frontiers | Frontiers in Education

CURRICULUM, INSTRUCTION, AND PEDAGOGY
published: 16 May 2022
doi: 10.3389/feduc.2022.860097

Design-Based Learning as a Pedagogical Approach in an Online Learning Environment for Science Undergraduate Students

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Design-based learning (DBL) is a learning strategy that requires students to use their theoretical knowledge to develop an artifact or system to tackle a real-life problem. DBL has long been utilized in design-related curricula in higher education such as engineering, computer science, and architecture. However, little is known about how DBL in non-design-based courses enhances students' learning experience, especially in recent years when the COVID-19 pandemic has compelled the worldwide education systems to adapt to online learning. Hence, this study aims to investigate the experience of science undergraduate students after one semester of participating in online DBL. The participants include 25 second-year science undergraduate students enrolling in the Managing New Technologies course. Using semi-structured interviews and thematic analysis, the findings of this study indicated that online DBL contributes to easy access to learning, enhances creativity, and allows students to think outside the box. Nevertheless, students highlighted online learning as an obstacle to their DBL experience. They claimed that online platforms as a means of communication are not practical due to insufficient interaction time and misunderstanding of information. In addition, some students stated that the online environment poses difficulties for collaborative learning.

Keywords: pedagogy, design based research, online learning, non-design based courses, higher education

OPEN ACCESS

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Specialty section:
This article was submitted to Higher Education, a section of the journal Frontiers in Education

Received: *22 January 2022*
Accepted: *11 April 2022*
Published: *16 May 2022*

Citation:
Azizan SA and Abu Shamsi N (2022) Design-Based Learning as a Pedagogical Approach in an Online Learning Environment for Science Undergraduate Students. Front. Educ. 7:860097. doi: 10.3389/feduc.2022.860097

INTRODUCTION

Design-based learning (DBL), also known as design-based science (Fortus et al., 2005; Vattam and Kolodner, 2006), design science research (Peffers et al., 2007), or learning by making (Shanta and Wells, 2022), is a learning method where students evaluate their understanding through design. Using their knowledge, students provide a solution by participating in designing activities (Felix, 2016) — a learning strategy that is frequently linked with design and technology education (Zhang et al., 2020) — to solve real-world problems through the construction of innovative and creative products.

According to Joordens et al. (2012), DBL enhances students' imagination, creativity, and talents while improving higher order thinking and understanding. Studies have shown that students improve their systems thinking, transdisciplinary activities, and collaborative skills through DBL (Wells, 2016; Baron and Daniel-Allegro, 2019; Huang et al., 2019), which further allows them

to apply concepts in various contexts. However, the nature of teaching and learning has altered due to rapid advancements in information and communications technology. The introduction of a new teaching and learning environment known as online learning has been facilitated by the digital transformation of education systems at all levels. It is a web-based system that uses digital technology with a range of web-based educational resources to provide students with an open, interactive learning environment that helps them learn more effectively (Rodrigues et al., 2019). At present, online learning is a form of education where students pursue learning activities digitally rather than in a traditional classroom setting.

While lecturers and students will benefit from online learning through the use of digital technology that provides insightful lessons, self-directed learning development, and interactive environments, online learning may still be a problem for those who do not have access to proper digital tools. This is further worsened by the coronavirus (COVID-19) pandemic, which has caused higher education systems worldwide to adopt online learning and impacted the students' mental health, study-life balance, and academic engagement.

Research by Irawan et al. (2020) shows online learning during the COVID-19 pandemic greatly effect students' mental health. They found that after 2 weeks of participating in online learning, students reported experiencing emotional instability, a lack of enthusiasm, and anxiety disorder. AlJhani et al. (2021) found similar results. Their study on medical students across Saudi Arabia found that 94.4 percent of respondents reported moderate-to-high stress levels due to the changes from normal classrooms to online classes during the COVID-19 pandemic.

Based on a study conducted on 367 Malaysian tertiary education students by Moy and Ng (2021), the sudden transition from face-to-face lectures to online classes, coupled with students' insufficient knowledge of information technology, hinders students' ability to adapt to the online environment, leading to a reduction in academic engagement. Meanwhile, Aguilera-Hermida (2020) and Farrell and Brunton (2020) reported that the most difficult problem students had during online learning due to COVID-19 was balancing between studying and daily life activities. There were numerous distractions, including family and household chores.

Since DBL in traditional classrooms has improved student skills and fostered collaboration (Wells, 2016; Baron and Daniel-Allegro, 2019; Huang et al., 2019), it is crucial to investigate the DBL experience of students in an online learning environment. Furthermore, as previous research has predominantly focused on engineering education or design-related courses, such as computer science and architecture, where the students are often trained in digital tools and software, it would enrich the field to explore DBL in the context of non-design-based courses.

