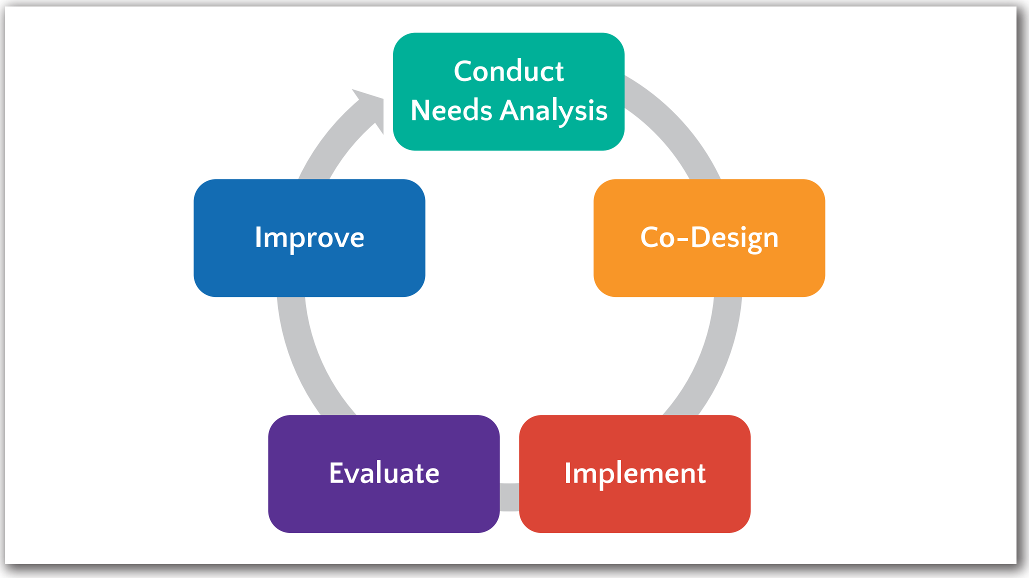
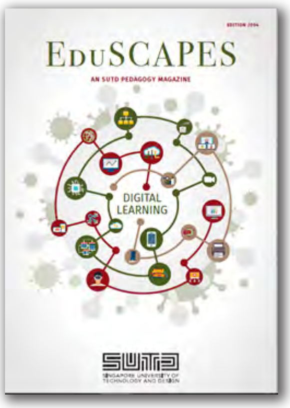


Figure 6. Instructional Design Framwork for Co-developing Emergent Technologies (Sockalingam, 2022)

This is part of the Scholarship of Teaching and Learning (SOTL) culture that SUTD has been nurturing over the last five years. Examples of many such studies from SUTD can be found in the EduSCAPES magazines. Please scan the QR code to access the magazines.



5. Current Practices in Blended and Online Learning

BROOKINGS INSTITUTION IDENTIFIES FOUR 'COMPARATIVE ADVANTAGES' WHICH EDTECH OFFERS TO IMPROVE LEARNER OUTCOMES

The Brookings Institution identifies four 'comparative advantages' which EdTech offers which have the potential to complement the work of educators to improve learner outcomes. These comparative advantages include:

1. Live one-on-one tutoring
2. Pre-loaded lessons
3. Pre-loaded hardware
4. Video tutorials
5. Games/Gamification
6. Practise exercises
7. Computer-adaptive learning
8. Distance education

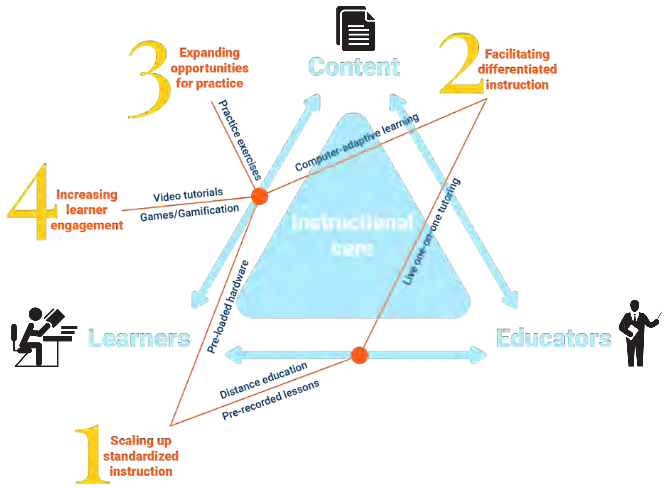


Figure 7. Brookings Institutions' Blended Learning Framework for Improving Learning Outcomes (Ganimian, Vegas & Hess, 2020)

Post-pandemic, blended learning is seen to be the pedagogy of choice by various reports and studies. In a paper on "Realizing the promise: How can education technology improve learning for all?', The Brookings Institution (Ganimian, Vegas and Hess, 2020) suggests several solutions (Figure 7) which include

- Scaling up quality instruction, through pre-recorded quality lessons
- Facilitating differentiated instruction such as through adaptive learning and live one-on-one tutoring
- Expanding opportunities to practice
- Increasing learner engagement through videos and games.

These suggestions are useful in improving learning experiences at the classroom level. However, this tends to focus mainly on the teaching and learning related changes (Figure 7). Also, they do not suggest which technologies can be adopted for online/blended learning. Hence, we decided to start with the bigger picture of Digital Singapore and relate that to higher education in Singapore in framing the ecosystem that we need to consider.

Singapore has identified four frontier technology as pillars for digital development in Singapore (Figure 8). These are artificial intelligence, immersive media, cybersecurity, and the internet of things. These are areas that are applicable to higher education and CET as well (Cheung *et al.*, 2021). Of these four pillars, immersive media and artificial intelligence in higher education are more application based. Internet-of-things and cyber-security are part of the infrastructure and contribute to the educational ecosystem.

5. Current Practices in Blended and Online Learning

Artificial Intelligence

Artificial Intelligence (AI) refers to the study and use of intelligent machines to mimic human action and thought. With the availability of Big Data, advances in computing, and invention of new algorithms, AI has risen as a disruptive technology in recent years.

Cybersecurity

Cybersecurity refers to measures and techniques to protect the integrity of data, computing devices, and other systems from damage or theft and prevent the disruption of the functionality of these systems.

Immersive Media

Immersive media refers to technologies like Virtual Reality and Augmented Reality. From sectors like engineering, media, healthcare, education and retail, immersive media is expected to play a key role in the development in the digital economy. It is projected to reach US$209.2 billion by 2022 and is one of the four technology frontiers that IMDA is focusing on.

Internet of Things

The Internet of Things (IoT) refers to the network of items and devices, from home appliances to vehicles, embedded with software and sensors that enable them to connect, collect and exchange data. This helps create value based on information and data from everyday objects.

Figure 8. Singapore's Four Pillars of Digital Development, (Tech Pillars, 2019)

We observe that the pandemic required educators and others to use technologies such as Webex, Zoom, Microsoft tools, and Google classroom to connect with each other and students. This brought about numerous challenges and opportunities to improve collaboration and engagement as online learning was a necessity. Hence, much innovation has been underway to improve the experience of video calls and chat to make collaboration fully seamless across time and space using emergent technologies such as Augmented/Virtual Reality, 360-degree cameras, holographic lectures, and video conferencing with three-dimensional avatars. The question is " How can we use techno-pedagogies in higher education and CET for effective learning?" To this end, we consider some of the existing use cases of techno-pedagogies.

5. Current Practices in Blended and Online Learning

Blended Learning

A well-known form of Techno-pedgogy is blended learning. Blended learning combines and interweaves synchronous and asynchronous learning modes of learning in a seamless fashion to create a workable teaching and learning experiences for teachers and students (Amenduni & Ligorio 2022). A wide variety of blended learning practices have been developed under this terminology. Considering the new technological awareness that educational settings have reached, there is a need to provide more detailed instructions and suggestions regarding how to design, implement, monitor, and assess blended learning.

Blended learning has evolved significantly from the simple 'flipped classrooms' of student-led discussions, active learning, and Socratic teaching methods to more sophisticated versions where technology such as robots, machine learning and algorithms to act as enablers or mediators of complex feedback mechanisms (Amenduni & Ligorio 2022; Bernard *et. al.*, 2014; Norvig *et. al.*, 2018). Future blended learning will involve a combination of media and tools that allow instruction, collaboration, and feedback in a combination of virtual and non-virtual contexts (Amenduni & Ligorio, 2022; Soliman *et. al.*, 2021).

One example of the use of technology to enhance blended learning in higher education is using a social platform called Edmodo as described in the study by Capone, 2022. They used the platform at the University of Salerno, to teach first-year engineering students Calculus. This platform was able to create a student-centered active learning environment through Just in Time Teaching (JiTT), and Peer-led Team Learning (PLTL) in a blended learning format. This showed an improvement in students' interest and motivation;

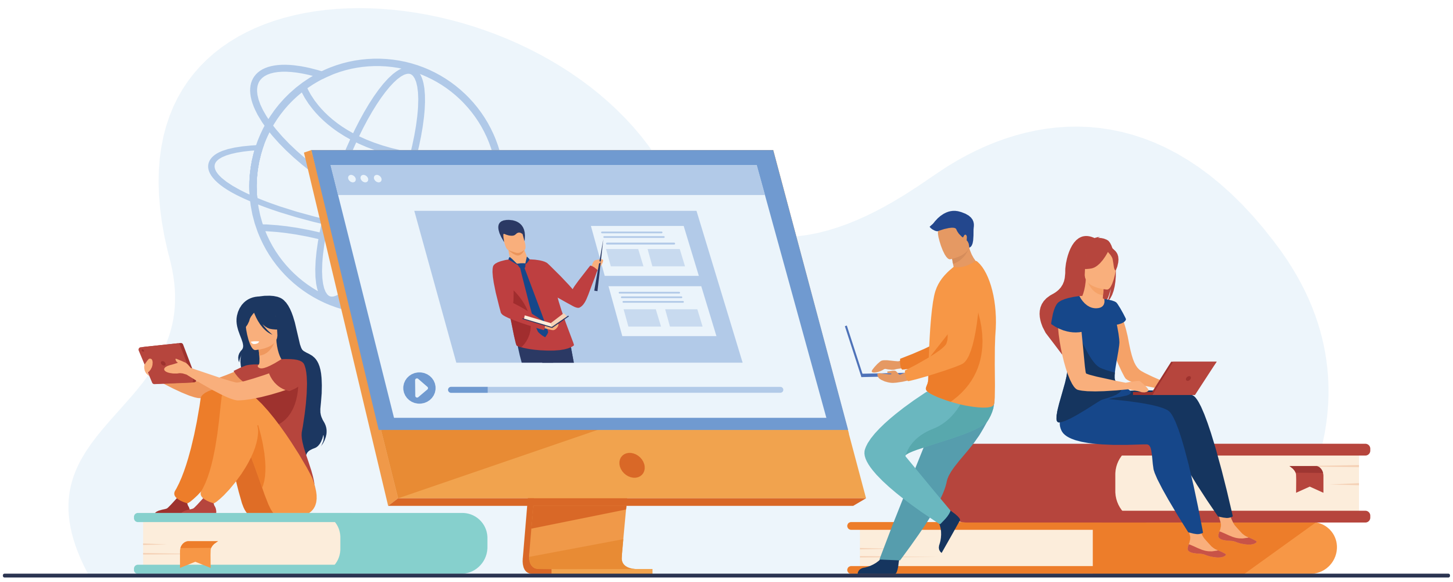
5. Current Practices in Blended and Online Learning

many students who were struggling earlier could achieve better exam results. This platform also allowed greater privacy since the faculty members could create a virtual classroom for registered students only. Some of the advantages of Edmodo include easy sharing of data via the platform; easy interaction with other peers and the teacher; effective graphical interface with ease of use via a mobile phone; absentees were able to easily catchup with the content online (Capone 2022). The learning outcomes were

- improvement in students' problem-solving
- increase in students' theoretical understanding
- betterment in students' attitudes
- drastically reduced failure rates

Blended learning is also used in corporations. One example is Shell corporation, which used blended learning to facilitate immersive experiences for their leaders and trainees in workshops and peer-peer coaching using digital resources and virtual learning. This included 360-degree feedback through forums that shared real-time leadership challenges and solutions and periodical virtual meetings to get advice and mentoring from managers and leaders (Collis *et. al.,* 2005). Blended learning was administered as Pre-In course-Post events and tied to employee's actual work. In other words, learning is placed in authentic context, and the lessons are designed meaningfully to introduce content, encourage teamwork, discussion, and collaboration, get the participants to analyze and solve presents, communicate, and evaluate.

The two examples illustrate that a creative mix of relevant pedagogies and technologies allows for meaningful blended learning experiences in both university and adult learning. It is important that our understanding of "how we learn" underpins the effective use of technologies, rather than being technology-led for successful blended learning.



5. Current Practices in Blended and Online Learning

Personalized Learning

While blended learning deals with the ways in which effective learning is delivered, such learning should be ideally targeted to *individual* needs and personalized. Personalized learning stems from the idea that humans learn from their experiences and prior knowledge. Hence the argument is that learning experiences are designed to cater to individual learners to adapt to their pace of learning, strengths, weaknesses, and interests (Shemshack and Spector, 2020). This is achieved through tools that facilitate the building of personalized information management systems consisting of curated network resources, content creation, and interconnectivity to share the information acquired. Here learning is customized for individual needs, catering to student diversity (Martínez-Hernández *et. al.*, 2016).

Alamri's study defines personalized learning as integrating three relevant theoretical frameworks. First, as per UNESCO International Bureau of Education (2017), personalized learning consists of paying particular attention to students' prior knowledge, needs, capacities, and perceptions during the teaching-learning processes to adapt future contents to their identified learning requirements, problems, or needs. In other words, personalized learning prioritizes each student's needs and goals, and tailors instruction to address those needs and goals in a clear and accessible manner. The goals and content are frequently discussed among both parties and updated accordingly (Pane *et. al.,* 2017). Finally, the purpose of personalized learning is that the students can apply practical and personal meaning to what they learn and have the possibility of choosing how they learn, when they learn, what they learn and where and with whom they learn (Coll 2015). Over the years, personalized learning has shifted focus from teacher-centered to learner-centered contexts. (Alamri *et. al.,* 2021) (Figure 9).

Examples of personalized learning include adapting online learning tools for individualized mentoring; providing specific feedback to students using technology such as smart glasses, smart watches, etc. so that the instructor can detect if a particular student needs help. For instance, "On Task" is a data analytics-learning system that was programmed to send automated and personalized emails and feedback to students (Pardo, 2019). The study involved 86 students across 4 different courses in two different institutions for 7-13 weeks. Students were motivated by

5. Current Practices in Blended and Online Learning

personalized feedback despite the fact that it was via automated emails (Lim *et. al.*, 2021). Students liked the fact that the emails would tell them which tasks were outstanding and had to be completed and that faculty were further able to add more individualized feedback to the automated email sent to them. They also felt that the instructors really cared about them and wanted them to perform well. However, students felt that the feedback provided was not indicative of their actual performance as they had done better than what the feedback indicated.

Personalized learning can also be used in the workplace for continuous learning and feedback programs where technology such as cameras, integrated software, and machine learning can deliver individualized learning to build a future-ready workforce (Anthony 2020). At Air Methods, a helicopter company in the United States, training is a matter of life and death as their pilots need to make split-second decisions. The company implemented Amplifire, a cloud-based learning system, that uses artificial intelligence to adapt and test each user's knowledge. The system is personalized so that each pilot gets specific training in areas where they struggle such that the system can wait on a particularly difficult section and present the information in novel ways before progressing to the next section or module. This has become a way to attract talent and provides a competitive edge to the organization.

As seen, personalized learning can vary in format: it can be used to connect with students and give a sense of personalized connection or it can be used to deliver personalized learning pathways. Both university and CET learners find personalized learning to be helpful and this seems to be an important pedagogy to focus on in driving the future of learning. Personalized learning can also be coupled with other technologies such as with robot-human interaction, augmented and virtual reality and data analytics in new and exciting ways to make learning interesting.

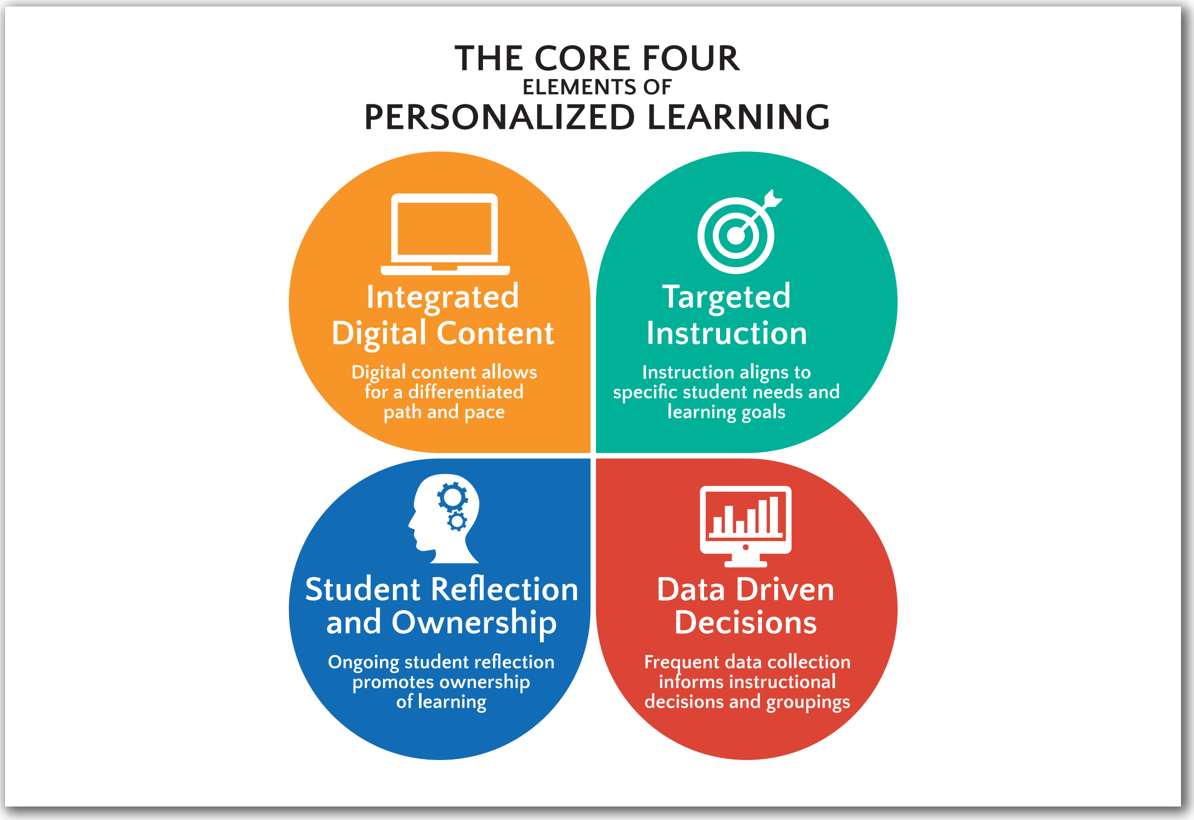
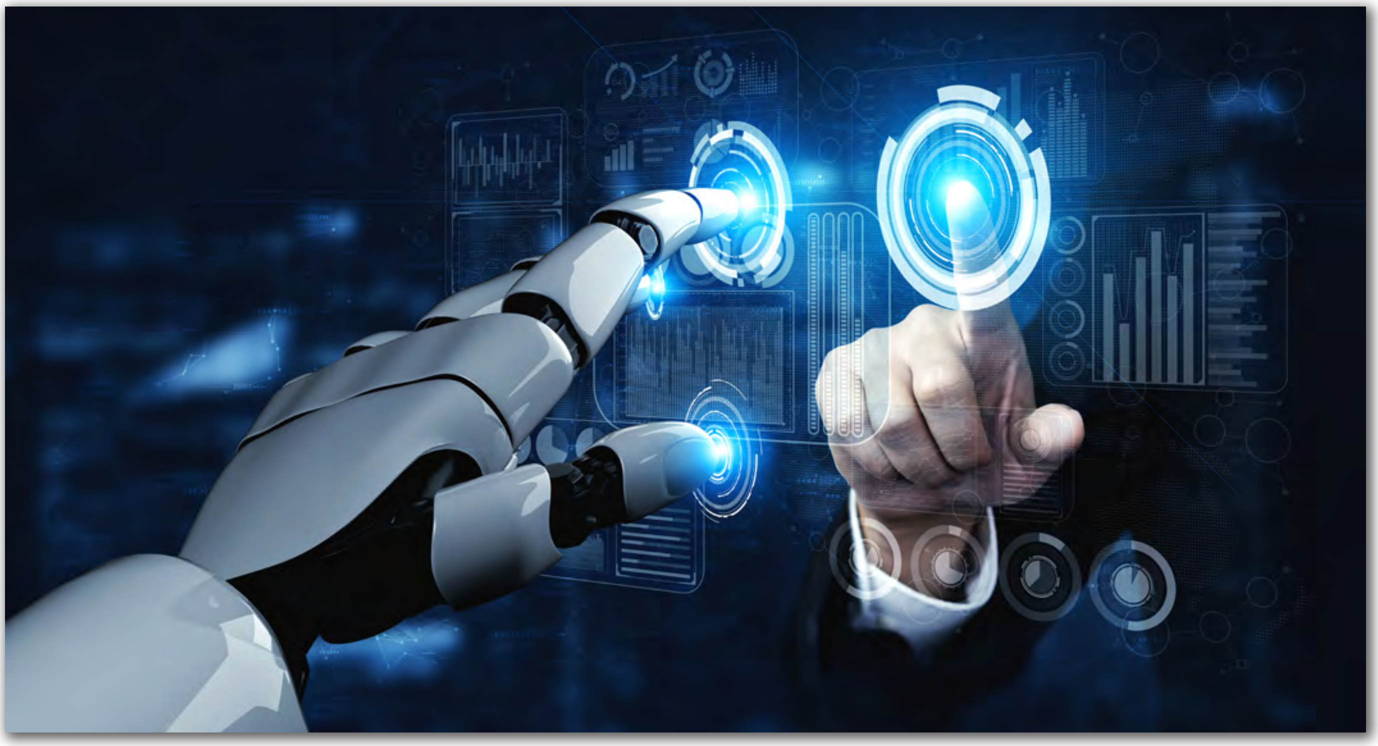


Figure 9. Elements of Personalized Learning (Vanstane, 2017)

5. Current Practices in Blended and Online Learning

Robots



The use of robots in the classroom is a good example of how blended and personalized learning can be combined for more engaging instruction in the classroom. There are several ways in which robots can be used in teaching and learning. A common example is to use robots to teach programming where participants are to write codes to automate/move the robots (Kurniawan *et. al.,* 2019). Robots can also be used as chatbots to answer students' queries or students can be asked to do peer-learning (Sjöström, *et. al.,* 2018). Another example is to use telepresence robots as teaching assistants (Reis *et. al.,* 2018). An important advantage of robots is that it allows for robot-human interaction when the actual presence of the instructor is not possible.

A telepresence robot is essentially a computer, tablet, or smartphone device with sensory features such as video camera, screen, speakers, and microphones so that one can connect through the robot to be tele present in a virtual space. In other words, it allows one to connect through an online application through the device to be remotely present in a different location, and hence the name, tele present. The user could navigate and operate the mobile/computer robot device to interact with the tele-space, that is, be tele-ported. The telepresence robot affords a shared workspace for a blended collaboration of face-to-face and distant, collaborative work. While video conferencing allows for a similar video connection, it is limited to being 2-Dimensional. On the other hand, telepresence gives a more 3-Dimensional experience and allows for user autonomy in moving around etc. In addition, the telepresence robots can be used in contexts that require personalized monitoring or observation. One such situation can be in laboratories.

5. Current Practices in Blended and Online Learning

Tan *et. al.* (2019) report an experimental pilot in which they implemented telepresence robot in a mock-up smart lab. Participants' perceptions of the use of the telepresence robot were collated. The main findings were that 1) online users can easily operate the telepresence robot; and 2) operating the robot manually increased the engagement of online users with the remote lab environment. The pilot study indicated that telepresence can possibly enable online students to conduct their lab work in a remote laboratory. The results also suggest avenues for further research and development of the system.

Rudolph *et. al.* (2017) reports the use of telepresence robot in clinical practice in nursing. The study shows that the telepresence robot is an effective method to promote engagement, satisfaction, and self-confidence in learning. The main advantage is that it allows for practice-oriented, skills-based online learning, which would have been otherwise not possible.

In summary, robots offer both synchronous and asynchronous learning, in cyber-physical educational contexts and are yet to be used more in education. They allow for remote monitoring, and support, and are especially useful in labs, classrooms, and library. But this is relatively a new field and more experimentation is still needed (Leoste *et. al.*, 2022).

5. Current Practices in Blended and Online Learning

Augmented and Virtual Reality

Figure 10. Using Simple VR tools for Engaging Students

Augmented and Virtual Reality is yet another set of technology applications that allow for a more immersive learning experience. Augmented reality, as the name implies, augments the real-world experience by adding virtual information to the real world and can be accessed through a digital code like the QR code and requires additional devices such as iPad or android phones to view the augmentation. Pokémon Go is a popular example of augmentation.

On the other hand, virtual reality is much more immersive in the sense that it completely disconnects us from the real world, and lets us experience a virtual world, and the teaching and learning happen completely in the virtual world; and this would require special visual devices, which can range from a simple mobile VR such as Google card box to more sophisticated Head-Moundted Displays (HMDs) such as Microsoft Hololens. This can be coupled with other computer accessories as well. Figure 10 gives an example of goggles used at the VR SUTD Pedagogy Day in 2017.

5. Current Practices in Blended and Online Learning

Imagine taking a short break to South Africa right now, as you pause to read the white paper. This is what you can possibly experience through the QR code here; If you had a Google cardboard. You can have a 360 virtual experience on your mobile phone through the QR code. There are several such free online resources to incorporate into your lessons. However specialized applications (which are often needed) will require development work and resources.

SCAN ME

Mystakidis *et. al.* (2022) conducted a systematic review of 45 studies on AR in higher education and STEM subjects. They found that

- AR is predominantly used in Engineering related subjects, followed by Science, Technology and Mathematics; Highest use was in Electrical/Electronic Engineering and Physics subjects.
- Text, multimedia, and 3D objects were the common AR elements.
- Visualisation was achieved through markers such as AR/QR codes and mobile phones, to trigger a static solution in specific positions. This is often used to help students to visualise detailed parts and label, or to interact with.
- Often, Experiential, Cooperative/Collaborative, Presentation, Activity-based and Discovery based instructional methods are used in integrating AR in teaching and learning.

They reported that several studies found AR to have led to student satisfaction, and learning, especially when meaningfully implemented.

Similarly, Radianti *et. al.* (2022) had conducted a systematic literature review of virtual reality in higher education. Their analysis was on 38 reports.

- 76% of the studies used high-end Head Mounted Displays (HMDs), such as Oculus Rift or HTC Vive, and 20% used Mobile VR.
- 68% of the studies did not explicitly state any learning theories and 11% mentioned experiential learning theory.
- Most of these studies focused on usability testing, rather than on evaluation studies of learning outcomes.
- Again, Engineering was the most popular field for VR applications 24%). This was followed by computer science (10%) and astronomy (7%).
- VR was used to teach procedural-practical knowledge (33%); declarative knowledge (25%), and analytical and problem-solving communication, collaboration, and soft skills (10%), behavioral impact (6%), and learning a language (2%).
- Basic interaction (24%) and realistic surroundings (17%) were the most used features. Immediate feedback and instructions were 10%. This was followed by interaction with other students (10%) and passive observation (9%).

In the workplace context, Bank of America was one of the first to use virtual reality to train its employees in 2021 to 4300 financial centres worldwide reaching 50,000 employees (Torsten n.d.). Participants reported more confidence and effectiveness in their jobs, and greater retention of training materials. Overall, training and development was found to be four times faster than they did in traditional classroom settings.

Augmented and virtual reality in cyber-physical has been useful in providing immersive and experiential learning and is used in educational contexts that would not have been possible otherwise and thus expands the scope of teaching and learning more than what is possible in face-to-face learning. This leads to student engagement, motivation and learning. The downside is that this needs customization, is resource intensive and is initially cumbersome to use, but the technology is getting better (Torsten n.d.). The literature also shows that augmented and virtual reality is still an emerging field, and that more pedagogical studies need to be conducted pertaining to the underpinning learning theories, and in evaluating the student learning outcomes.

5. Current Practices in Blended and Online Learning

Learning Analytics

Learning analytics involves the measuring, collection, analysis and reporting of data about learners and in order to optimise the learning contexts and environments (Long *et. al.,* 2011). For the measurement and collection of data about learners, studies have used surveys and text data (e.g. textual feedback) to understand aspects of learning such as cognitive load during problem-solving (Larmuseau *et. al.,* 2019) and the processes during collaborative learning (Choi *et. al.,* 2019). Such data is easy to collect as learners would be interacting with the learning management systems during their time in education.

However, such data (surveys and text) are snapshots of a students' thoughts and response, and do not fully capture the processes that occur as the lesson progresses, whether it is physically in the classroom or not. The uses of electronic devices such as cameras, wearables and other sensors enables data on learners to be captured in real-time and provide for a rich source of data on learners' responses to the task at hand in real time.

The learning analytics of such diverse sources of data collected from the actual educational context is known as Multimodal Learning Analytics (MLA), defined by Blikstein as, "a set of techniques that can be used to collect multiple sources of data in high frequency (video, logs, audio, gestures, biosensors), synchronize and code the data, and examine learning in realistic, ecologically valid, social, mixed-media learning environments." (2013).

One application of MLA that shows promise is providing feedback to learners. The "DB Collab" system was designed to provide feedback to learners during group work about their level of collaboration, so as to prompt further individual reflection about how they could improve (Echeverria *et. al.,* 2017). This system included

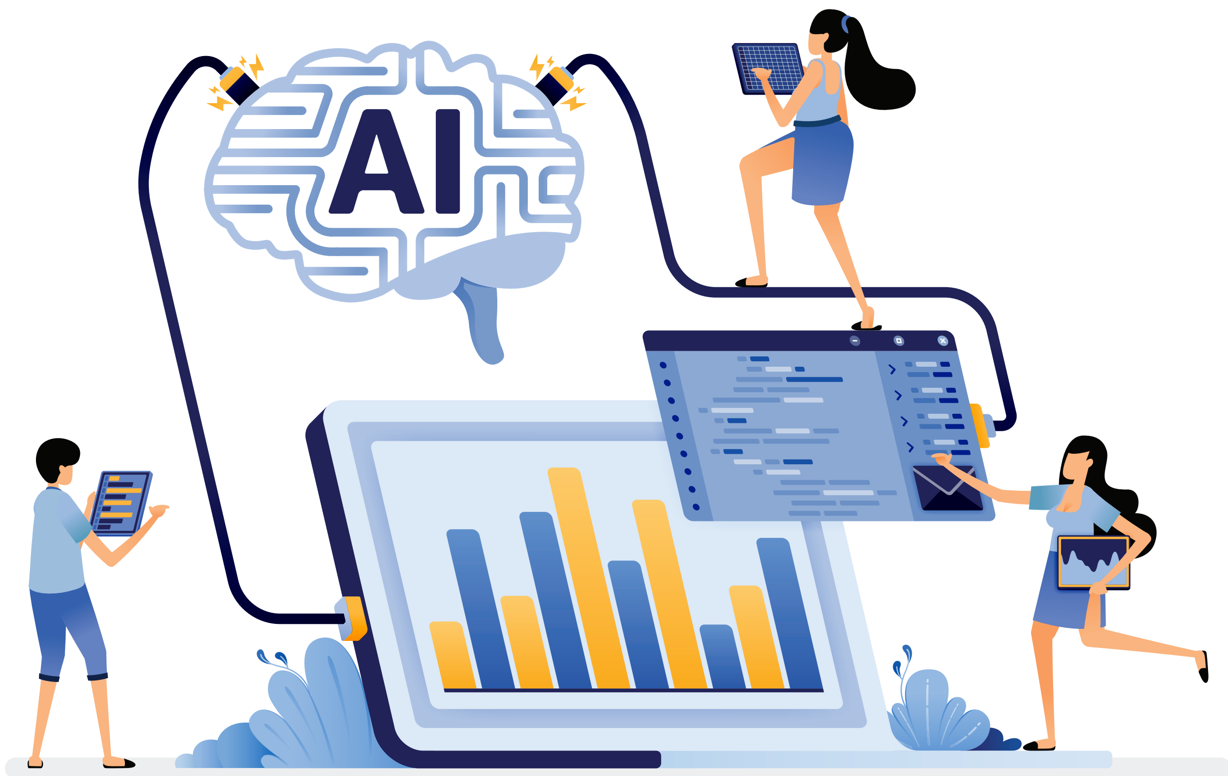
5. Current Practices in Blended and Online Learning

an interactive tabletop to simultaneously collect input from more than one user, individual tablet devices that allowed each user to send data to the shared tabletop, a Microsoft Kinect sensor to distinguish each user, and a dashboard that provided various indicators on social interaction. The study showed that the dashboard helped to spur in-depth reflections in the learners that used the system.

In the context of adult learning, studies have analysed log data from learning management systems (Jo *et. al.*, 2014) to study the time management strategies of adult learners, showing that adult learners' regularity of logins to the learning management system is predictive of their learning performance (Jo *et. al.*, 2015). Hansen *et. al.*, (2016), in their analysis of the vocational training of firefighters, reported that learning analytics can address the need to identify gaps in necessary competencies, both in individuals and in teams, and thus better identify learning and training needs.

As a result of the Covid-19 pandemic, higher education needs to be able to facilitate teaching, learning and collaboration between physical and remote learners. One example of a tool that facilitates this is the ColabAR toolkit, which is designed to support collaboration between students during laboratory sessions remotely (Villanueva *et. al.*, 2022). The next step, then, is to apply learning analytics to such cyber-physical collaborative systems to continue to provide effective feedback to learners.

Learning analytics allows us to design human-centric pedagogies that leverage on suitable technologies. One easiest starting point would be to leverage on existing learning management systems, to keep track of student learning and achievement.



5. Current Practices in Blended and Online Learning

Metaverse

Ernest Cline's science fiction Novel ready Player One (2011) sets the scene for how a metaverse can be used to provide low-cost interactive, personalized mass education to the entire world. This vision is no longer a dream. With the rapid evolution of. technology over the past few years, we are now witnessing the birth of metaverses for diverse purposes, including education. At SUTD, we are at the forefront of this development through our Metaverse and Blockchain for Education trust.

Mystakidis (2022) defines the metaverse as a "post-reality universe, a perpetual and persistent multiuser environment merging physical reality with digital virtuality. It is based on the convergence of technologies that enable multisensory interactions with virtual environments, digital objects and people such as virtual reality (VR) and augmented reality (AR)." Such an environment creates the perfect blend of reality and virtuality so as to bend the rules of space and time when it comes to education.

The opportunities for metaverse in the education sphere are myriad. In the first place, it provides a modern, digital space where students and teachers can interact easily and attend virtual classes as avatars (Kanematsu *et. al.*, 2014). This idea is makes sense in the natural evolution of our digital habits, from email to texting, zooming, to metaverse calls. Teaching in the metaverse becomes particularly relevant in a post-pandemic world, when exchange students are involved, student with physical disabilities (Su & Ahn, 2022), or in the context of classes that demonstrate complex models and procedures such as engineering and medical (surgical) classes (Kye *et. al.*, 2021).

5. Current Practices in Blended and Online Learning

Metaverse technology also provides us with opportunities to make this digital space persistent through blockchain technologies, making whatever exists in the digital space unique, secure, and certified. Examples of this may include reward badges of learned skills or grade certificates that suddenly become unique NFTs in a student's wallet that can be used to prove skills to future employers. Blockchain technology provides the opportunity to rethink how universities issues certificates (Cheng *et. al.,* 2018).

In general, the vision of a metaverse for learning can be expanded into a hub for learning. It may become a platform, a digital campus equivalent, where students go to learn, interact, socialise and have fun. Through the integration of learning analytics, AI technologies and gamification mechanisms (Tlili *et. al.,* 2022), the metaverse can be leveraged into a fully-fledged hybrid learning (and teaching) experience. The latter is particularly interesting, given the that the origins of virtual reality worlds lies in computer games. Gamification provides us with a particularly powerful tools that enables us to create an environment that is fun, rewarding, and engaging. This creates an environment for learning that the students *want* to spend time in, and motivates them to perform well. Examples of such game mechanics may be as simple as leaderboards and avatar upgrades.

A survey by Suh & Ahn (2022) reports that 97.9% of elementary school respondents had prior experiences using the metaverse, with 95% that continued using the metaverse after this initial use. This new generation will be the future generation of students at universities. In order to provide a truly student-centred learning experience, we should adopt the technology of the incoming generations.

5. Current Practices in Blended and Online Learning

What Can We Learn

Based on the above examples, we can see that there are several relevant teaching methodologies (blended and personalized learning) and technologies (Robots, Augmented and virtual reality, Learning analytics, Metaverse and Blockchain) that can support us in online and blended teaching and learning. We note that the use of technology in higher education and in the CET/ workplace is highly evolving with an integration of technology and a human element. It will be important to evaluate the usability as well as user's learning experience and impact on student learning. Technology is being customized to make possible complex learning environments feasible between the physical and virtual possible across time and space. With the growing complexity, we can also see that it is no longer sufficient to just consider technology and pedagogy.

Benefits of Blended/Online Learning if implemented well

- Distance learning
- Personalised learning
- Immersive learning
- Improved visualization
- Real time analytics and feedback
- Improved teaching and learning
- More meaningful and positive teaching and learning experiences
- Cost effective in the long run
- Makes learning fun and engaging
- Greater student motivation
- Students have more confidence
- Brings the real-world into the classroom
- Connects the class with external experts/ assessors/peers
- Peer-to-peer learning
- Knowledge management/Archiving for tracking
- Better instructor support

6. Digital Transformation in Higher Education: Cyber-Physical Learning

According to the National Science Foundation, the term "cyber-physical" is used in reference to systems that integrate and harness the power of computational and physical resources. We have borrowed and adopted the term "cyber-physical" to the *educational ecosystem* as "cyber-physical learning" to denote an ecosystem that combines online and physical resources for teaching and learning. Mourtzis *et. al* (2018) describe a cyber-physical teaching factory in the manufacturing field. We extend this the terminology and concept of "cyber-physical" learning to all subjects as networked educational ecosystem to prepare learners for the changing VUCA world and the future.

Cyber-physical learning can be compared to blended learning. Garrison and Kanuka (2014) define blended learning as the meaningful integration of classroom face-to-face learning experiences with online learning experiences; with a focus on lesson delivery and learning experiences. The traditional definition of blended learning is often linked with the mode of delivery and is known as the blend of "physical" face-to-face with "virtual" online sessions.

There can also be other versions of blending as described by Heather in her Educause article (Scan the QR code for the article) on the 6 Models for Blended Synchronous and Asynchronous Online Course Delivery (Farmer, 2020). As seen in these examples and as summarized by Hrastinski (2019), the term "blended learning" tencds to focus on instruction and learning.

SCAN ME

However, the definition of blended learning, as hybrid mode of learning and instrctutional practicees, may need a review and redefinition.

During the pandemic, many instructors went completely online, and were interweaving synchronous and asynchronous sessions in the online mode. This is a new type of blending; completely online and yet blended in the form of synchronicity.

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 pronounced when we use learner-centered pedagogies such as that by SUTD (Sockalingam, Pey, & Lim, 2021); where teaching happens in teams, using interdisciplinary learning curricula, involving team-teaching, and is driven by hands-on project-based learning pedagogies.

While we realized that lectures can be swiftly moved to online mode as asynchronous lectures and flipped learning, experiential and project-based learning may not be sufficiently supported by the existing technologies to be conducted online.

Comparatively, certain collaborative activities are restricted when conducted online than 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 feature does not allow the teacher to have a complete oversight of the class unlike a face-to-face class. When the teacher is in a particular breakout room, he/she may not be able to physically monitor student engagement in the other breakout rooms. This would have been available as peripheral vision otherwise in a face-to-face class. Hence, it is useful to innovate new pedagogies as well as technologies that cater to blended and cyber-physical learning.

> "Cyber-physical learning can be seen as blended learning, and yet it is much more"

6. Digital Transformation in Higher Education: Cyber-Physical Learning

In our definition, cyber-physical learning is more holistic and broader in nature than blended learning and 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. In addition, we should consider the concept of cyber-physical learning at the institutional level rather than just at the individual class-level.

Cyber-Physical learning is the new age digital transformation of (higher) educational institutions. This can be defined as the holistic summation of digital processes and systems to transform higher education institutions optimally, and this includes the entire aspect of learning environment, from tools to back-end IT infrastructure (Oliveira, and de Souza, 2022; Kopp, 2019).

At SUTD, we see cyber-physical learning as a form of joint and seamless learning by physical students who are physically present in class and by cyber students who are participating from remote off-campus locations, but who are represented in the physical class via technological means. Cyber-Physical learning also encompasses the learning and teaching interactions among physical students, cyber students, and physical or cyber instructors.

Although cyber-physical learning is a promising proposition, realizing it presents many challenges, in terms of pedagogies and technology. Conventional pedagogies would not be appropriate given the presence of both cyber and physical students who are learning and interacting together at the same time. This requires new teaching practices to effectively engage both types of students. Particularly important is the aspect of learning socialization, i.e., how cyber students can establish a learning presence which enables them to interact authentically and engage effectively with physical students and instructors, and vice versa, how physically present students and instructors can interact and engage effectively with remotely located cyber students, as though such students are physically present.

Another aspect to address is the ability to provide various learning options for students, i.e. how can students learn at any place, at whatever time, and with whomever. One more key aspect is the personalization of learning, which enables students to customize their learning experiences by leveraging advanced learning analytics and artificial intelligence to achieve optimal learning outcomes. Therefore, to realize cyber-physical learning, much research, partnerships, and collaborations are needed to understand the dynamics of learning and teaching in such an environment, to identify new education delivery models and technology platforms that can enable a seamless and effective cyber-physical learning experience.

7. SUTD's Approach Towards Cyber-Physical Learning: SUTD campusX

SUTD campusX

Singapore University of Technology and Design (SUTD) aims to leverage the latest digital learning pedagogies and cutting-edge technology to advance itself as a future-ready university to prepare lifelong tertiary learners and innovators with its campusX initiative. 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-centred education experience in the form of personalised, immersive, collaborative, and socially connected learning.

The vision of campusX is to pioneer a fun, safe, and inclusive educational experience at SUTD, where lifelong tertiary learners (undergraduates, postgraduates, and adult CET learners) can leverage innovative cyber-physical techno-pedagogies to personalise their learning journeys and achieve optimal learning outcomes.

Realizing that we must go beyond the aim of using existing tools to innovating our own pedagogies and technology tools for cyber-physical learning, SUTD started the "SUTD campusX" initiative in 2021. In the past five years, Technology-enhanced Learning and Scholarship of Teaching and Learning (TEL-SoTL) projects tend to use existing technology tools in general. However, the existing technology tools have limitations in terms of active and interactive learning. For instance, how can we teach practical skills to both cyber and physical students? Or how can we get cyber-physical teams to co-design and build a prototype synchronously? While existing technologies such as Zoom, Microsoft, Google allow a certain level of collaboration, there are limitations when it comes to higher-order human-centered and design-based collaborative learning.

To this end, a group of 60 faculty and staff members are currently involved in the SUTD campusX initiative, in innovating and testing out the efficacy of new technologies and pedagogies for cyber-physical learning. From consultations with

7. SUTD's Approach Towards Cyber-Physical Learning: SUTD campusX

students, instructors, and SUTD leadership team, SUTD campusX has identified three important themes focusing on user experience and learning outcomes:

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

To achieve these important outcomes, SUTD is conducting various minimum viable products (MVP) and research and development (R&D) projects, prototyping, and partnership activities to develop appropriate pedagogies and technology tools that can enable SUTD to create a human- and design-centric cyber-physical learning environment, i.e. SUTD campusX.

Philosophy of SUTD campusX

The philosophy of SUTD campusX is powered by "Learning Science" and "Educational Technology" (the two grey boxes in the following figures), together with the interactions between these two enablers.

Learning Science involves educational pedagogies, teaching and learning principles and methods, including learning analytics (both real- and post-time); while Educational Technology involves applications, software, and hardware tools that provide seamless and immersive learning experience (such as virtual/augmented reality, gamification, robots, learning analytics, and artificial intelligence).

The two enablers ("Learning Science" and "Educational Technology") interact through various campusX programs and initiatives (e.g. partnerships, MVPs, research projects), and it is through these interactions that outputs that contribute to the development of campusX are generated.

One such output is knowledge, expertise, and competency to create a campusX pedagogy that is suited to the human- and design-centric curriculum of SUTD, termed SUTD Techno-Pedagogy of learning. This unique blend of SUTD Techno-Pedagogy has three important dimensions: Technology of cyber-physical Learning (TOL), Science of cyber-physical Learning (SOL), and Ethics of cyber-physical Learning (EOL) (Figure 11).

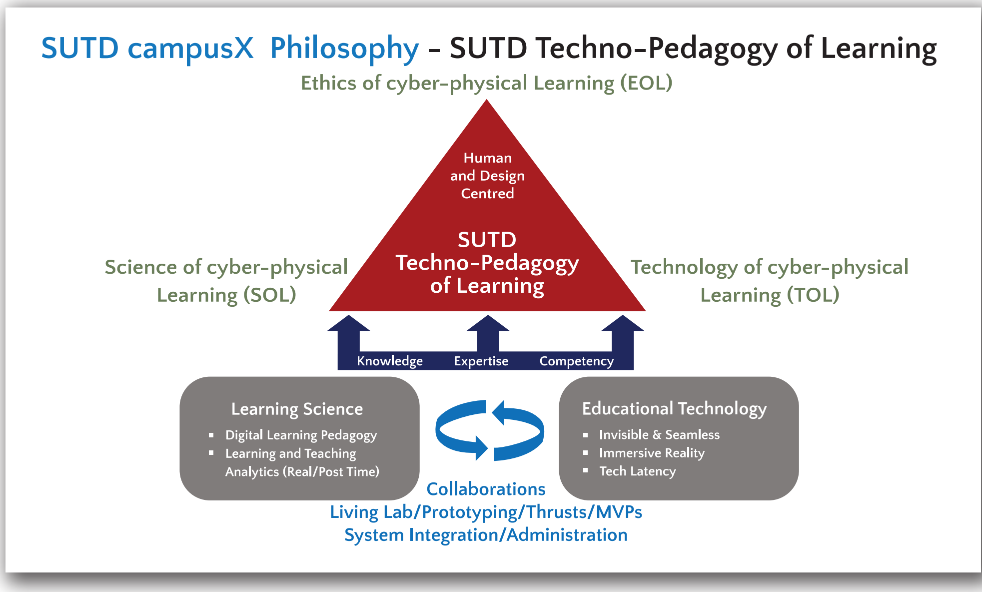


Figure 11. SUTD campusX Techno-Pedagogy of Learning (Pey, Teo, &, Lo, 2022)

7. SUTD's Approach Towards Cyber-Physical Learning: SUTD campusX

Technology of cyber-physical Learning (TOL) involves knowledge and competency in the various technology platforms and tools that enables cyber-physical learning such as learning analytics, artificial intelligence, and robotics, while Science of cyber-physical Learning (SOL) involves proficiency and understanding of pedagogical and andragogical principles and techniques that supports effective cyber-physical learning for lifelong tertiary learners, and lastly, Ethics of cyber-physical Learning (EOL) involves comprehension and capability to discern appropriate rules and guidelines to provide a fun, safe, and inclusive learning environment.

Together all these three dimensions constitute the Techno-Pedagogy of SUTD campusX. Both the campusX Techno-Pedagogy of Learning (in short "Big-T") and SUTD's "Big-D" of design learning work hand-in-hand to create a unique educational experience at SUTD that centres on interdisciplinary learning and research and nurturing lifelong tertiary learners who are design-focused and human-centred.

Cyber-Physical Learning Environment of campusX

One other output generated by the two enablers (i.e. "Learning Science" and "Educational Technology") are the systems, components, and tools that build up campusX, where campusX is orientated towards the previously mentioned themes (Figure 12) of focusing on user experience and learning outcomes of lifelong tertiary students (undergraduates, postgraduates, and adult CET learners):

- Learning Intimacy/Learning Socialisation
- "Anywhere, Anytime, Anyone" Learning
- Safeguarding Governance

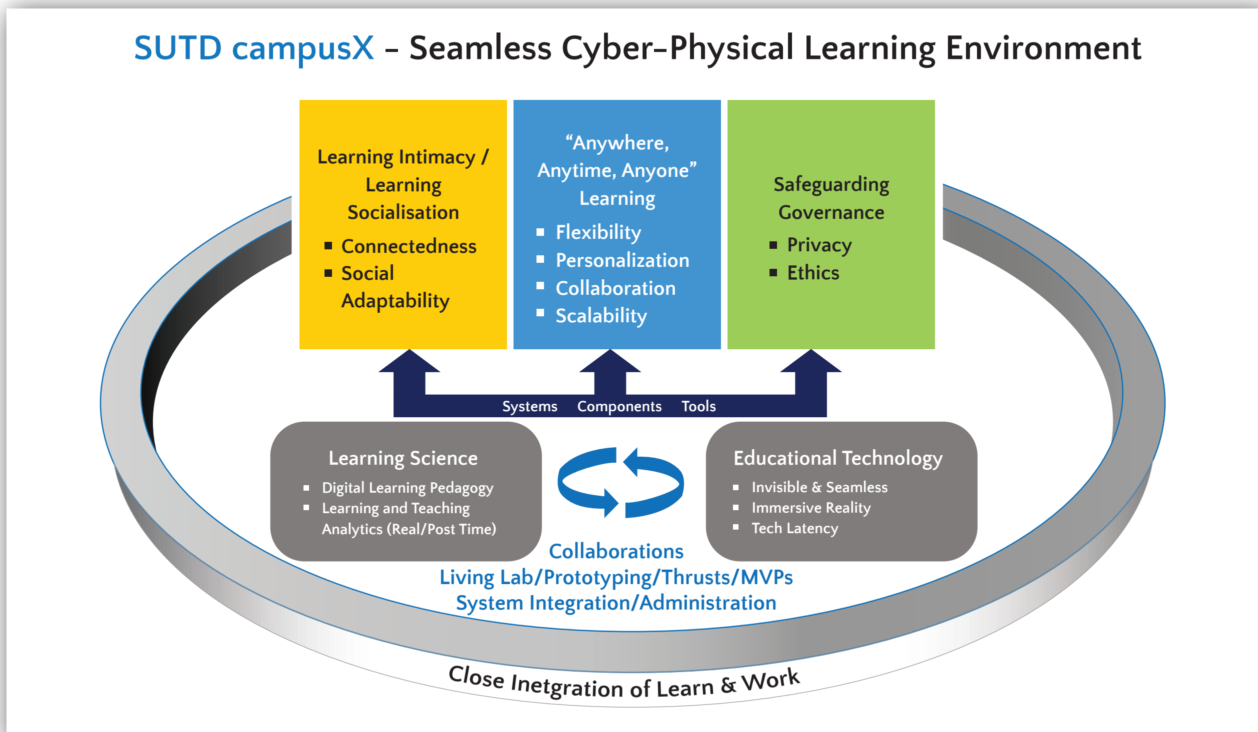


Figure 12. SUTD campusX Cyber-Physical Learning Environment (Pey, Teo, &, Lo, 2022)

7. SUTD's Approach Towards Cyber-Physical Learning: SUTD campusX

Both cyber and physical students can personalise their learning experiences to achieve optimal outcomes, have various options to learn at any place, at whatever time, with whomever, and learn in a socially connected, fun, safe, and inclusive environment.

Where SUTD Positions Itself

Relative to the three dimensions of cyber-physical learning [i.e. technology (TOL), learning science (SOL), and ethics (EOL)], campusX (represented by the campusX North Star which symbolises the meaning and purpose of campusX) is positioned as follows (Figure 13).

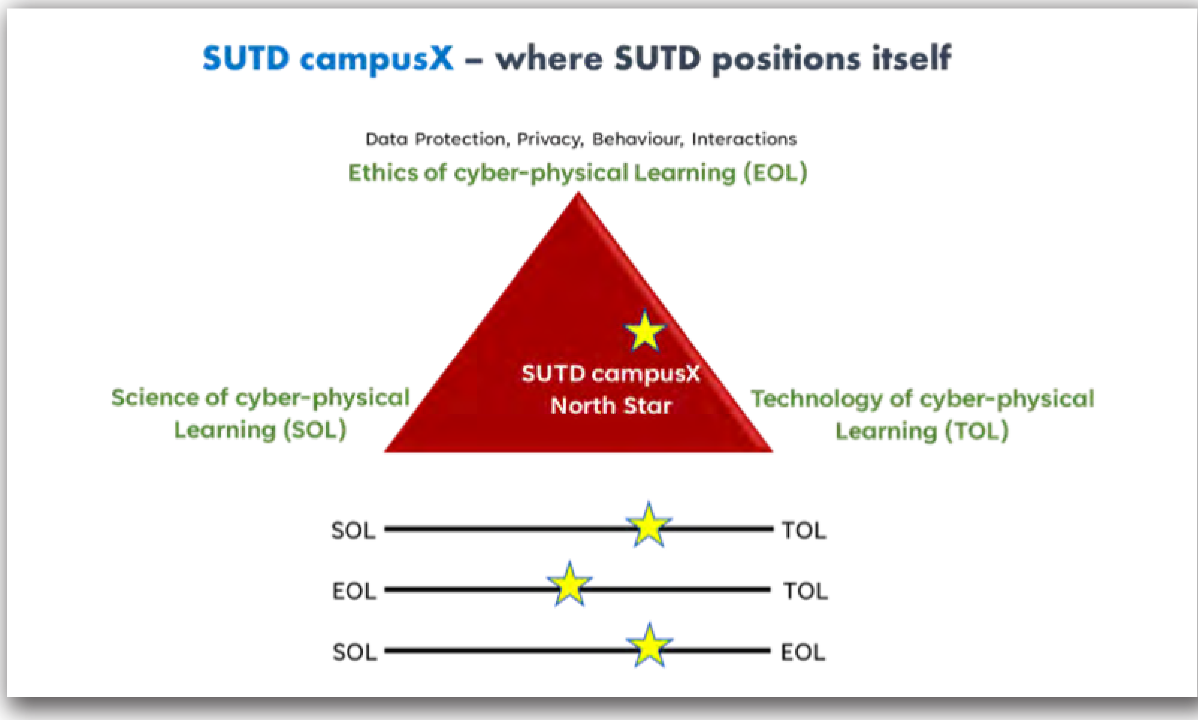


Figure 13. SUTD campusX North Star (Pey, Teo, &, Lo, 2022)

- Between SOL and TOL, SUTD is orientated more towards TOL.
- Between EOL and TOL, SUTD has equal emphasis on both (in line with the human- and design centric focus of SUTD).
- Between SOL and EOL, SUTD is orientated more towards EOL

> The position of the campusX North Star reflects SUTD's core emphasis on human- and design-centric learning.

7. SUTD's Approach Towards Cyber-Physical Learning: SUTD campusX

The Six Thrusts of SUTD campusX

Overall, the central thinking behind campusX is that cyber-physical learning, when powered by Educational Technology and Learning Science, is an intimate, interactive, and impactful learning pathway that will drive educational innovations to improve learning outcomes, grow skills and knowledge, and sustain personalized lifelong tertiary learning in a fun, safe, and inclusive way.

By focusing on a human-centric approach, SUTD campusX identified three grand challenges in cyber-physical learning that are aimed at developing innovative systems, software, tools and educational practices. These are (i) Learning intimacy and socialization, (ii) "Anywhere, Anytime, Anyone" Learning, and (iii) Safeguarding governance. These three grand challenges were identified to ensure relevance of learning outcomes of lifelong tertiary students in both cyber and physical space.

Learning intimacy and socialization focuses on seamless interactions across learners-learners and learners-faculty that are fun, safe, and inclusive (i.e., connectedness), with engaging and authentic social presence of learners and faculty that are supported by intuitive, unintrusive, easy to use, and stress-free technology. Learning anywhere, anytime, with anyone provides not only flexibility and scalability in learning options, but also personalization and collaboration of learning. Safeguarding governance aims to provide an environment where both data protection and privacy are protected, and safe and inclusive cyber-physical learning ethics is observed.

To address the 3 grand challenges and ensure that the learning outcomes are achieved, SUTD campusX has adopted a set of thrusts (i. e., key initiatives) to develop the required human- and design-centric capabilities leading to new pedagogical practices, guidelines, policies, and educational innovations. We term this as "Techno-Pedagogy" of Learning (ToL). These six thrusts are intended to focus not only on a strategic set of activities by themselves but also the interactions across them.

These Techno-Pedagogy thrusts are

- 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

Living Labs

To focus and emphasize human-centric ToL methodology, two Living Labs are planned – one focusing on higher education learners while the other on adult CET learners. The Living Lab approach allows SUTD to constantly innovate and adopt new pedagogies, andragogies, and technologies that best suit the needs and expectations of tertiary lifelong learners. Besides this, SUTD also aims to use the Living Labs to (i) build networks in the cyber space for both formal and informal activities, (ii) establish testbed and innovation hub, (iii) conduct educational technology validation, (iv) set up cyber-physical learning standards and benchmarking, (v) develop joint R&D projects with partners, and (vi) foster start-ups. Currently, SUTD campusX has set up the first Living Lab for piloting undergraduate related programmes while it is at a planning stage to set up a second Living Lab for CET lessons with SkillsFuture Singapore and the Institute for Adult Learning as joint collaborators.

8. SUTD Leadership Perspectives on SUTD campusX

This section summarizes the perspective of key leaders and stakeholders in SUTD campusX obtained through interviews. Their vision for SUTD campusX, key activities being carried out, and its potential benefits and challenges will be described below.

> "The future of education is going to be very different"
>
> **Professor Phoon Kok Kwang**
> *Provost*

Professor Phoon Kok Kwang explains that in the current external global landscape, changes are occurring such that "jobs that used to exist are no longer in existence, and new jobs or fields of work are being created as we speak" and this pace of change is being accelerated by the pandemic.

Professor Phoon also notes that the traditional learning environment, where students and instructors are physically in the same venue, is being challenged by technology, citing how Massive Open Online Courses (MOOCs) providers have been popular and have also received the attention of investors.

According to Professor Phoon, this is just the beginning of the transformation of higher education, as "many digital technologies are converging to make the cyber-physical environment a reality in the foreseeable future". This means that learning environments and experiences will be re-imagined, such that "the future of education is going to be very different".

Thus, the SUTD campusX initiative was started to explore how a cyber-physical environment can be applied to learning in higher education. Professor Phoon stressed that the development of SUTD campusX is centred on learners and instructors and aims to make the SUTD learning experience "as enriching and rewarding as possible", so that SUTD students will be prepared "for the future of work and the workplace".

To keep these aims in focus, he lists out three core principles for SUTD campusX, namely

- to create a safe, inclusive and enjoyable space to learn and interact,
- curate a personalized learning journey that is optimal in learning outcomes, and
- provide a living lab for the SUTD community to experiment and innovate teaching and learning.

8. SUTD Leadership Perspectives on SUTD campusX

Learn any time, any place, anywhere

Professor Pey Kin Leong
Associate Provost, Office of Digital Learning

Professor Pey Kin Leong articulates a vision for higher education where students are given "full control, so that they can learn almost anytime, anyplace, anywhere". He envisions a platform where both students and instructors are learning together, even though they may not be in the same physical space.

To achieve this vision, faculty members are currently exploring an entire suite of technologies. Professor Pey describes a learning analytics system that could provide real-time feedback, using technologies such as eye-tracking, sensor networks and other technologies. This real-time feedback can be provided both to students and instructors to enhance teaching and learning.

To enable faculty to prototype, test and develop the technologies involved, a living lab has been set up. Furthermore, Professor Pey also hopes that this living lab can also enable SUTD to collaborate with industry and other external parties, such that it becomes a "testbed for us to work with industry on bringing their ideas into SUTD campusX".

SUTD campusX will allow borderless learning everywhere, not bound by space and time

Professor Tai Lee Siang
Head, ASD

Professor Tai Lee Siang, Head of Pillar, Architecture and Sustainable Design Pillar, agrees with the vision of SUTD campusX, which will allow "borderless learning everywhere, not bound by space and time". As SUTD makes extensive use of group work in its pedagogies for undergraduate education, Professor Tai hopes that the technologies developed in SUTD campusX can also help facilitate group learning and collaboration but will require more investigation and understanding of how it can be done, stressing that "it is important that pedagogy and communication are tailored to the medium".

Furthermore, Professor Tai emphasized that it is important to ensure that new educational technologies are easily adoptable by students and faculty.

8. SUTD Leadership Perspectives on SUTD campusX

“Implementation is key to SUTD campusX”

Professor Ricky Ang
Head, SMT

Professor Ricky Ang, Head of Science, Mathematics and Technology Cluster, sees that the technologies under development in SUTD campusX can enhance learning by providing instructors with real-time feedback during lessons and helping students to be continually aware of their strengths and weaknesses. However, when adopting these technologies, he stressed the importance of good and effective implementation, obtaining feedback from students, and supporting faculty in using them.

“SUTD campusX is the vision of expanding the university beyond what it currently is”

Dr. Oka Kurniawan
Senior Lecturer, ISTD

To Dr. Oka Kurniawan, Deputy Director of SUTD campusX, campusX is about implementing the vision of expanding the university beyond what it currently is. He sees SUTD campusX as a chance to influence the changes in higher education that have been brought about by the Covid-19 pandemic. He points out that the shift to remote learning during the pandemic caused students’ preferences to change, such that some students actually “prefer to interact and learn through online learning.” Thus, SUTD campusX is a platform for him to explore “the technologies out there and how we as educators can make use of these to enhance learning in tertiary education”.

As he believes that “we should be the driver of change”, Dr. Oka is spearheading several projects under the SUTD campusX initiative. One of his projects is to develop a collaborative augmented reality application to teach python programming so that students can apply this in real-world team-based settings, even when they are not in the same physical location. Other projects involve using Artificial Intelligence to develop a chatbot that can provide immediate feedback as students work on their programming assignments and working with the SUTD Games Lab on how to gamify the university experience. He works with Learning Sciences Lab and other faculty members on these projects.

8. SUTD Leadership Perspectives on SUTD campusX

"It is important and essential to create proper data protection processes at the university while implementing SUTD campusX to make sure that we are protecting everyone"

Assistant Professor **Nilanjan Ragunath**
HASS

The technologies under development in SUTD campusX requires the collection, storage and analysis of data from students and faculty. This requires an awareness of the ethical principles of the collection and use of data from human subjects, as well as compliance with the Personal Data Protection Act. Hence, Assistant Professor of Sociology Nilanjan Ragunath stresses the importance of data protection, not only to comply with legislation on data protection and privacy, but more importantly, to "create a safe place for faculty students and the university itself, to make sure that we are protecting everyone in the process". Together with her team in the Data Governance Element, Prof Nilanjan works with the faculty in the various campusX projects to ensure that data protection is taken care of.

"Cyber-Physical Learning needs to be grounded on learning theories and principles, and substantiated by evidence-based evaluations of teaching and learning."

Dr. Nachamma Sockalingam
Program Director, Learning Sciences Lab

Dr. Nacha recommends that our understanding of "how we learn what we learn" is key to successful cyber-physical learning implementations. She urges that technology integrations are underpinned by learning theories and principles, and are substantiated by evidence-based evaluations of teaching and learning. She suggests approaches such as "Scholarship of Teaching and Learning" (SOTL) and Science of Learning (SOL) to this end. SOTL is characterized by scholarly teaching, evidence-based practices, and public sharing/community building. SOTL offers experiential, reflective and personalized learning for the teachers so that they can enhance and support student learning. On the other hand, Science of Learning (SOL) is useful to understand how we learn what we learn and why. SOTL and SOL coupled with tools of learning analytics will provide us valuable insights to help our teachers and learners in adapting to the new age of cyber-physical learning.

8. SUTD Leadership Perspectives on SUTD campusX

In summary, SUTD campusX:

- Centers on the learners and instructors and adopts a user-centric approach
- Enables anywhere, anytime learning by anyone
- Personalises individual and team-based learning experiences by leveraging advanced learning analytics for positive intervention
- Gives both cyber and physical students an engaging and authentic learning social presence
- Generates educational innovations in partnership with students, instructors, professional staff, academic partners, and industry partners.
- Aims to advance our knowledge on how students learn and how instructors teach in a cyber-physical learning environment through Technology of cyber-physical Learning (TOL), Science of cyber-physical Learning (SOL), and Ethics of cyber-physical Learning (EOL)
- Uses evidence-based approaches to evaluate learner/instructor experiences and learning outcomes through Scholarship of Teaching and Learning and Science of Learning
- Safeguards learners and instructors by providing a fun, safe, and inclusive learning environment, in addition to protection of privacy and personal data.
- Adapts and scales the new ways of teaching and learning, so that it is user-friendly, intuitive, and cost-effective
- Creates new possibilities in human- and design-centric teaching and learning as intended by SUTD's "Big-D" Design philosophy, and SUTD campusX "Big-T" (Techno-Pedagogy) Teaching Philosophy

9. Cyber-Physical Learning @ Partner Institutions

In this section we present four case-studies from our partner institutions on how they are adopting cyber-physical learning.

Tecnológico de Monterrey, Mexico

Monterrey Institute of Technology (also known as Tec) is a private university in Mexico, with about 35 campuses, catering to 90000 students throughout Mexico. Tec was founded by a MIT-educated industrialist in 1943. Tec offers innovative undergraduate, graduate and continual learning courses that respond to social, economic, labor, scientific and technological changes. Tec has been engaged in educational innovation projects for over a decade.

The Institute of Future Education focuses on the needs of higher education and lifelong learning and aims to create the future of education through the following three pillars.

9. Cyber-Physical Learning @ Partner Institutions

Transforming
Open platforms will be created for research that generates innovation in educational issues. It will also be sought that these innovations get translated into entrepreneurship, licensing, consulting, and continuing education programs.

Connecting
The IFE will promote collaborative work among educational institutions, the private and public sectors, and society.

Making it happen
Constructing an entire ecosystem that improves educational quality is driven by the generation of knowledge, research, innovation, and entrepreneurship.

During 2021, 474 educational innovation projects were developed at Tecnológico de Monterrey (1). 597 professors and more than 27,000 students participated in these projects. Among these projects you can find the use of immersive learning with technology and the design of innovative spaces. Immersive technology was used for making 2D and 3D environments on which 3,003 students participated during Feb-Jun 2021 (e.g. Heineken brewery and Athens city tour). The future of learning beckons all involved in the education sector, from academia to industry and across local and global partners, to respond together in partnership to build integrated and seamless cyber-physical learning ecosystems.

Tecnológico de Monterrey has developed an ecosystem of experimental classrooms that served to explore the technologies that were later deployed during the COVID-19 pandemic, in order to continue with remote and hybrid classes. A number of classrooms were equipped with smart cameras, projectors, screens, audio, keypads and Zoom for enabling a blended learning environment, i.e. part of students in person and the rest of them at home. In addition, a Hall immersive room was developed for teaching virtual courses integrating video, communication, interaction and artificial intelligence technologies, to break the distance barriers between students and teachers (Figure 14).

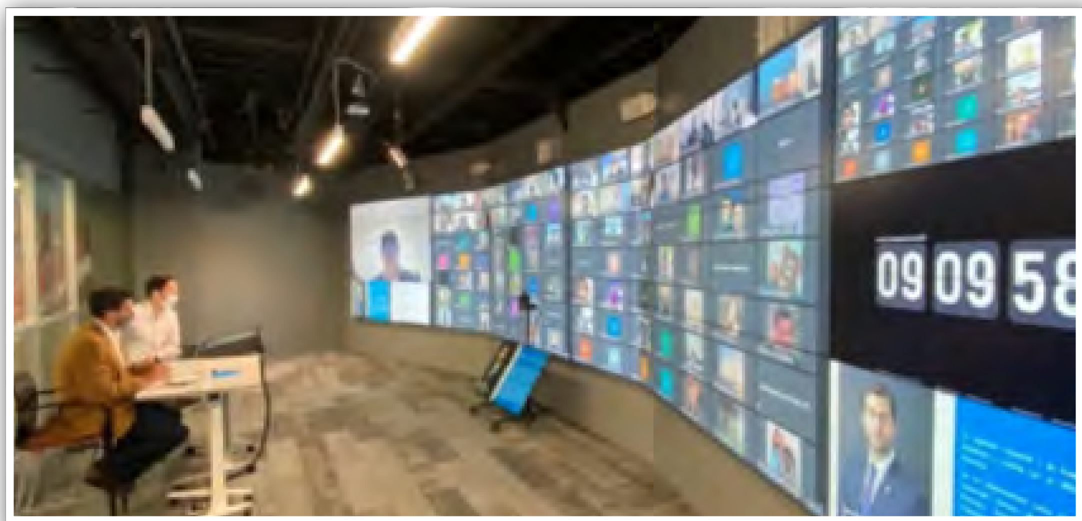


Figure 14. The Tecnológico de Monterrey's Hall Immersive Room

9. Cyber-Physical Learning @ Partner Institutions

At the Living Lab and Data Hub of the Institute for the Future of Education (IFE) we have embarked on creating an Experimental Classroom that not only provides a blended learning environment, but also allows researchers to study students' collaboration, engagement and learning. In this space, researchers, teachers, and students will experience and experiment with multi-modal technologies, therefore promoting state-of-the-art educational innovation research (Figure 15).

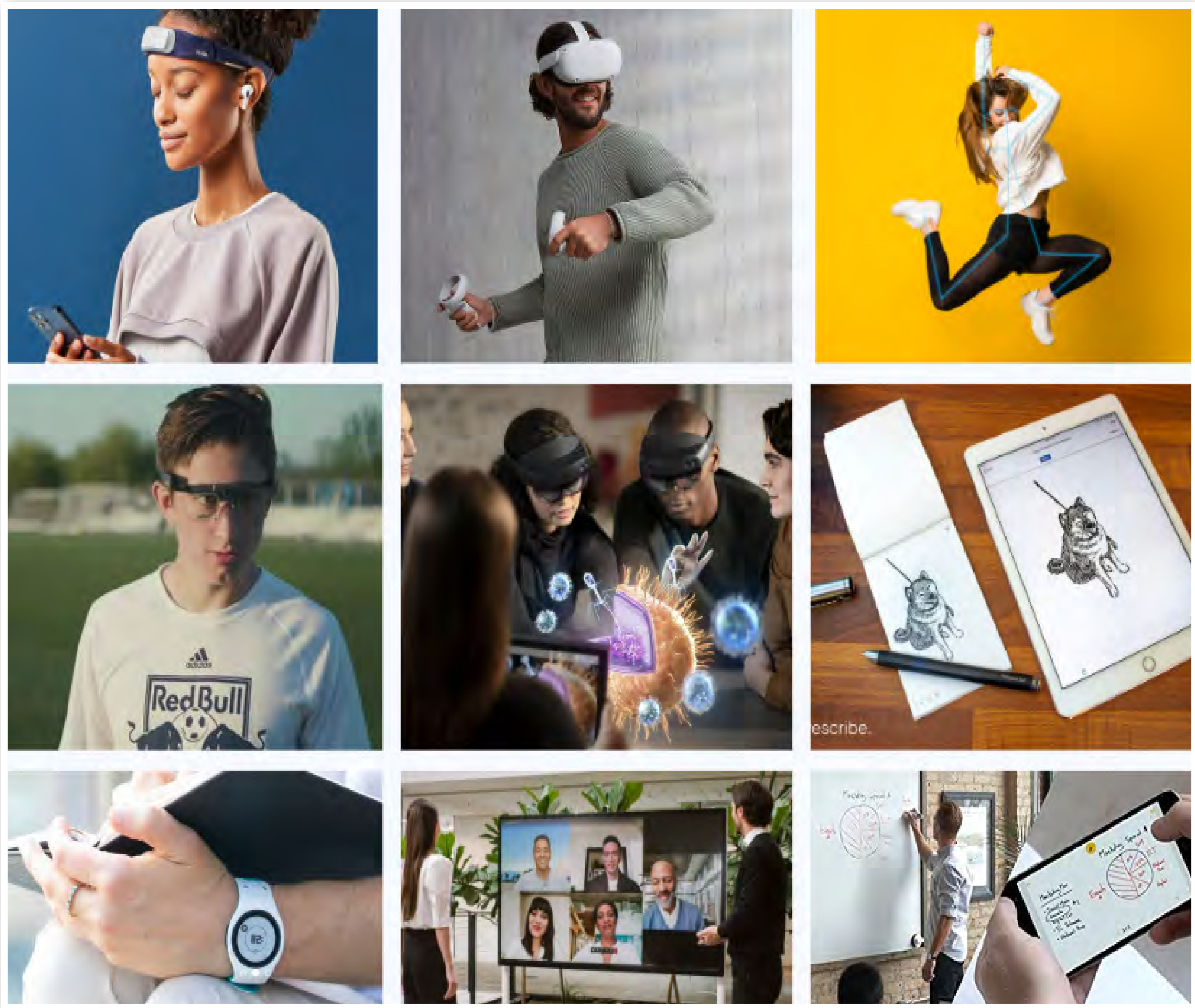


Figure 15. Multimodal Technologies for the IFE Experimental Classroom

9. Cyber-Physical Learning @ Partner Institutions

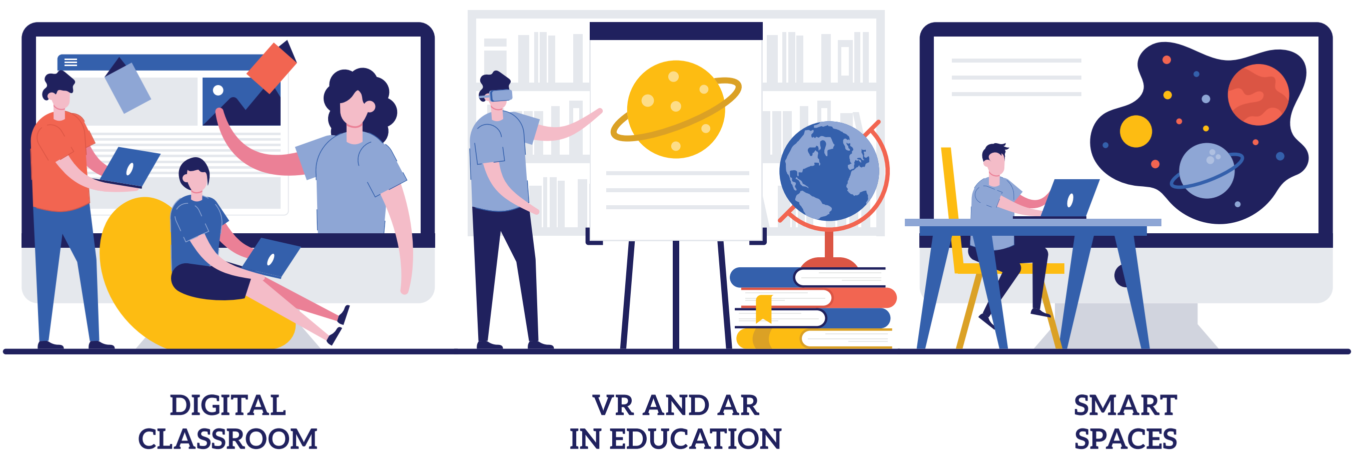
The IFE Experimental Classroom will focus on research projects that require the collection, processing, and analysis of auditory, visual, tactile, neuronal, and emotional traces in a hybrid environment. The IFE Experimental Classroom is looking for:

- Multidisciplinary research groups looking to conduct research on educational innovation.
- Companies and R&D Departments looking to conduct research studies on their products and services.
- EdTech companies offering their devices and technologies to be included and tested on-site.

The Experimental classroom operates based on research calls, i.e. an experimental setting proposed by researchers will be deployed and the experimentation will be conducted with the participation of students and teachers in a real-world scenario. Researchers from all over the world are invited to participate in these calls.

The blended learning nature of this initiative will allow the interaction of our students with international students, as well as Tec students located at other campuses or at home. Hence, joint courses will be a good opportunity to collaborate with other universities. We are also looking for similar spaces to replicate experiments and share experiences on the technology used in our facilities.

The Experimental Classroom will be built at the Expedition building which will be ready in 2024. In the meantime, we are already acquiring and testing multimodal technologies in the existing hybrid classrooms.



9. Cyber-Physical Learning @ Partner Institutions

Zhejiang University, China

ZJU is one of China's top higher education institutions, as well as one of its oldest. ZJU is located in Hangzhou, the University is organized across seven faculties and 39 schools. It is home to 4,383 full-time faculty members, including 30 members of the Chinese Academy of Sciences and 31 members of the Chinese Academy of Engineering. ZJU has 63,136 full-time students, over 53% of whom are postgraduate students. Laying claim to several areas of research strength, ZJU currently ranks among the top three on Chinese mainland and within the top 100 in the Times Higher Education World Reputation Rankings and QS World University Rankings.

As a research and innovation-oriented comprehensive university with distinctive characteristics and significant impact at home and abroad, Zhejiang University embraces 12 disciplines, 7 faculties, 37 colleges (departments), 1 Polytechnic Institute, ZJU-UIUC, ZJU-UoE and 7 affiliated hospitals.

ZJU strives to explore and build a super-large scale online and offline integrated teaching innovation system driven by digital intelligence. ZJU promotes muti-modal resilient integration, precise and personalized learning models, no boundary contact to talent training and massive cross-integration of interdisciplinary resources.

This new era has given education a new mission. Educational informatization, as an endogenous variable of educational systematic reform, promotes idea innovation, model innovation and system reconstruction. ZJU has the responsibility to support the national educational modernization development goal, relying on the new technology such as cloud computing, artificial intelligence, virtual reality which are the leading research area in ZJU.

To comprehensively promote the construction and practice of the super-large scale online and offline integrated teaching system driven by digital intelligence. ZJU innovatively adopts the theoretical framework of K-CPS (Knowledge, Classroom, Platform, Cloud-Services) intelligent teaching (Figure 16). This provides a safe and reliable teaching base, a service support mechanism and a holistic teaching ecosystem of crowdfunding group intelligence.

9. Cyber-Physical Learning @ Partner Institutions

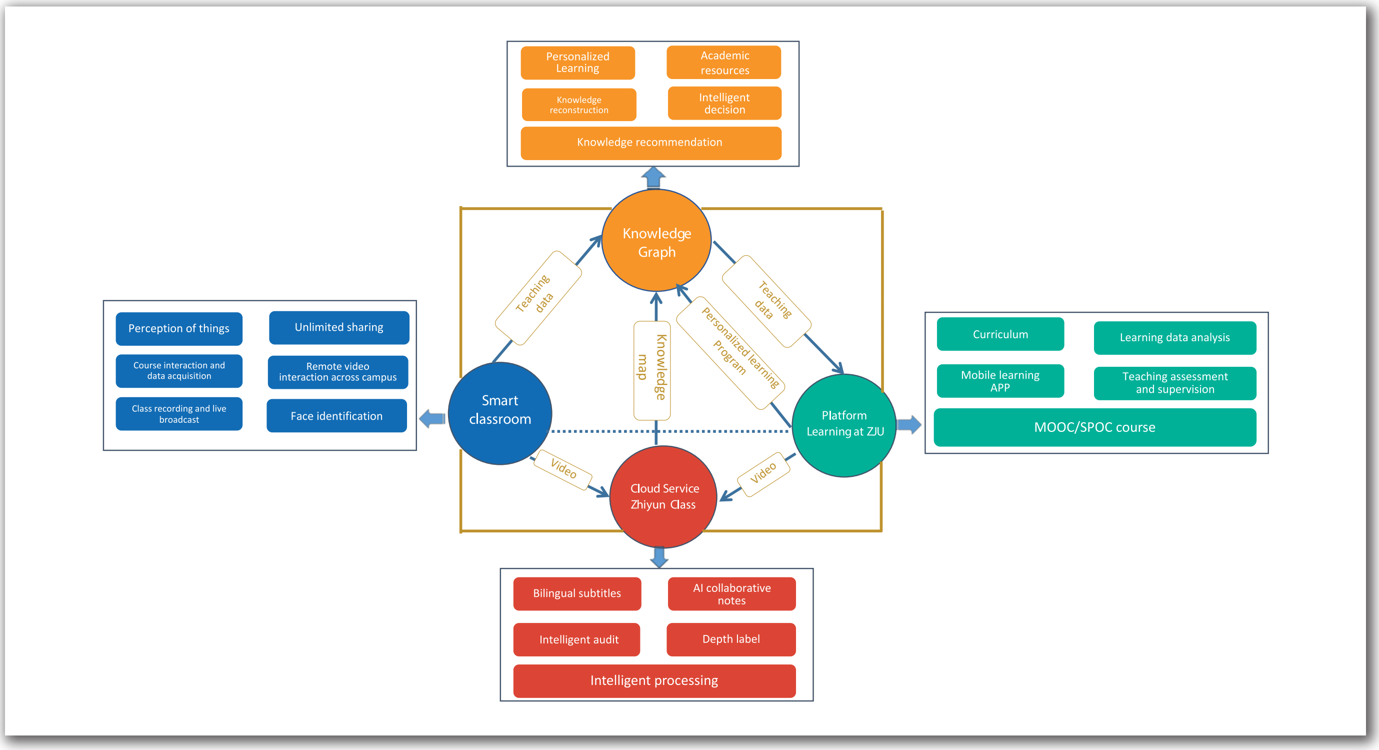


Figure 16. The Knowledge Classroom Platform Cloud-Services (K-CPS) Intelligent Teaching Framework from Zhejiang University

The University also has an online learning platform-Learning in Zhejiang University (http://course.zju.edu.cn/) with the initiative of promoting the deep integration of information technology, education and learning. At present, it has a great number of online courses, with 216 courses at Chinese Universities MOOC platform at https://www.icourse163.org/, 7 online courses at iCourse International. Moreover, over 190 MOOC courses are under construction and it is planned that more quality MOOC courses are to be set up annually in the 14th Five-Year Plan period so as to build an "Internet + Teaching" system with the characteristics of the University.

To promote the integration of disciplines, enhance students' innovation design ability and the development of comprehensive quality. ZJU actively promotes university-industry cooperation, proposed an innovative cultivating mode called "innovation + entrepreneurship" , built a bridge between the campus and industry, training and actual practice, knowledge and application, also promotes the same frequency resonance between supply and demand. ZJU constructs a 'Coupling and Win-win' ecology of talent cultivation among the government, enterprises, capital, media and university, the University supports the full link of science and technology design talents from entry to practice.

Together with Alibaba and other companies, ZJU has jointly created many courses such as Design thinking and innovate design, Information and interaction design technology, Introduction to Swift innovation, and information product design, based on cyber-physical learning.

The innovative programs are work in progress. Resources in terms, of time, finance, and facilities are in need. With continual efforts and attempts, we hope to achieve a better result and take effective measures to correct errors. We see that we need to empower every classroom, no matter what scale of the class, with digital intelligence and integration of disciplines based on cyber-physical learning.

9. Cyber-Physical Learning @ Partner Institutions

Singapore Polytechnic, Singapore

Singapore Polytechnic (SP) is Singapore's first polytechnic and was established in 1954. It has 10 schools that offer 30 full-time diploma courses and three common entry programmes for more than 12,800 students. SP adopts a proven creative teaching and learning framework and offers students a holistic, authentic and industry-relevant curriculum, innovative and vibrant learning spaces, and enriching overseas programmes. The Polytechnic is committed to producing competent and versatile graduates who are also imbued with sound values, so that they can be work ready, life ready and world ready. SP has more than 223,000 graduates and among them are successful entrepreneurs, top executives in multi-national and public-listed corporations, and well-known professionals across various industries and leaders in government. For more information on Singapore Polytechnic, please visit www.sp.edu.sg.

The SP Education Model (Figure. 17) shows SP's mission to be a polytechnic for all ages, by preparing our learners to be life ready, work-ready and world ready, for the transformation of Singapore. It also shows SP's clear intent to develop a strong *Data and Digital Culture* by leveraging on data and digital tools to enhance quality and innovation in Teaching and Learning; and to provide better learner experience by transforming the infrastructure and learning environment.

As part of cultivating a *Data and Digital Culture*, we aspire for each SP Staff to develop digital mindsets and skills so that SP can become *Digital to the Core*. By this we mean that lecturers will be proficient in the use of Teaching and Learning (T&L) digital tools; they will be able to harness the power of Analytics in Education so that every student can experience an effective, *Differentiated Learning,* according to their learning needs.

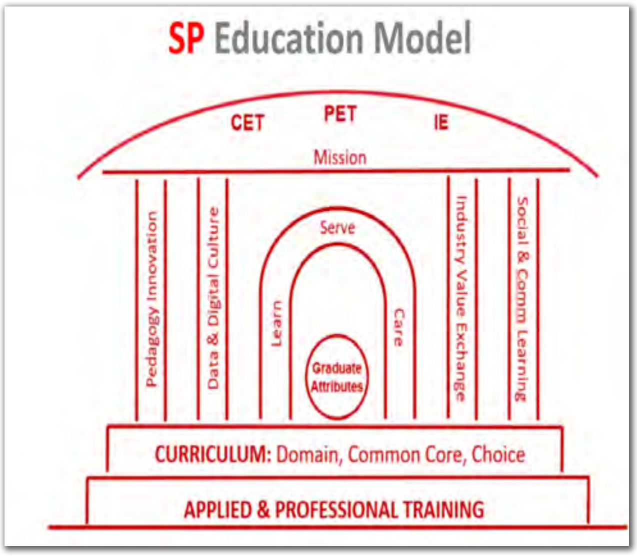


Figure 17. Singapore Polytechnic's Education Model (2020)

9. Cyber-Physical Learning @ Partner Institutions

Lecturers encounter and use a variety of data in different ways in their daily teaching and distinct roles they have at work. For example, a class teacher gathers and analyses student assessment performance and feedback data to draw insights and generalisations to make adjustments to their teaching. Course leaders, on the other hand, may go beyond classroom data to data on course application and withdrawals and also industry trends for more long-term decision making. As the use of data and learning analytics is key to enabling a data and digital culture, concerted effort to build capabilities of data gathering, data visualisation and data analysis in the context of teaching and learning has become a requisite that underpins our initiatives.

The SP Digital Learning Roadmap draws together the polytechnic's Digitalisation and Transformation efforts for teaching and learning. Institution-wide multi-year initiatives involving all teaching staff, programmes, and students have been implemented, to enable an envisioned transformation of the state of digital learning vis-a-vis Differentiated and Innovative Pedagogy, Timely Focused Support, Adaptive Learning Experiences, and Data Analytics Driven decisions to better support our learners. Selected initiatives will be elaborated in more detail in the sections below.

In Singapore Polytechnic, we adopt "Digital" flipped learning where the traditional face-to-face lecture is replaced with Asynchronous Online Lecture. Students prepare for tutorial by going through the materials (e.g. videos) in the Asynchronous Online Lecture at their own pace and attempt the embedded quizzes to check their understanding. Lecturers will make use of the data generated by the embedded quizzes to identify common areas of difficulty so that they can adjust the tutorials to focus on students who require more assistance in a timely manner.

In this approach, there is no increase in student workload and Credit Units as it is a replacement of traditional face-to-face lecture with Asynchronous Online Lecture. Lecturer workload savings from conducting face-to-face lectures can be channelled to other areas of work, such as assisting students who require more support. SP piloted flipped learning in 3 schools in 2015. Evaluation of the pilot, conducted in 2017, involving 2805 students, showed that flipped learning encouraged students to be take responsibility of their learning and to be more self-directed.

Encouraged by the outcomes of the pilot, SP rolled out flipped learning to all 10 academic schools in 2018, and pivoted towards Asynchronous Online Lectures with Embedded Data during the Covid-19 pandemic. The Asynchronous Online Lectures helped SP to weather disruptions caused by Covid-19 and opened up new possibilities. By 2020, 207 modules (28% of 730 modules) had digitalised their lectures and were adopting flipped learning. In September 2022, we completed the conversion of all modules with lecture components (503 modules) to flipped learning.

A survey conducted on teaching staff's perspectives of the flipped approach in 2021 showed that 80% (198 out of 247) of lecturers who responded to the survey felt that students learn better through flipped learning. The respondents also felt that they were able to adopt more active learning activities with flipped learning (87.3%), had more interactions with their students (73.4%), and were better able to provide the support their students needed (83.5%).

An advantage in this approach is that the Asynchronous Online Lectures allow lecturers to gather data on students learning before they enter the classroom for face-to-face lessons. By analysing the quiz performance data, lecturers can identify students who are finding the lessons challenging and those who are more advanced. Hence, rather than only 'teach to the middle', lecturers can plan and design differentiated learning experiences that cater to students who require more support, and students who can be stretched further. A variety of in-class activities involving hands-on, collaborative problem solving, case study analysis, presentations and discussions can now be implemented; and early, individual support and interventions can especially be provided to at-risk and underperforming students.

SP is also exploring better classroom designs and technologies for the Classroom of the Future. One example of this is the ePracticals. In this approach, advanced features of an e-learning authoring software, plain images and videos were manipulated and converted into interactive objects. These interactive objects were programmed to simulate certain functions and operations of equipment/tools for the learner to interact with the mouse or touch screen to "operate" while learning. Students' preparedness and understanding of the upcoming practical sessions were enhanced through accessing the pre-practical package. The e-practical packages offer alternative economical learning opportunities for skills based lessons.

9. Cyber-Physical Learning @ Partner Institutions

Institute for Adult Learning, Singapore University of Social Sciences, Singapore

The Institute for Adult Learning (IAL) is an autonomous institute of the Singapore University of Social Sciences. IAL works closely and supports Adult Education professionals, businesses, human resource developers and policy makers through its comprehensive suite of programmes and services on raising capabilities and catalysing innovations in Continuing Education and Training (CET). IAL also champions research in sustaining economic performance through skills, shaping employment as well as CET decisions, and develops innovations through learning technology and pedagogy to heighten adult learning. In 2021, IAL served more than 12000 adult learners through various programmes and engagements. For more information, please visit: www.ial.edu.sg.

IAL exists with dual objectives – providing a meaningful effective learning experience for our learners who are also adult educators and arming these very adult educators with the skills and capabilities to offer their learners an equally meaningful and effective learning experience. This has put us in the unique position of sustaining a virtuous cycle of learning as both process (for our own learners) and outcome (the learners our learners will be facilitating / training).

Our take on cyber-physical learning stems from the need to integrate the different spaces for learning – classroom, virtual, work and personal space – especially for adult learners who are often juggling multiple diverse responsibilities and struggling for time, and then adding on their need or interest to learn for work and personal growth. One focus in IAL to widen access to learning arose from the proliferation of mobile devices that has become pervasive in everyday life and where its wide usage has led to an increased development and implementation of Microlearning (Corbeil *et. al.*, 2021). Studies suggest that delivery of MicroLearning on mobile devices are particularly useful and impactful for workplace learning as it helps workers to gain small bite-sized knowledge quickly (Jahnke *et. al.*, 2018).

9. Cyber-Physical Learning @ Partner Institutions

While there is a demand for MicroLearning courses, strategies adopted in the design and implementation of MicroLearning is equally, if not, more important, as sound pedagogical concepts embedded in such learning would ensure that the MicroLearning course is engaging, relevant and meaningful.

IAL's design and implementation strategies is encapsulated in a MicroLearning pedagogical framework that took reference from Gutierrez's *3 Key Concepts That Will Help You Understand Learning in the Digital Age* (2014). The three concepts – Heutagogy, Peeragogy and Cybergogy are captured in the graphic below (Figure 18) and briefly explained in the following three paragraphs:

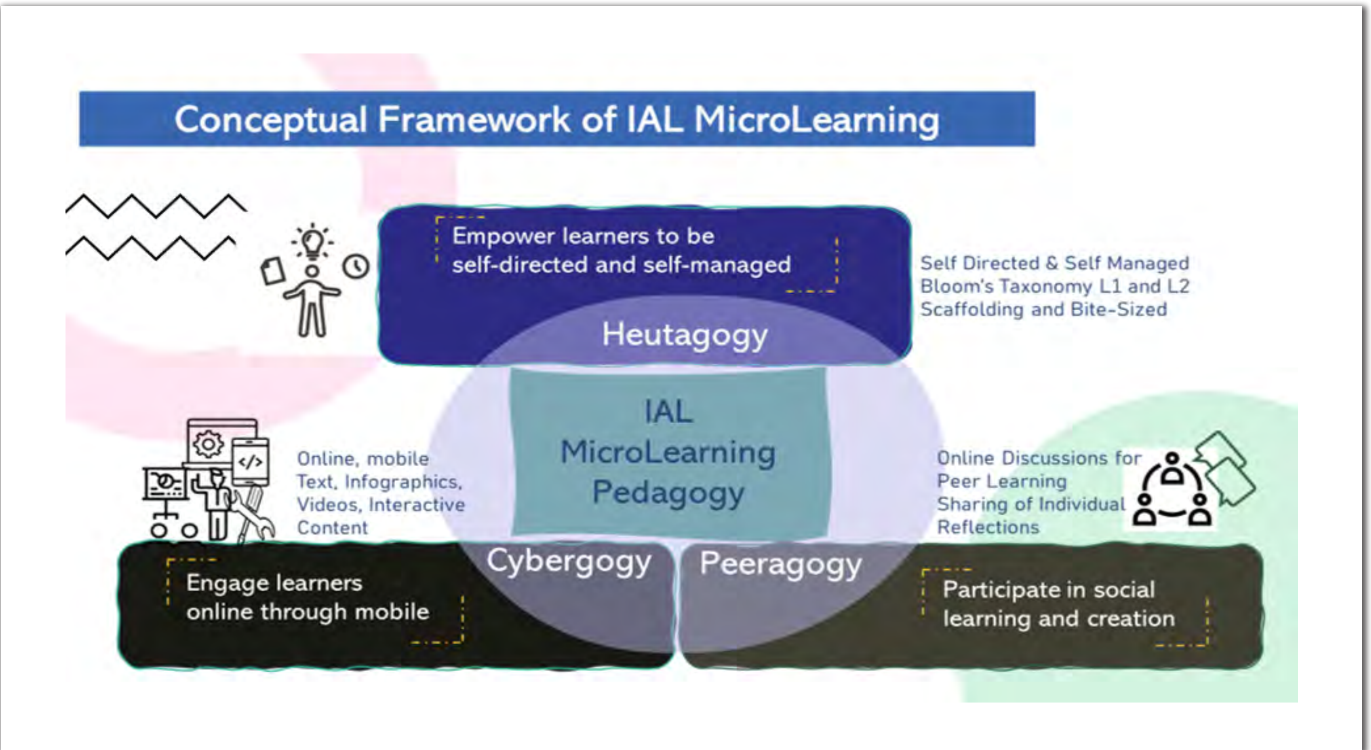


Figure 18. Conceptual Framework of IAL's MicroLearning (Gutierrez, 2022)

Heutagogy

The concept of heutagogy emphasizes 'learner agency'; empowering learners to take ownership of their learning. With an array of MicroLearning courses being made available, learners are 'self-directed' thus enabling them to determine the topics or subjects that are most relevant in their operating environment, e.g., workplace (the 'what' of learning). Correspondingly, MicroLearning also enables learners to 'self-manage' as they can determine the duration spent on learning (the 'how much' to learn) as well as determine the moments to learn (the "when" to learn). The very nature of MicroLearning where learning contents tend to be bite-sized so that information can be processed easily are enabling affordances for learners to self-direct and self-manage their own learning. MicroLearning are pegged at level 1 (Remembering) and 2 (Understanding) of Bloom's Taxonomy and knowledge (in MicroLearning) can be scaffolded from the basic levels and then be complemented with further learning through other modalities (classroom learning or work-based learning) to augment the overall learning experience.

9. Cyber-Physical Learning @ Partner Institutions

Peeragogy

The key principle that drives the peeragogy concept, as the name implies, is peer-learning; learning together to construct new knowledge. Embedding elements of social constructivism within the MicroLearning structure to provide opportunities for learners to learn from other learners. This can be achieved with the use of technological tools such as an online discussion forum. This allows learners to share their thoughts, provide different perspectives and share best practices that will widen the understanding of other learners.

Cybergogy

The concept of cybergogy refers to delivery of learning content through the Internet. Cybergogy enables the concepts of Heutagogy through enablement of self-directed and self-managed learning giving learners the capability to personalise learning experiences and of Peeragogy where social learning through online tools can be accessed. This alluded to the suitability of MicroLearning for the online environment rather than face-to-face learning. In the online environment, MicroLearning content is presented in various forms – text, images – infographics and interactive content hosted on Learning Management System delivered on mobile devices through mobile applications that are accessible anytime, anywhere. As learners are familiar with mobile devices and applications, there is little to no learning curve for learners to install and access MicroLearning courses on their mobile devices.

The three concepts Heutagogy, Peeragogy and Cybergogy provide guidance for MicroLearning design and implementation taking into consideration the learners' agency, learning theories to adopt in MicroLearning structure for engaging and impactful learning and content delivery strategies suitable for online learning delivery.

Future Plans

The disruption to learning brought about by the COVID pandemic has brought to the fore the need to better integrate the different spaces for learning. Coupled with developments in the Internet of Things and the proliferation of connected devices from desktop to laptop to mobile, the concept of an "Educational Cyber Physical System" as proposed by Bachir and Abenia (2020) would definitely be a boon to all learners. Such a concept calls for "a consistent and harmonious platform, that could bring together the different aspects of learning/teaching with the smartness of things, to offer a better learning / educational experience" (Bachir and Abenia, 2020).

This is very much in line with IAL's ultimate mission to raise the quality of learning offered to adult learners. IAL has set up an innovation lab, in.lab, precisely to nurture an innovation ecosystem that will encourage the development and adoption of proven innovations and learning technologies, again strengthening the different spaces for learning with sound pedagogical practices. As the heart of innovation and digitalisation for the Training and Adult Education (TAE) sector in Singapore, IAL is exploring the latest possibilities in the use of Artificial Intelligence, Virtual, Augmented and Mixed Reality, Gamification, as well as Mobile and Micro learning. Collaborations with like-minded organisations and institutes like SUTD on its metaverse and learner telepresence are critical in advancing our efforts to co-develop and jointly implement cyber-physical learning initiatives.

9. Cyber-Physical Learning @ Partner Institutions

What Can We Learn

In the previous sections, we have considered various reports and studies from literature, perspectives from educators and students in higher education, and identified the needs, challenges and possible technology tools that can be possibly used to enable and enhance cyber-physical learning. We have also considered the implementation strategies in 5 different institutions: Singapore University of Technology and Design, Tec Monterrey, Zhejiang university, Singapore Polytechnic, and the Institute for Adult Learning at the Singapore University of Social Sciences. These institutions are varied and cater to diverse groups of learners, are in various parts of the world etc.

Institution	SUTD	TEC	ZJU	SP	IAL
Country	Singapore	Mexico	China	Singapore	Singapore
Caters to	Undergraduate Postgraduate CET	Undergraduate Postgraduate Adult learners	Undergraduate Postgraduate	Polytechnic CET	Adult learners CET
Number of students (approximately)	2500	90000	64000	13000	12000
Type of campus	Single	Multi	Multi	Single	Single

Table 1. Educational Contexts of the Various Institutions Considered in this Report.

Despite these variations in the educational context, there seem to be some common lessons that we can draw from their experiences in implementing cyber-physical learning. Some valuable takeaways we can gather are given next as strategies and tips in adapting cyber-physical learning.

9. Cyber-Physical Learning @ Partner Institutions

Strategies and Tips on Adopting Cyber-Physical Learning

1. There is a consensus that cyber-physical learning is the way to go forward in todays' context of VUCA world. The Covid-19 pandemic is only one trigger point.

2. We need to self-assess our institutional readiness in planning the way forward for cyber-physical learning. Prioritizing will help us to identify areas that need to be addressed soon, and in future. We need to build on existing materials and resources and embrace the digital transformation in phases. SUTD's and Singapore Polytechnic's efforts over the years give some ideas on this in adopting to asynchronous lectures to flipped learning and to data-driven flipped learning.

3. It is good to start with a vision and mission for cyber-physical learning, with clearly stated strategies, niche areas of focus so that it is possible to communicate and engage stakeholders. We can see such guiding statements in all the institutions considered.

4. It is necessary to have adequate resources and capabilities and infrastructure in key areas. Examples of this includes SUTD's Living Lab and Tecnológico de Monterrey's Virtual Campus. We should also consider cost-effective strategies as used by Singapore Polytechnic's e-Practicals. In reaching out to diverse learners, we could also apply MicroLearning as practiced by the Institute for Adult Learning.

5. We need to take a holistic and comprehensive approach in cyber-physical learning. Cyber-Physical learning is not just all about technology. We need to also make conscious and concerted efforts towards innovating the pedagogical and ethical aspects as well. An example of such a framework can be seen adopted by Zhejiang University, SUTD, Tecnológico de Monterrey, Singapore Polytechnic and Institute for Adult Learning.

6. It is important to use an evidence-based approach in understanding the needs and evaluating the implementation. Scholarship of Teaching and Learning (SOTL) and Science of Learning (SOL) will be the ways to approach this. We can see many of the institutions like SUTD, Tecnológico de Monterrey and Singapore Polytechnic are practising this.

7. We need to build a community of practitioners across academia and industry so that there is peer support. This is seen in efforts by SUTD, Institute for Adult Learning, Tecnológico de Monterrey, and Zhejiang University etc.

10. Moving Forward: Collaborations and Partnerships

In the previous section, we saw the innovative efforts in cyber-physical learning by the various institutions. Through sharing and exchange of ideas and initiatives, we can learn from each other, leverage on each other's strengths to collaborate on projects to enhance teaching and learning, and co-develop new ways of teaching, and technology tools. In the next few paragraphs, we present some ideas on how we can collaborate with various stakeholders to realize the vision of a cyber-physical learning as an international consortium.

EDUCATIONAL COLLABORATIONS

Educational institutions should explore the possibilities of offering joint cyber-physical courses for their students. Classes can be opened for remote cyber students to allow greater exposure and interactions with locally present physical students. Similar ideas can be extended to postgraduate courses, adult CET courses, and research activities. Such flexibility would allow a richer experience for students at various stages of their learning journeys.

RESEARCH AND DEVELOPMENT

Another area of collaboration is through joint research and development by various institutions (across academia and industry and among local and global partners). This can be done through matchmaking of the various expertise from different institutions and partners. Collaborative research projects to study the impact of cyber-physical technologies or pedagogies / andragogies should be explored. Experiments conducted at various institutions' sites would shed light on how to build an effective and seamless cyber-physical learning environment.

INDUSTRY INVOLVEMENT

Next level of collaboration would be with industries. Cyber-Physical campuses should leverage the potential of tapping into the technology know-how of industry and create collaboration opportunities. A richer collaboration with industry partners helps to accelerate technological adoption for cyber-physical campuses. Moreover, remote internships, and Work and Learn scheme with various companies can be explored through this collaboration which will enable greater learning opportunities for students.

EXCHANGE AND SHARING OF PRACTICES

Another vital area of collaboration is on the exchange and sharing of practices between educational institutions and industry partners. Sharing knowledge and practical implementations will speed up the development and adoption of cyber-physical systems and technologies. Errors need not be repeated but rather be learnt and avoided through these sharing. Building up a community of like-minded practitioners would be an important initiative to advance cyber-physical learning.

Data sharing

The potential of a cyber-physical campus can be truly realised when trial experiments are done across institutions, countries, time zones, and cultures. To facilitate this effort, sharing of experimental data is essential. In order to protect personal data and privacy, a framework to obtain consent and anonymising data should be included in such collaborations. Different countries may have different laws regulating the protection of personal data, and collaboration agreements should take into account these differences. Legal teams should be part of the process in forming such collaboration.

11. Conclusion

The Covid-19 pandemic has initiated the way for transformation of higher education and adult CET landscape. Numerous studies from literature, interviews, discussions, and surveys within SUTD and external partners show that

- there are several challenges in adopting online/blended learning. These can be identified as operational and strategic challenges,
- while we may be doing well in some aspects of online/blended learning, we need to improve in other areas (e.g., social connectivity in teaching and learning), and
- we need to move beyond the current practices of online/blended learning to cyber-physical learning.

Cyber-Physical learning encompasses learning, training, and development for learners at various stages, across undergraduates, postgraduates and adult CET learners. Cyber-Physical learning also requires an integrated approach to teaching and learning and includes:

- Technologies that enable a seamless and effective cyber-physical learning environment
- Pedagogies/Andragogies, such as Personalisation of learning and Microlearning, that are suited for learning by both physically and remotely present students
- Ethics and governance for a fun, safe, inclusive, and secure learning environment
- Learning analytics and artificial intelligence (real and post-time)
- Scalable campus-wide technical and physical infrastructure
- Instructors capacity building
- Partnerships and collaborations among educational institutions and between academia and industry

We can see that the PET and CET institutions showcased in this paper are addressing the needs of cyber-physical learning in various innovative ways. By sharing good practices, we can learn from one another, collaborate, and build communities of practitioners.

In adopting cyber-physical learning, the most common question is whether to start with technology or pedagogy/andragogy. The answer is broader than both. If we adhere strongly to our traditional teaching methods, we may overlook the possibilities afforded by emerging technologies. Likewise, if we only consider the technological affordances, we may miss the human and ethical connectivity needed in education. We need to combine technology, pedagogy/andragogy, and ethics together to reimagine new possibilities, and enhance current teaching and learning.

Teaching and learning in higher education are evolving, and both higher educational institutions and industry will have to work hand in hand to address the needs of higher education for seamless cyber-physical learning. This will be a journey of innovations, changes, and collaborations. The white paper has described the need for such developments and partnerships in advancing higher education, CET and has also highlighted the key areas of growth and development.

To achieve better learning and teaching outcomes and a more personalised educational experience for lifelong tertiary learners, now is the time to embrace change and embark on this exciting and challenging endeavour.

> “The future of learning beckons all involved in the education sector, from academia to industry, across local and global contexts, to respond together in partnership, to build integrated and innovative cyber-physical learning ecosystems.”

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