A CRITICAL ANALYSIS OF COLLABORATIVE AND DISRUPTIVE DIGITAL-DRIVEN BUILT ENVIRONMENT EDUCATION

The Covid-19 pandemic has driven the teaching and learning provisions more towards virtual platforms, exposing lack of resilience and technology preparedness. This study aims to provide a critical appraisal of existing pedagogical studies on built environment (e.g., Building Information Modelling or BIM) challenging the opportunism and agency theories in response towards remote education provision provoked by the pandemic. The study consists of critical review of two literature samples, namely how the education sector as a whole has been responding to the pandemic, and the digitalisation-based pedagogy in built environment especially how the pedagogy addresses the pandemic. The review of the second literature sample evaluates longitudinally how BIM-based built environment education had evolved. A conceptual framework incorporating multiple factors from the review of the two literature samples is finally proposed. These factors include educational theories (e.g., Bloom's Taxonomy), curriculum development addressing assessment, student experience, collaborative learning, delivery approaches, and teaching methods. This review-based study not only provides an overview of the digital built environment pedagogical work in higher education, but also contests the opportunism response to remote or blended learning and how the post-pandemic era could embrace the remote delivery-platforms to engender a variety of pedagogical principles, for example, cross-disciplinary team-based information sharing, experiential learning, and project-based learning. The findings of this study represent a barometer and roadmap for measuring the resilience of higher education and built environment programmes towards pandemic and technological disruptions.

Keywords: Pedagogy, Digitalisation, pandemic, Digital built environment, Remote education

INTRODUCTION

The global Covid-19 pandemic has caused unprecedented interruption on higher education including the built environment (BE) sector. Prior to Covid-19, there had been some earlier studies addressing how the education sector could respond to any potential pandemic. Saravara (2007) suggested alternative assessment methodologies to be adopted by academic staff in higher education to respond to pandemic, such as web-based environment and other pre-planning initiatives. The adoption of remote technologies (e.g., video conferencing and web-based instruction) could also be found in earlier educational studies around different disciplines such as healthcare (Ismail-Allie and Van Ryneveld 2008).

Like most sectors, the BE education sector has been affected by the Covid-19 lockdown and disruption particularly the restrictions on face-to-face teaching. At the same time, emerging Industry 4.0 technologies have also brought innovations in practice and research in BE, such as augmented reality featuring digitalisation and virtual immersion. Existing educational studies in digital-driven BE can be found highlighting virtual learning environment (VLE). For example, Afrooz et al. (2019) experimented the 3D collaborative VLE for built environment courses by introducing online learning. Student feedback was collected to provide lessons learned in immersive virtual learning. Ovtšarenko et al. (2020) proposed the universal electronic courses by utilising virtual technologies integrating building information modelling (BIM) for civil engineering education.

With all these developments, teaching innovation by integrating VLE with BIM-featured engineering pedagogical approaches requires an overview of existing

educational programmes. So far, there is a lack of critical analysis of how the BE education sector has been responding to the pandemic. There is also a need to study how BE education could develop its pedagogical resilience against any interruptions by integrating existing pedagogy theories and latest Industry 4.0 platforms. Aiming to address these needs in BE education, this study addresses these research objectives: 1) performing an overview of how the whole educational sector has been handling a pandemic with coping strategies or alternative delivery approaches; and 2) proposing how digital-driven BE could enhance the pedagogical resilience. The study fills the knowledge gap in BE education on its responses to pandemic or other interruptions. The critical analysis from existing educational studies generates key factors in developing a conceptual framework on how BE education could be more standardised or systematic by incorporating digitalisation.

REVIEW METHODOLOGY

This study started from an overall literature review of the education sector in responding to pandemic especially the most recent Covid-19. The bibliometric literature search was not limited to higher education but to any teaching and learning related activities. Neither was it limited to any specific discipline. The scope of the review aimed to cover the following themes: alternative educational methods or platforms (e.g., remote learning), student experience, pedagogy management, and assessment of teaching delivery, etc. The initial keyword search was performed in the chosen database of Scopus as shown:

 TITLE-ABS-KEY ("higher education" OR "remote education" OR "teaching and learning" OR "tertiary education" OR pedagogy) AND
TITLE-ABS-KEY (pandemic OR covid)

Following the bibliometric analysis of educational studies amid pandemic, this study moved a step forward to focus on BE's education sector in terms of how it responded to the pandemic. Further, the study sought the answer to how the existing digital-driven BE had addressed the pandemic. BIM has been identified as an emerging theme in the education of digital BE or general engineering education, as indicated by Chen et al. (2019). Other latest digital technologies or concepts in Industry 4.0 for BE are also highly linked to BIM, for example, immersive technologies (Elghaish et al. 2020), digital twins (Wahbeh et al. 2020), and artificial intelligence (Huang et al. 2021). Therefore, the bibliometric search of references in digital BE education was based on BIM as demonstrated below following the procedure illustrated by Wang et al. (2020):

TITLE-ABS-KEY (BIM OR "Building Information Modelling" OR "Building Information Modeling") AND TITLE-ABS-KEY
(education OR curriculum OR institution OR teaching OR pedagogy OR students) AND TITLE-ABS-KEY (architecture OR engineering OR construction)

The text-mining and data visualisation software tool, VosViewer (van Eck and Waltman 2020) was adopted to assist the literature review. More justifications and procedure to adopt this text-mining tool with in-built algorithms can also be found in Wang et al. (2020) and van Eck and Waltman (2020).

Based on the prior text-mining-based review of two different literature samples, researchers conducted critical analysis and provided a conceptual framework for

enhancing the resilience of BE education in responding to any future pandemic or other unexpected disruptions to teaching and learning.

RESULTS AND DISCUSSIONS

An overview of education sector responding to pandemic

Following the initial literature search in Scopus and continuing with a screening of the literature sample, a total of 1,385 references were selected for the text mining-based analytics. The sample of references included journal articles, conference proceedings, review, and book chapters, etc. Although 1,373 references or 99% of references in this sample were published in or after 2020 corresponding to the outbreak of Covid-19, it is worth noticing these earlier published studies addressing potential epidemics or pandemic that could interrupt educational work. For example, White et al. (2010) proposed the remote education approach for any possible pandemic in the future.

The literature sample was imported into VOSViewer for keyword analysis, and yielded the keyword map shown in Figure 1. Covid-19, with the largest font and circle sizes, is the most frequently studied keyword because the bibliometric search focused on the pandemic and educational sector. Figure 1 is displayed to indicate what other linked keywords had been emphasised in the existing educational studies.

Figure 1: Data visualisation of existing educational studies coping with pandemic

The distances of linked keywords also indicated the inter-correlation between keywords. For example, gamification can be co-studied with distance education or web-based learning (Guérard-Poirier et al. 2020) in response to Covid-19. Corresponding to the 106 most frequently studied keywords displayed in Figure 1, a further text-mining analysis is summarised in Table 1. These keywords were categorised into ten different clusters according to their co-occurrence or being co-studied in the literature. These

keywords in Table 1 are listed according to the cluster (C) number, together with two other attributes, namely Total Link Strength (TLS) and frequency (F) of appearing in the literature sample. TLS is the quantitative measurement corresponding to Figure 1 in evaluating the link or connection of the given keyword to other keywords. Essentially, a higher TLS value would indicate a higher influence of the keyword. The ten different clusters of keywords in Table 1 highlight the remote or distant teaching and learning in responding to the pandemic. Keywords used in these studies include mobile learning, E-learning, active learning, computer-based learning, flexible learning, hybrid learning, MOOC, open education, virtual learning, blended learning, collaborative learning, digital education, online learning, gamification, problem-based learning, student-centred learning, web-based learning, and remote teaching, etc. TLS values reveal that besides Covid-19 and pandemic, higher education, distance education, and online are the most frequently studied topics with strong linkage to other keywords. It is hence inferred that higher education or university had been the main targeted sector in educational studies amid the pandemic.

Table 1: Data analytics of keywords studied in the literature sample of educational studies

Keyword	C	TLS	F	Keyword	C	TLS	F	Keyword	C	TLS	F
Augmented Reality	1	6	7	Active Learning	3	14	18	Education Technology	6	43	49
Communication	1	8	8	Australia	3	6	6	Flexible Learning	6	5	5
Digital Competence	1	13	17	Collaboration	3	6	6	HEIS	6	5	5
Digitalisation	1	23	25	Crisis	3	18	20	Hybrid Learning	6	5	5
Engagement	1	19	20	Ecology	3	6	6	Instructional Design	6	10	10
Equity	1	13	13	Educational Innovation	3	22	22	MOOC	6	10	12
Gender	1	4	5	Experiential Learning	3	3	5	Open Education	6	7	9
Higher Education	1	312	345	Leadership	3	11	11	Virtual Classroom	6	7	7
Library	1	6	6	Pandemic	3	127	132	Virtual Learning	6	12	12
Mobile Learning	1	7	8	Pedagogy	3	57	66	Effectiveness	7	5	5
Motivation	1	8	8	Policy	3	13	14	International Students	7	9	10
Social Networks	1	8	8	Resilience	3	13	13	Moodle	7	5	5
Study Abroad	1	4	5	Social Work Education	3	7	8	Perceptions	7	6	6
Survey	1	8	8	Anxiety	4	9	10	Teaching and Learning	7	17	19
Virtual Reality	1	10	13	China	4	8	8	Whatsapp	7	6	6
Youtube	1	5	5	Covid-19	4	606	708	Zoom	7	4	5
Case Study	2	6	7	Students	4	50	52	Blending Learning	8	36	39
Challenge	2	7	7	Stress	4	10	10	Collaborative Learning	8	5	6
Creativity	2	7	7	Mental Health	4	16	16	Digital Education	8	13	16
E-Learning	2	88	96	School	4	16	16	Engineering Education	8	12	12
Education	2	71	76	Social Distancing	4	11	11	Learning Analytics	8	4	6
Learning	2	35	36	Teachers	4	12	12	Online	8	262	298
Learning Management System	2	4	5	Assessment	5	31	32	Synchronous Learning	8	5	5
Nursing Education	2	6	7	Computer-Based Learning	5	5	5	Digital Transform	9	18	18
Performance	2	5	7	Curriculum	5	21	22	Gamification	9	5	8
Research	2	6	6	Distance Education	5	135	145	ICT	9	9	10

	C	TLS	F		C	TLS	F		C	TLS	F
Social Media	2	23	24	Media-Based Learning	5	8	8	Problem-Based Learning	9	5	5
South Africa	2	4	5	Professional Development	5	12	12	STEM	9	7	8
Sustainability	2	7	8	Student-Centred Learning	5	11	12	Medical	10	30	32
Teaching	2	33	35	Teacher Education	5	19	20	Qualitative Research	10	6	6
Teaching Methods	2	5	5	Undergraduate	5	24	25	Remote Teaching	10	71	81
Tertiary Education	2	3	5	Web-Based Learning	5	19	20	Student Experience	10	6	6

Key: C denotes the cluster that the keyword belongs to; TLS means the total link strength; F represents frequency, which is the number of times that the keyword is studied from the literature sample.

Assessment, curriculum, and student feedback are also highly studied keywords in the literature. These educational activities covered different subjects such as engineering, medical, and ecology. The clusters of keywords regarding different disciplines showed that very few educational studies targeted the BE sector. Among the very few studies focusing on BE, Boton (2020) collected student feedback on BIM education in the remote approach during the pandemic. That study served as post-teaching student experience, which was one of the studied keywords according to Table 1. There is still a lack of information of how BE education could be more proactive in designing and delivering the educational work in order to enhance pedagogical resilience.

Critical analysis of education in the digital built environment sector

Following the bibliometric search related to digital BE education, a total of 265 references mainly including journal articles and conference proceedings were finalised as the literature sample. Figure 2 and Table 2 are generated following data analytics in VOSViewer. Similar to the prior round of literature review, keywords related to BIM-based digital BE education were also categorised into different clusters according to their closeness of being co-studied in the literature sample.
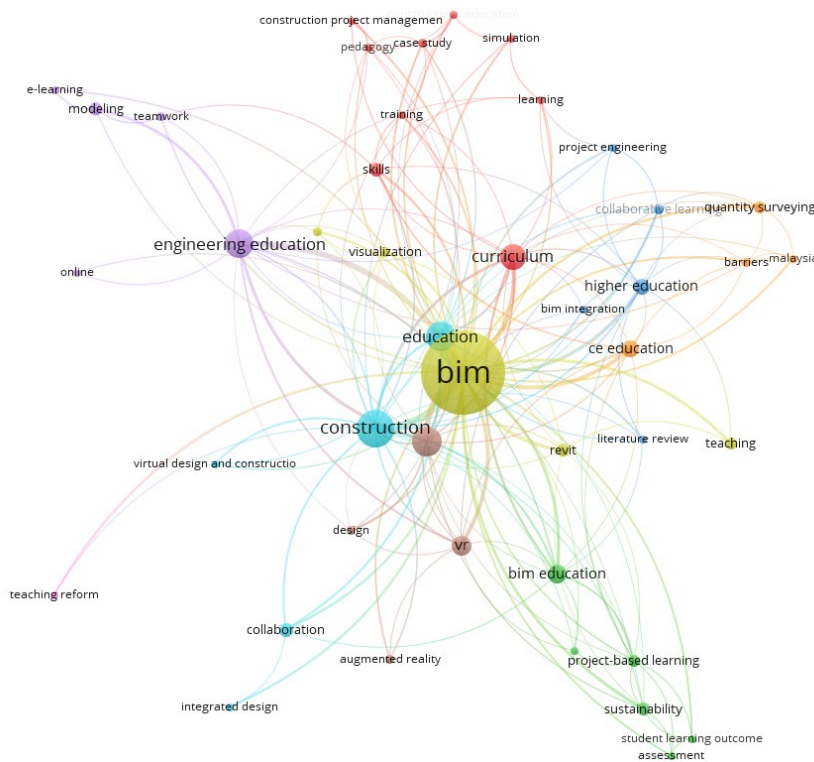

Figure 2: Data visualisation of existing educational studies in digital built environment

A new measurement item named Average Publication Year is added in Table 2 to show the recency of each keyword being published. These keyword attributes shown in Table 2 allow the longitudinal and cross-sectional comparisons.

Table 2: Data analytics of keywords studied in the literature sample of digital BE education

Keyword	C	TLS	F	Avg. Pub. Year	Keyword	C	TLS	F	Avg. Pub. Year
Case Study	1	4	4	2018	BIM	4	151	196	2017
Construction Project Management	1	3	3	2016	Problem-Based Learning	4	4	4	2016
Construction Education	1	3	3	2019	Revit	4	7	7	2016
Curriculum	1	23	24	2017	Teaching	4	5	6	2018
Learning	1	3	3	2020	Visualization	4	4	5	2013
Pedagogy	1	3	3	2015	E-Learning	5	2	3	2014
Simulation	1	3	3	2017	Engineering Education	5	29	29	2016
Skills	1	7	8	2020	Modelling	5	6	7	2011
Training	1	3	3	2018	Online	5	1	3	2020
Assessment	2	3	3	2015	Teamwork	5	3	4	2018
BIM Education	2	13	14	2018	Collaboration	6	7	8	2015
Experiential Learning	2	2	3	2018	Construction	6	45	47	2016
Project-Based Learning	2	6	6	2017	Education	6	28	31	2015
Student Learning Outcome	2	3	3	2016	Integrated Design	6	3	3	2016
Sustainability	2	7	7	2015	Virtual Design and Construction	6	3	3	2015
BIM Integration	3	2	3	2016	Barriers	7	4	4	2018
Collaborative Learning	3	5	5	2019	Civil Engineering Education	7	12	12	2019
Higher Education	3	11	11	2019	Quantity Surveying	7	5	6	2018
Literature Review	3	3	3	2019	Architectural	8	31	32	2017
Project Engineering	3	3	3	2019	Augmented Reality	8	3	4	2019
					Design	8	4	4	2020
					VR	8	13	15	2019

Note: C, TLS, and F denote the same as introduced in Table 1. Avg. Pub. Year is the term to quantify the average publication year of the given keyword, indicating the recentness of the studied keyword.

The longitudinal analysis according to the average publication year in Table 2 reveals that BIM-related digitalisation education in BE had focused more on modelling (Ave.Pub.Year at 2011) and visualisation (Ave.Pub.Year at 2013), which could be considered the fundamental functions of BIM. Collaboration and integration then became popular topics around 2015 or afterwards, highlighting the importance of cross-disciplinary coordination within BIM, and BIM compatibility with other digital tools. Student learning outcomes and assessment were also widely studied in educational research around 2015 or 2016. More recently, different teaching methods such as collaborative learning, project-based learning, and experiential learning have been more widely studied. In recent years, it is also noticed that other linked digital technologies such as augmented reality and virtual reality (VR) had been incorporated in BIM to enhance digital education of BE. Online learning, as well as skills that refer to digital literacy and competency, have been highlighted in the latest studies.

A concept of BE education resilience framework

The text-mining based reviews of the two literature samples reveal the gap between higher education sector and digital-driven BE teaching. From the overall education sector review, few studies could be found focusing on the BE subject. And among the few studies (e.g., Boton 2020) focusing on BE, there is still a lack of proactive approaches to engineer resilience into the pedagogical design and implementation to anticipate, respond, monitor, and learn from a crisis like the COVID-19 pandemic. It is argued that more educational studies in the BE subject are needed to demonstrate how to transform from reactive mechanism to proactive design and delivery of education. The second literature sample targeting digital BE education has been emphasising more on the features of different digital technologies (e.g., BIM) for being embedded in the BE subject. There are numerous studies that illustrated different features for BIM-based digital technologies to be incorporated in various BE disciplines, such as quantity surveying (Xin and Aziz 2020). But few studies on digital BE education were found for specifically responding to the pandemic, nor have they sufficiently demonstrated how BIM or other digital technologies could be embedded in higher education in response to any future pandemic. Nevertheless, the nature of digitalisation has the potential for promoting virtual pedagogy. The question remains as to whether digitalisation education in BE could be standardised for post-pandemic teaching delivery, and whether it is also discipline dependent. Both gaps and opportunities could be found from the review of BIM-featured digital BE education for post-Covid-19 pedagogy. BIM or other digitalisation courses in BE could be delivered in a virtual or blended environment, which serves as a primary means to deliver educational activities amid the pandemic.

By comparing the keywords from the two literature samples as displayed between Figure 1 and Figure 2, as well as between Table 1 and Table 2, several shared topics can be found. For example, these themes could be identified from frequently studied keywords in the two literature samples: remote or e-learning, digital platform, ICT such as VR, collaborative learning, and learning methods (e.g., experiential learning and problem-based learning). These shared topics between the two literature samples provide the list of key factors of how digital BE education could adapt itself to be more proactively resilient in the post-Covid era. These key factors can be summarised in six categories, namely adaptation of educational theories, assessment of teaching and learning, the discipline or the subject, teaching methods, delivery approach, and student experience. These six factors are illustrated in Figure 3, which demonstrates a conceptual framework to bridge digitalisation and BE educational resilience.

The two main themes (i.e., higher educational activities and digital-driven BE education) in Figure 3 correspond to the data analytics from the two literature samples. They either inform or enable the ultimate goal driven by this study, which is to develop the resilience of BE education in responding to any future outbreak of pandemic. The factors were generated from the thorough literature review of the two samples, including adapting educational theories, remote learning as the delivery approach, experimental learning as the teaching method, and research-informed teaching, etc.
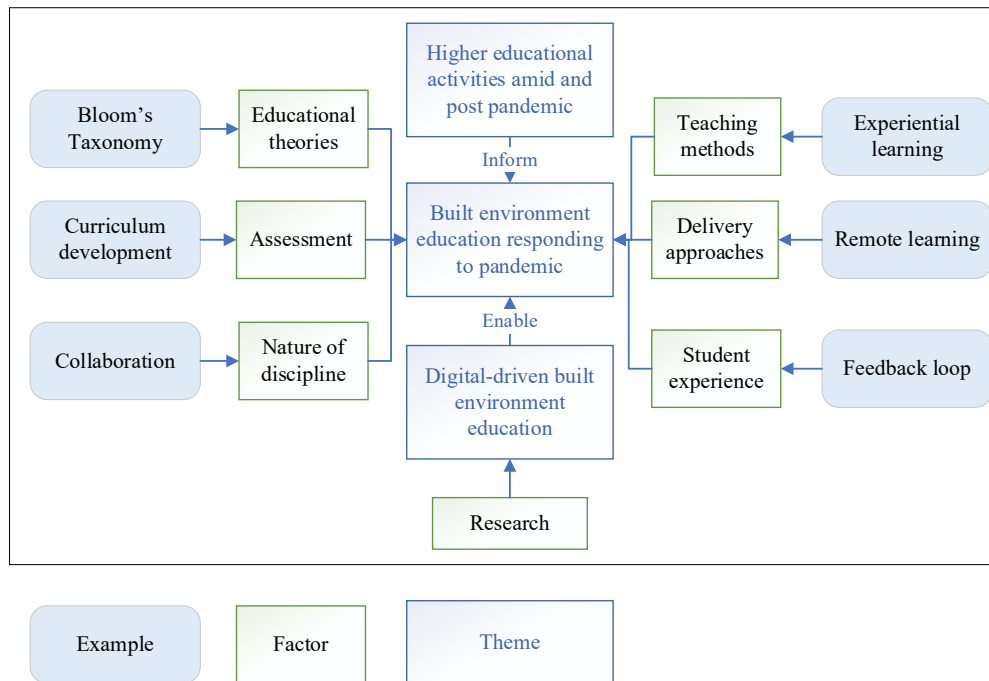
Figure 3: A conceptual framework for resilient digital-driven built environment education

These six factors shown in Figure 3 can be considered the synergy generated between the overall higher educational studies responding to a pandemic and the existing digital driven BE education, specifically: 1) the adaptation of classic educational theories can be found in several existing studies in responding to the pandemic, e.g., Oerther and Peters (2020). It is advised to design online or blended teaching activities by incorporating the different levels of student learning, involving understanding knowledge, application, analysis, and evaluation as defined in Bloom's Taxonomy (Bloom 1956); 2) curriculum development is one of the key proactive measure to prepare for any disruption such as Covid-19 that may create barriers for physical teaching. For example, flipped classroom as an alternative or mixed with traditional teaching could be designed in a curriculum as inspired from the literature sample (e.g., Revilla-Cuesta et al. 2021); 3) it is worthwhile to investigate the features or the nature of the discipline as indicated from both literature samples. BE subject is comprised of several disciplines, cross-disciplinary teaching and learning requires a collaborative approach as evidenced from existing studies (e.g., Anderson et al., 2020). It would be a challenge but also an opportunity to develop resilient yet innovative pedagogy in the digital-driven BE education which fits both physical and online deliveries; 4) a variety of teaching methods have been incorporated in educational work from both literature samples. It is not uncommon to integrate different methods of teaching in the higher education. For example, case-based and problem-based learning were designed for remote delivery, as demonstrated in Kalbarczyk et al. (2020); 5) multiple educational studies can be found by adopting remote or online delivery to reduce virus transmission during the pandemic, as evidenced from the literature sample in this study. It is recommended to consider how to balance online and physical education in the post-Covid era; and 6) student feedback forms the loop of continuous development of education resilience. Feedback loop is found as one of the emphases from the literature sample (e.g., Reinhold et al. 2021) crossing different subjects. Whilst addressing the specific features of a studied discipline or subject such as digital BE in this study, the universally learned lessons from other subjects could inform the resilient education of BE.

It is worth noticing that these six factors summarised from reviewing the two literature samples are inter-connected, for example, teaching methods and delivery approach. The current initialised framework would in future lead to further educational studies in the continuous development of digital BE that is more resilient to any interruption. More research methods could be adopted in developing the educational framework, for example, pedagogical case study.

CONCLUSIONS

This study adopted a literature review approach to investigate how the built environment (BE) education sector had and could better respond to any future interruptions such as pandemic. Two different literature samples were recruited related to the general education sector's responses to pandemic, and the BIM-featured digital BE education respectively. Although the remote-based pedagogical deliveries had been frequently studied in how the education sector had adapted teaching activities amid pandemic, very few references could be found from BE field addressing during-pandemic education delivery. A second literature review focusing on BIM-based digital BE analysed how digitalisation education had evolved since the early 2010s. BIM-related education had evolved from its initial focuses on modelling, visualisation, collaboration, and to more recently, digital skill development and integration with other Industry 4.0 technologies (e.g., VR).

Although the nature of BIM or other digital technologies enabled virtual and collaborative work, a further framework was needed to bridge the existing digitalisation education for BE and its resilience to respond to any future pandemic. The key factors or elements for enhancing digital-driven BE education were generated from the existing literature, for example, remote learning as the delivery approach, and curriculum development addressing assessments. The current conceptual framework based on the review of the two literature samples would lead to more educational studies in digital BE on how it could rely on its virtual and immersive feature to enhance its resilience. Future educational work could emphasise the resilience of BE education, for instance, standardisation of blended pedagogy enabling cross-disciplinary collaborative project-based learning.

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