AN OVERVIEW OF DESIGN-BASED LEARNING AS PEDAGOGY

Design-based learning is based on the constructionist theory, which states that learners construct knowledge rather than passively taking in information. While it highlights the importance of producing or engaging in designing activities as a means of learning, the design process also offers a valuable learning environment. Therefore, DBL values both the learning process and its outputs or products. DBL was created in the 1980s, and it was initially used in high schools to educate science and develop design skills (Doppelt et al., 2008). Designers (learners) build products or artifacts that symbolize a relevant learning output, and this is an active learning process that puts students at the center, encouraging them to participate actively in class. Briefly, in DBL, students are taught to develop prototype models or artifacts of a problem-solving solution. It is a teaching technique that helps students generate creative products and improves their willingness to study (Ahmad Alif and Syahrul Nizam, 2019).

This pedagogical approach combines problem-based learning with project-based learning in which students apply theoretical information obtained in the classroom to design products, systems, and inventive solutions (Gómez Puente et al., 2013; Zhang et al., 2020). DBL has been utilized in design-related courses in higher education such as engineering, computer science, and architecture; nonetheless, courses other than design such as science, accountancy, and social sciences have recently begun to incorporate DBL into their curriculum (Ford et al., 2017; Tang and Sun, 2017; Fried et al., 2020; Zhao et al., 2021).

The literature has discussed good learning outcomes from DBL as a student-centered approach. Besides fostering collaboration, DBL also allows students to learn at their own pace, encourages transdisciplinary learning and cooperation, stimulates creativity, and increases student confidence (Raber, 2015; Chen and Chiu, 2016; Zhang et al., 2021). Since the complexity of a task usually involves collaboration and specific responsibilities, students can become "experts" in a specific area by establishing goals and constraints using representational approaches, idea development, and prototype construction for design projects. As a result, students can work in groups, share information, and develop their abilities (Doppelt et al., 2008). DBL also helps improve students' cognitive and social abilities, for instance, public speaking and critical thinking skills during an oral presentation by defending and justifying their products and how they fit the standards. Ultimately, this helps enhance their interpersonal communication and problem-solving skills (Doppelt, 2006; Zhang et al., 2021).

ONLINE LEARNING

The digital transformation of education systems worldwide has facilitated the introduction of a new teaching and learning environment known as online learning or electronic learning (e-learning), which allows students to share information regardless of their locations. Owing to its flexibility in delivering and accessing learning content, online learning also enables students to study whenever and wherever they want.

Various studies have highlighted the benefits of online learning. For instance, online learning enables self-paced learning that fosters lifelong learning (Njenga and Fourie, 2010;

Al-Fraihat et al., 2017), while the internet and multimedia technologies in the classroom have increased delivery and learning accessibility (Elfaki et al., 2019). Roddy et al. (2017) also outlined four pillars to ensure student success in online classes: (i) academic supports through easy access to online academic resources and student-instructor interaction opportunities; (ii) technical assistance that helps students prepare for online learning; (iii) support for health and wellbeing, (iv) a sense of belonging to a community in terms of how students interact with their peers, lecturers, and the environment.

Nevertheless, according to Roddy et al. (2017), technical difficulties, confusion with the learning content, balancing between study and family responsibilities, perceived isolation, and a lack of motivation are among the difficulties of online learning that should be considered. This includes communication and engagement between teachers and students, which is a barrier in the online learning environment (Alawamleh et al., 2020). In addition, Dumford and Miller (2018) also asserted that online learning hinders students' collaborative learning experiences by resulting in lower-quality interactions.

DESIGN-BASED RESEARCH FRAMEWORK

Design-based research methodology entails a research design that combines design and scientific methods to create new theories, artifacts, and practices (Easterday et al., 2014). According to Amiel and Reeves (2008), the design-based research approach involves four phases:

1. An analysis of real-world issues.
2. Solution development based on existing design concepts and technological advancements.
3. Evaluating and refining solutions in iterative cycles.
4. Reflection to develop design ideas and improve solution implementation.

These phases are systematic yet flexible, and the principles are adjustable and feasible for others interested in studying similar settings. However, despite a variety of design-based research processes highlighted in the literature, there is no one-size-fits-all design-based research process as the planning and implementation of research projects differ depending on the situation (Rossi, 2021) and can, therefore, change depending on the design goals and circumstances. Nonetheless, many of these design-based research frameworks have been discussed in the context of related technical activities such as engineering, information science, and computer science where the students are mostly equipped with digital tools and software training (e.g., