Developing a Framework for Blended Design-Based Learning in a First-Year Multidisciplinary Design Course

Jac Ka Lok Leung, Samuel Kai Wah Chu, Ting-Chuen Pong, Davy Tsz Kit Ng, and Shen Qiao

***Abstract*—*Contribution:* While design project courses offer first-year students a practical introduction to engineering, a portion of class time is usually spent on lecturing foundational knowledge instead of practicing engineering design. This article presents a blended design-based learning (bDBL) approach that makes class time more efficient and explores the changes in students' design competencies and intrinsic motivations.**

***Background:* Current approaches to cornerstone courses face challenges, such as heavy faculty involvement and heterogeneity of design projects. bDBL draws on the self-directedness of blended learning and the open-ended nature of design-based learning which may be a worthwhile instructional approach for cornerstone courses.**

***Intended Outcomes:* bDBL was applied in a cornerstone course that intended to let students understand what engineers do and motivate them in the field. Students' design competencies and intrinsic motivations were examined through pre- and post-self-reported surveys. Focus group interviews were conducted to elicit students' views on bDBL.**

***Application Design:* Online self-paced learning modules were created to deliver knowledge-based content. Students transfer what they learned from the online modules through launch-level demos. Then, students spend most of the class time working on team design projects to learn through mistakes and receive first-hand feedback from peers and instructors.**

***Findings:* From Fall 2018 to Spring 2020, 201 first-year students experienced bDBL. Quantitative results demonstrated increases in students' design competencies and intrinsic motivations. Four themes representing both positive and negative views of bDBL were elicited. A conceptual framework that connects the theoretical foundation, design elements, examined effects, and students' perceptions, is proposed.**

***Index Terms*—Blended learning (BL), design-based learning (DBL), first-year engineering (FYE), multidisciplinary design.**

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I. Introduction

FIRST-YEAR design-rich courses and programmes are common in many engineering curricula (e.g., [1]–[6]) and are primarily referred to as first-year engineering (FYE) design or cornerstone design [7]. A wide variety of cornerstone design experiences are described in the literature, varying in duration, scale, and subject demographics. The University of British Columbia introduced a 5-week cornerstone design module as a quick introduction to its FYE curriculum [3], Pennsylvania State University introduced a cornerstone course for over 3600 students across 20 campuses [4] and the American University of Sharjah in the United Arab Emirates reported the successes of its college-wide first-year common core engineering course [5].

Introducing cornerstone design courses in a curriculum can aim to serve different purposes, such as improving retention [8], [9], reinforcing engineering identity [2], [8], [9], increasing learning motivation [2], improving student design and innovation competencies, and increasing motivation for engineering [6], [7].

Unlike capstone design courses, cornerstone design courses focus on a range of conceptual understandings and presentations rather than on an in-depth mastery of a specific topic or domain. These approaches are often grounded in student-centered instruction (SCI), with students empowered to influence "the content, activities, materials, and pace of learning. If properly implemented, the SCI approach strengthens retention of knowledge and increases motivation to learn" [10, p. 446]. Cornerstone design courses aim to solve real-world problems and emphasise experiential learning, which usually involves entry-level hands-on projects. However, instructors have reported difficulties associated with coping with complex course designs, demand for teaching resources, and identification of appropriate projects. The main challenges are lining up expertise from multiple faculties, fitting domain knowledge, and project construction into a limited timeframe and integrating all subject matter into a single coherent project.

To lay a foundation for first-year students to tackle design problems, familiarizing them with the *process* of designing a product is often more important than learning about the *product* itself. As such, design-based learning (DBL) is a viable approach. DBL applies "design thinking in a problem-based or project-based learning context" [11, p. 2]. It is grounded in constructionism [12], which advocates that effective learning occurs when part of the learning experience involves constructing meaningful and physical objects [12]. Despite the focus of most studies on the application of DBL in K–12 education (e.g., [13] and [14]), a growing number of recent studies examine DBL applications in university settings [15], [16].

Projects designed to be completed using DBL approaches usually feature information that students already know, which limits FYE students' opportunities to learn new engineering concepts. In this respect, adding blended learning (BL) by combining classroom interactions with online learning modules may increase learning flexibility [17]. With asynchronous online modules, learning is no longer bounded by time and space. Students can view various engineering disciplines through a wider lens, target what to learn according to their interests and learn at their own pace. Studies on e-learning often describe this process as students' self-directed learning [18]. Students gather appropriate resources and choose their preferred learning strategies with individualized learning needs and goals. Self-directed learning is "the manner in which individuals obtain new and first-hand understanding, awareness, thoughts, skills, attitudes, and experience" [19, p. 52].

BL has been incorporated in PBL and project-based learning in subjects, such as electrical engineering [20], computer science [21], and design engineering [22]. Also, there are some examples of success using BL to enhance flexible learning in Hong Kong [23], [24].

In the context of this study, the First-Year Cornerstone Engineering Design Project Course (ENGG1100) was introduced as an elective to first-year students at the Hong Kong University of Science and Technology (HKUST). The course aimed to develop students' design competencies early in the program and encourage students to pursue an engineering major.

This study developed an approach named blended DBL (bDBL), an integration of DBL and BL, to guide the design and implementation of ENGG1100. To the best of the authors knowledge, no prior work was found that reported this integration nor examined its effects. Therefore, this article examines whether bDBL provided the intended learning experiences to students over four consecutive regular semesters at HKUST by addressing the following research questions.

1) What are the effects of bDBL on students' perceived design competencies and intrinsic motivations in engineering?
2) How do students perceive bDBL?

The first question was answered by comparing the results of pre- and post-self-reported surveys before and after taking the course. Results indicated that the latter improved significantly. The third question was addressed by eliciting views from focus group interviews with students. The significance of this study lies in two folds. First, it demonstrates an application of synthesizing constructionism [12] and self-directed learning [18] theories with DBL and BL. Second, it proposes a model of bDBL as a reference for practitioners adopting similar approaches.

TABLE I
SUMMARY OF THE ENGG1100 CLASS SCHEDULE

Week	Activity	Assessment
1–3	Project brief, precursor design	None
4–6	Self-paced online learning modules	Online quizzes
7	Launch-level demos	Hands-on demo
8–9	Prototype design, feedback	Drawings, reflection, peer evaluation
10–13	Iterations, final design	Design portfolio
13	Final competition	Competition performance, reflection

II. COURSE OBJECTIVES AND INSTRUCTIONAL DESIGN

The First-Year Cornerstone Engineering Design Project Course (ENGG1100) is a 3-credit, single-semester, elective introductory engineering course offered at HKUST. As ENGG1100 has no prerequisites, it is designed for students engaging in engineering design activities for the first time. According to the course's intended learning outcomes, students should be able to achieve the following.

1) Understand some foundational concepts and applications of different engineering disciplines.
2) Apply acquired knowledge and skills to a design project.
3) Design and implement the project by working collaboratively in a team setting.
4) Explore possible innovative engineering solutions via experiential learning and self-initiated BL processes.
5) Present and demonstrate their projects orally and in writing.

A summary of the class schedule, activities, and assessment items is shown in Table I. At the beginning of the semester, the students were presented with a design project that included team-building and precursor design activities. They then learned the knowledge and skills required to tackle the design problem through self-paced online learning consisting of lecture videos, exercises, and quizzes on the Hong Kong Massive Open Online Course (HKMOOC) platform (https://learn.hkmooc.hk/). No face-to-face or synchronous online classes were conducted during weeks 4–6. Instead, all students were given an identical electronic kit to work within parallel with the online modules. In week 7, the students were assessed on their demonstration of some hands-on tasks that exemplified their understanding of the HKMOOC content. In the design phase, spanning weeks 8–13, the students experienced iterations of a design-build-improve process to improve their performance in the final competition. They were assessed on how well they reflected on their experiences in written reflections and on their design portfolios and peer evaluations. The goal was to emphasise the importance of the design process as much as the product.

The teaching team, course structure, intended learning outcomes, and areas of assessment remained the same across the four offerings. However, the instructional materials and design projects were continuously improved, and they evolved according to the context of the given semester. A total of 201 students enrolled in the four offerings. The change in the mode of instruction in the third and fourth offerings

TABLE II
OVERVIEW OF THE COURSE COMPONENTS FROM FALL 2018 TO SPRING 2020

	Fall 2018	**Spring 2019**	**Fall 2019**	**Spring 2020**
Class size	59	34	67	41
Mode of instruction	3 weeks online, 10 weeks face-to-face		6 weeks online, 7 weeks face-to-face	Fully online
Engineering disciplines	Electronics, programming, mechanics	Electronics, programming, mechanics, chemistry		Electronics, programming, mechanics
Online platform	3 core discipline-specific modules		3 core discipline-specific modules + 6 technical tutorials	3 core discipline-specific modules + 6 technical tutorials + 2 launch-level projects
Facilities	HKMOOC + makerspace			HKMOOC + Zoom
Collaborators	Faculty experts, course facilitators, instructional designer, STAs			
Design project	An airship	A chem off-roader	A multi-purpose buggy	An air-car
Design processes	Paper design - Precursor design - Prototype design - Final design			
Assessment	Online activity: 20%; Lab activity: 15%; Idea presentation: 25%; Project demonstration: 30%; Team evaluation: 10%			
Demonstration of final design	Team-based competition in campus communal area		Performance recorded for video submission	Live online relay race

(Fall 2019 and Spring 2020) occurred due to external factors. In Fall 2019, face-to-face classes were not feasible in the final three weeks of the semester due to social unrest in Hong Kong [25]. Those classes were switched to online provision and the instructors provided technical consultation via an online conferencing platform. The final assessment was changed from a competition to video submissions.

In Spring 2020, most universities in Hong Kong canceled face-to-face classes and switched to fully online teaching due to Covid-19 [26], [27]. The face-to-face sessions were replaced with synchronous online classes [28]. Electronic components were mailed to the students in parcels. The design product was changed from a team output to individual outputs constructed by the students at home. The final demonstration took the form of a synchronous virtual relay race via the students' video feeds.

Although this course arrangement could be delivered following the design elements of bDBL, whether it represented a BL approach is debatable. BL can be defined as "combining face-to-face instruction with computer-mediated instruction" [29, p. 5]. In this case, the presence of both online and face-to-face instruction is necessary. However, BL can also be described broadly as a combination of different instructional modalities and methods [30]. The adapted bDBL in this offering is a blend of asynchronous and synchronous online learning, which has been termed "bichronous online learning" [31].

The instructional design of bDBL in this study involved two major components: 1) the creation of instructional materials in an online learning platform and 2) the planning of multidisciplinary design activities and design projects. The six design elements of bDBL were "online platform," "facilities," "collaborators," "design project," "design processes" and "assessments," as summarized in Table II.

A. Online Platform

HKMOOC contained asynchronous teaching materials, such as lecture videos, tutorials, discussion forums, exercises, and quizzes. The theories and concepts taught via HKMOOC were closely relevant to the design project and the content was kept concise and practical. As first-year students have different backgrounds, the online learning approach allowed them to learn at their own pace according to their individual backgrounds and learning styles. The online platform was used for three stages of learning: 1) acquiring essential knowledge and skills through self-paced learning modules; 2) following tutorials to practise hands-on applications, such as electronic circuit assembly; and 3) using the platform as a resource library during the design process.

B. Facilities

Facilities were provided via a collaborative makerspace where the students could construct their design projects. Broadly, a makerspace, a key feature of the maker movement, is a physical workspace where individuals design their projects using shared physical or digital tools, materials, and resources [32]. Instructing in the makerspace requires advance planning of the course schedule and consideration of the limitations of the assigned project. The instructors allotted most of the class time to allowing the students to explore solutions independently and to guiding the students on the adequate use of prototyping tools to complete their design projects.

In the fourth offering, when the students could not access physical facilities, this design element was provided in the form of virtual facilities, such as Zoom,[1] which served as a virtual space for student collaborations and in-class facilitation by instructors.

C. Collaborators

The teaching team included four roles: 1) in-class facilitators; 2) faculty experts; 3) instructional designers; and 4) student technical advisers (STAs). The in-class facilitators guided the students through the design process and

[1]Zoom video conferencing platform: https://zoom.us/.

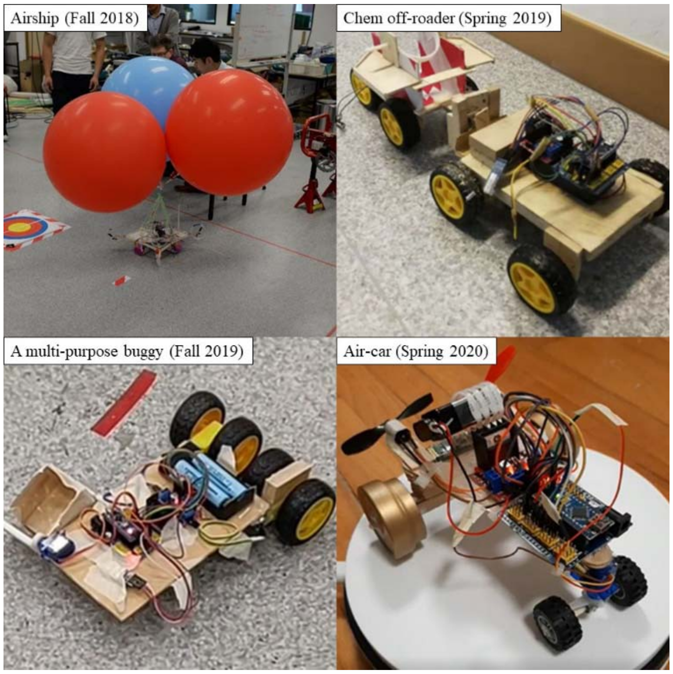

Fig. 1. Examples of students' work in ENGG1100.

provided timely feedback. The faculty experts delivered content on discipline-specific topics. The instructional designers developed, managed, and maintained the online platform. The STAs had previously taken this course and were recruited to provide technical assistance during the assembly and construction phases of the design process. In the first offering, STAs were openly recruited. Given the limited teaching resources, faculty and staff could assume multiple roles, except the STA role.

D. Design Projects

The design projects set out the scope, objectives, and goals for the students. The instructors considered relevance, difficulty, and resources when planning the projects. In this study, the project topics differed between course offerings. The project in the first offering involved the construction of an airship, which required knowledge of mechanics, electronics, and programming. The project in the second and third offerings involved the construction of a ground vehicle powered by student-constructed chemical batteries, which required additional mastery of chemical engineering. The project in the fourth offering involved the construction of an air car. The air car was a land vehicle which its thrust is created by propellers, instead of conventional motors connected to the wheel axle. The primary aim of the projects was to integrate discipline-specific and technical content with practical applications. A secondary consideration was that the projects should be achievable with the available time and resources yet challenging enough for first-year undergraduate students. For visual representation, examples of students' work from the four offerings are shown in Fig. 1.

E. Design Processes

Design processes are the systematic steps that students follow in creating an engineering artefact. In this study, they also represent the processes by which the students understood, practised, and developed design competencies. The bDBL offerings included multiple stages of design activities, such as precursor design and prototype design, to give the students opportunities to practise these processes.

F. Assessments

The assessments were mainly process based and competency based. The process-based assessments included milestones, reflections, and final outcomes. The students were encouraged to test new ideas while taking minimal risks; hence, credit was given based on the students' attempts and their reflections after these attempts, even if the final designs were not optimal. The competency-based assessments provided the students with specific feedback about their progress that could lead to better understanding of content and improved skills. Finally, essential knowledge and skills were assessed through online assignments and quizzes.

III. Method

To evaluate students' design competencies and their motivations in engineering, two surveys were adapted and administered to students before and after the course in each offering. A 22-item design competencies perceptions survey was modified from the Team Design Skills Growth Survey [33], designed by Gentili and colleagues to measure the design capabilities of students in introductory engineering design classes. In it, design competencies were identified as the demonstratable characteristics of the engineering design process, teamwork, and communication [33]. For the survey on motivations in engineering, 13 items were adapted from the Intrinsic Motivation Inventory by Ryan [34]. A short scale version of this inventory proposed by Wilde and colleagues [35] was used. The survey consists of four subscales, namely, interest/enjoyment, perceived competence, perceived choice, and pressure/tension. While the first three subscales were positive measures of intrinsic motivations, pressure/tension was regarded as the negative or reverse predictor of intrinsic motivations. The questions of the two surveys are included in Appendix.

For both surveys, students rated the level of agreement for each statement using a 7-point Likert scale, from 1 indicating "not at all true" to 7 indicating "very true." Some items were reverse coded questions (indicated in the Appendix), thus scores for these items were inverted during analysis. Results were analyzed using paired sample *t*-tests. Incomplete paired samples were removed from analysis.

Semi-structured focus group interviews were conducted to collect qualitative responses on how the students perceived bDBL. Sixteen focus groups were conducted, four in each offering, including approximately one third of the enrolled students. From the first to fourth offering, 17, 15, 15, and 13 students were interviewed, respectively. The interviews in the first three offerings were conducted in a classroom while

TABLE III
FOCUS GROUP INTERVIEW QUESTIONS

Warm up questions	
1.	Can you recall the design activities in this course?
2.	Can you briefly describe the design project?
Key questions	
3.	Are you taking (or have you taken) other engineering introductory courses? If yes, can you tell any differences in your learning experience or the way you learn?
4.	How did you use the content on HKMOOC?
5.	Do you think the content is relevant to your project? Why or why not?
6.	[Briefly explain what is blended learning] Do you think blended learning format helps you to learn more effective? Why or why not?
7.	In what ways do you think the people in this course (instructors, STAs, peers) had facilitated or hindered your learning?
8.	What are the key takeaways from this course?
9.	What did you like or dislike about this course?
10.	Overall, do you have any suggestions on how to improve your learning experience?

TABLE IV
PAIRED SAMPLE *t*-TEST OF EFFECTS OF BDBL IN FOUR OFFERINGS

			df	Mean	S.D.	*t*	Sig. (2-tailed)
Fall 2018 (n=41)	Design competencies	pre	40	5.03	0.09	2.44	0.031*
		post	40	5.25	0.92		
	Motivations	pre	40	5.61	0.64	2.5	0.016*
		post	40	5.68	0.51		
Spring 2019 (n=34)	Design competencies	pre	33	4.61	0.94	2.25	0.031*
		post	33	4.96	0.68		
	Motivations	pre	33	5.19	0.82	2.22	0.034*
		post	33	5.54	0.94		
Fall 2019 (n=40)	Design competencies	pre	39	5.14	0.75	1.71	0.044*
		post	39	5.39	0.49		
	Motivations	pre	39	4.88	0.65	1.93	0.033*
		post	39	5.04	0.54		
Spring 2020 (n=32)	Design competencies	pre	31	4.84	0.78	1.27	0.21
		post	31	4.99	0.3		
	Motivations	pre	31	4.83	0.48	3.81	0.001*
		post	31	5.18	0.48		

* $p < 0.05$

those in the fourth offering were conducted via Zoom. The same interview questions, which consisted of three parts, was used for all interviews. The first part asked the students about their experience following the class activities in chronological sequence. They were asked to compare the format of this course with other introductory courses that they were taking concurrently or had previously studied. The second part asked for their views on the instructors and interaction within their team. The third part asked for other comments and suggestions for course improvement. Table III lists the guiding questions of the interviews.

The interviews were audio recorded and transcribed. Thematic analysis was used to guide the analytical process [36]. The first author familiarized himself with the transcripts and identified preliminary patterns to formulate initial codes. The codes were refined by applying to the transcripts and cross-checked by another researcher. Key themes related to students' perceptions toward bDBL were identified, including explicit views (e.g., "the course had clear phases of work") and concrete examples of learning experience (e.g., "one of our team members seldom showed up in our meetings which made us quite frustrated"). Recurring themes were grouped into larger categories. To reduce the risk of decontextualizing the data, as the integrity and wholeness of each individual can be lost during the process of mapping codes into preordained themes [37], the data was analyzed progressively as we gained more understanding cycle after cycle.

IV. RESULTS AND DISCUSSIONS

A. Design Competencies and Motivations in Engineering

The average pre- and post-test scores of the self-reported surveys are presented in Table IV. Normality of the data was tested using one-sample Kolmogorov–Smirnov tests separately for each group. The normality of data was acceptable ($p > 0.05$). Paired sample *t*-tests of the pre- and post-test results showed statistically significances on the improvement of students' perceived design competencies in all offerings except Spring 2020, and increased intrinsic motivations in engineering in all offerings.

In Fall 2018, the average paired differences comparing post- and pre-test scores for perceived design competencies and intrinsic motivations in engineering are 0.22 and 0.07, respectively. Paired sample *t*-tests confirmed statistical significance with $t(40) = 2.44$, $p = 0.031$ and $t(40) = 2.5$, $p = 0.016$, respectively.

In Spring 2019, the average paired differences comparing post- and pre-test scores for perceived design competencies and intrinsic motivations in engineering are 0.35 and 0.35, respectively. Paired sample *t*-tests confirmed statistical significance with $t(33) = 2.25$, $p = 0.031$ and $t(33) = 2.22$, $p = 0.034$, respectively.

In Fall 2019, the average paired differences comparing post- and pre-test scores for perceived design competencies and intrinsic motivations in engineering are 0.25 and 0.16, respectively. Paired sample *t*-tests confirmed statistical significance with $t(39) = 1.71$, $p = 0.044$ and $t(39) = 1.93$, $p = 0.033$, respectively.

In Spring 2020, the average paired differences comparing post- and pre-test scores for perceived design competencies and intrinsic motivations in engineering are 0.15 and 0.35, respectively. Paired sample *t*-tests showed no statistical significance for perceived design competencies with $t(30) = 1.27$, $p = 0.21$. However, statistical significance was confirmed for intrinsic motivations in engineering with and $t(30) = 3.81$, $p = 0.001$, respectively.

The positive outcomes suggest that bDBL can be adopted for design competencies development. The results were consistent with other studies in the literature which used design-based instructional strategies [38], [39]. Team-based design projects with opportunities for formal and informal presentations increased effective communication and teamwork competencies. Immersing students in active discussions on open-ended and real-world design problems is an effective means to cultivate design competencies.

TABLE V
STUDENTS' PERCEPTIONS OF bDBL BY THEMES

Theme	Sub-theme	Description	Code for positive views	Code for negative views
Outcomes	Tangible	Learning outcomes that can be measured or assessed	Multi-disciplinary knowledge, hands-on skills, learning the engineering design process	
	Intangible	Outcomes operationalised on the level of perception	Motivation to explore, communication skills, teamwork skills	Heavy workload, stressful environment, less confident in subject
Content	Online	Content delivered through the asynchronous online platform	Flexibility to learn, easy to use, useful functions	Difficult to adapt, confusing instructions, difficult to navigate
	In-class	Content delivered in face-to-face (or synchronous) classes	Useful advice, interesting topic	Irrelevant topic, lack of follow-up after asynchronous online modules
Engagement	Teacher-student	Quality of teaching, instruction and quality of support	Proximity with teachers, low power distance, clear instructions	Confusing instructions
	Student-student	Experience related to working in teams and peer learning	Learn from peers, share workload, achieve more than individual	Dealing with free-loaders, peer pressure, sense of unfairness
Organisatio n	Design project	Organisation and arrangements of the design project	Clear phases of work, integration of subjects	Uneven workload, confusing and sudden changes
	Blended learning	Interface between asynchronous online and face-to-face (or synchronous) sessions	Smooth transition, theory to practice	Disconnection between modes

The result in Spring 2020 was positive yet did not reach statistical significance may be explained by the difference in design experiences students had at home compared to working in a makerspace. In face-to-face setting, bDBL uses makerspace as the main learning facility. Previous studies argued that learning activities in makerspace can support effective development of design competencies.

Two foremost evident features of bDBL that can promote student motivations are its student-centeredness and active learning approach. Many studies had explored the affordances of and made comparisons between student- versus teacher-centered and active versus passive learning approaches (e.g., [40]–[42]). Most argued that student-centered approaches are shown more effective in terms of students' intrinsic motivation to learn, understanding of content, retention of knowledge, and students' achievement [40]. bDBL follows this notion. First, it utilizes self-paced learning modules which provide opportunities for students to learn independently as compared to whole class knowledge transmission. Second, it involves hands-on and authentic projects to enhance engagement as compared to teacher-led instruction and academic content which is inherently dull. Third, the design projects also enable cooperative learning among student teams for setting common goals, explorations, experimentations, and co-construction of meaning.

Moreover, studies reported on active learning environments also advocated that students are more intrinsically motivated in contrast with passive learning [43], [44]. bDBL takes away traditional lecture-style instructions and lets students actively participate in the design processes then provide just-in-time formative feedback to help students reflect-on and -as they learn. Further, the course content ought to be applicable and sense-making to students' cornerstone design projects.

B. Students' Perceptions of bDBL

In the focus group interviews, the students provided many examples of their learning experiences in the cornerstone course. Themes on students' perceptions were reviewed and redefined by summarizing transcripts of all student interviews. Four main themes emerged, encompassing different areas of the students' positive and negative feedback: 1) outcomes; 2) content; 3) engagement; and 4) organization. These themes were each divided into two subthemes, as shown in Table V. These subthemes are not necessarily the opposites of the other, but more concise categorizations of which part or feature of bDBL the students had referred to.

The "outcomes" theme concerns what the students learned from the experience. Tangible outcomes can be measured by objective tests and assessments, whereas intangible outcomes refer to more subjective perceptions that cannot be quantified through assignments or tests. Most of the students enjoyed exploring different areas of engineering and gained experience in a hands-on project. Immersing the students in every step of the design process also enabled them to understand the role that it plays in engineering. This notion agrees with findings from another study, which suggested that an engaging and collaborative environment not only supports the development of professional practice but also enhances student motivation and persistence in engineering [45]. One student stated:

> "It provides us with knowledge in various streams ... This is especially helpful for first-year students, as we have an undeclared major … it ultimately it helps us make up our mind as to which major to choose in the future."

"Content" captures the students' views about platforms, systems, and instructional materials for learning. Online content in this context is the asynchronous HKMOOC platform, and in-class content is what the instructors delivered during the face-to-face or synchronous online sessions. Mixed views on online learning were elicited. Some of the students claimed it provided the flexibility to learn. A student stated:

> "I can learn anywhere, anytime. I sometimes still go back to the online modules for reference."

However, some had difficulty adapting and lost the motivation to continue.

> "Having further explanations of the online course topics can save me a lot of time from searching for answers on the Internet on my own."

This finding supports the claims of previous research about online learning [46], [47]. Online learning platforms, such as HKMOOC, offer access to and tools for a high volume of knowledge, yet a lack of motivation, retention, and interaction are often barriers to online learning. For in-class content, most of the students preferred conversations and receiving advice from their instructors rather than listening to lectures. In contrast, some of the students felt that learning from the online platform was no different from learning by themselves, and they preferred being taught in class. One student said:

> "I think the basic knowledge should be taught to us (in class) first. But I actually feel that I learned everything by myself in HKMOOC."

Indeed, creating an effective self-directed learning environment requires not only a shift in physical class arrangement and teaching content, but also alignment with learners' preferences, attitudes, and past teacher-directed learning experiences [48]. The transition from teacher-directed to self-directed learning may be daunting for some students. Previous study argued that increasing students' awareness of the concept of self-directed learning could positively reinforce this transition [48].

"Engagement" refers to the students' perceptions of the quality of engagement with teachers and peers. Teacher–student engagement concerns the quality of teaching, instruction, and support; student–student engagement involves how students learn from each other in a team. Although a few of the students felt slightly confused when inconsistent feedback was given by different instructors, nearly all of the interviewees agreed that they experienced more personal interactions with the instructors than in other courses in terms of both time and quality. An exemplary response as follows:

> "I think one good thing about the course is the teachers and STAs. Usually, we listen to lectures then revise by ourselves. The teachers and STAs in this course can guide me through the questions."

This is not surprising because "teachers as facilitators" has been widely advocated in studies of constructivist learning (e.g., [49] and [50]). In addition, the students perceived the STAs as highly approachable for quick advice and technical support. Having senior students provide teaching support or some form of mentorship is a common practice in team-based first-year programmes (e.g., [51]). bDBL advances the constructivist learning concept by allocating maximum in-class time to instructor–student interactions and increasing the proximity of instructors and students with the help of STAs.

Regarding student–student interaction, the respondents offered polarized views on team dynamics. bDBL places great emphasis on team collaboration because collaboration is an essential component of design competencies and is regarded as one of the skills necessary for the 21st century [52]. Some of the students struggled to manage problems that arose in teams, such as issues with free-loaders, peer pressure, and conflict between teammates, whereas others expressed that their teams achieved more than they could have done as individuals. Unlike task-oriented teams in which work can be clearly distributed, student teams in bDBL require high commitment and intensive collaboration to succeed at every stage of the engineering design process. Any team members not pulling their weight will significantly affect the entire team's learning experience.

The "organization" of the design project corresponds to how well the subjects were integrated and disseminated to the students, and the organization of BL relates to whether there was a smooth transition between the online and face-to-face sessions. Most of the responses regarding how the design project was organized were positive, as the students could make sense of what they were learning and created a clear goal for the course. A student said:

> "At first, I struggled in the launch-level demo, but I realized this was important for me to work on my project."

However, a few of the responses mentioned an uneven workload weighted toward the final competition. One respondent suggested announcing the design requirements of the final project early in the semester to enable planning ahead of schedule.

Most of the students mentioned that the in-class activities that checked their understanding of the online modules provided a smooth transition from the online to in-class sessions. However, a few claimed to feel a disconnection between modes. One gave an example of learning about momentum in the online mechanics module but being unable to readily apply this knowledge as the students were not asked to demonstrate momentum in their project. A limitation of bDBL is that the content covered online cannot always be demonstrated in the design project, depending on how the project is scoped and what design solution is generated by the teams.

C. bDBL Framework

A conceptual framework of bDBL summarizing our work is illustrated in Fig. 2. bDBL is a learner-centred approach based on two learning theories: 1) self-directed learning [20], [53] and 2) constructionism [12]. Its integration of online learning and DBL explains the overlapping part of the two circles as shown. Within the overlap are the design elements of bDBL, described by six components: 1) online platform; 2) facilities; 3) collaborators; 4) design project; 5) design processes; and 6) assessments. Regardless of whether the mode of instruction was blended or fully online, all design elements of bDBL were consistent though particulars were adjusted to adapt to different situations. Findings from this study reveal that bDBL benefits students in both cognitive and

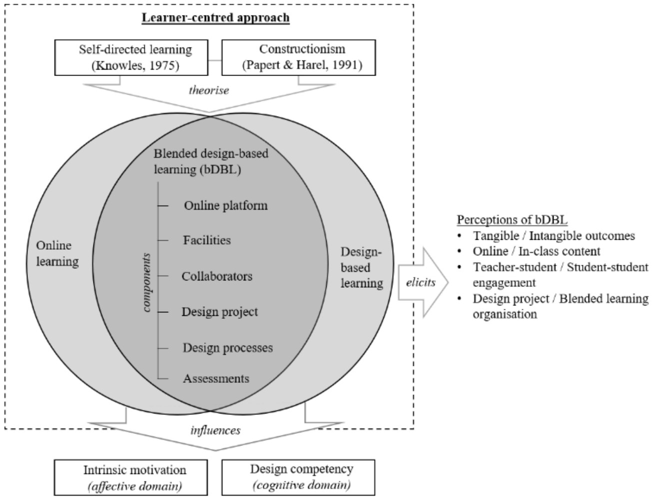

Fig. 2. Conceptual framework of bDBL.

affective domains. Cognitive domain refers to students' perceived design competencies, and affective domain as regards to students' intrinsic motivation in engineering. Finally, the themes arising from the students' perceptions are listed on the right.

This framework depicts the connections between the theoretical foundation, design elements, examined effects, and students' perceptions of bDBL. It may be used in future pedagogical development, instructional design, and evaluation for instructors intended to adopt similar approach. New insights shall be uncovered as this framework is applied in more contexts.

V. Conclusion

This study describes a cornerstone design course that used a bDBL approach. The approach was implemented through different modes of instruction in four semesters, which demonstrates its adaptability and potential. The careful selection of a design project and the establishment of an appropriate scope for students are paramount for bringing seemingly disparate pieces together. This course fills a gap in FYE education by integrating self-paced online modules and hands-on multidisciplinary design experience. Students indicated improvements in the effects examined. The themes revealed and the students' perceptions facilitated the development of a clearer understanding of the advantages and shortcomings of bDBL. The proposed conceptual framework summaries our work over the past two years and provides a guide for further research. Details of the course's instructional materials and arrangements are available upon request for colleagues looking to implement a similar course.

While bDBL was applied in face-to-face delivery and fully online settings, the potential differences in students' attainment of learning outcomes need to be further explored. Future work includes comparing effects with other introductory courses, examination of the impacts of class size, and integration of bDBL to wider engineering disciplines.

Appendix
Perceived Design Competencies and Motivations in Engineering Survey Questions

DESIGN COMPETENCIES	
1	I participate effectively in a team.
2	I understand my own and my team's style of thinking and how it affects teamwork.
3	I understand the different roles included in effective teamwork and responsibilities of each role.
4	I can gather information, use various sources and techniques, analyze validity and appropriateness.
5	I use important visual and oral techniques (questioning, observing) for information gathering.
6	I use resources (e.g. internet) effectively in accessing relevant information.
7	I can define design problems, which includes specific goal statement, criteria and constraints.
8	I understand the open-ended nature of design problems (no right or wrong answers).
9	I recognize the importance of problem definition for development of an appropriate design.
10	My team utilizes effective techniques for idea generation.
11	My team brainstorms effectively.
12	My team identifies and utilizes environments that support idea generation.
13	My team utilizes critical evaluation and decision making skills and techniques, including testing.
14	My team follows an iterative approach that employs evaluation repeatedly in their design process.
15	My team applies simple matrix techniques for evaluating proposed solutions.
16	My team implements a design to a state of usefulness to prospective users.
17	My team manages time and other resources as required to complete our project.
18	My team follows instructions provided.
19	I communicate with team members at all stages of development and implementation of design solutions.
20	I practice effective listening skills for receiving information accurately.
21	I give and receive constructive criticism and suggestions.
22	I communicate geometric relationships using drawings and sketches.
MOTIVATIONS	
1	While I am working on engineering tasks, I think about how much I enjoy it.
2	I do not feel at all nervous about doing engineering tasks.
3	I feel that it was my choice to study engineering.
4	Engineering is something that I cannot do very well (reverse item)
5	Engineering activities did not hold my attention at all (reverse item)
6	I feel relaxed while doing engineering tasks.
7	I think I do pretty well in engineering, compared to other students.
8	I enjoy engineering very much.
9	I am satisfied with my performance in engineering.
10	I feel like I am doing what I want to do while I am working on things related to engineering.
11	I feel pressured while doing engineering tasks. (reverse item)
12	I feel like I have to take engineering. (reverse item)
13	I would describe engineering as very enjoyable.

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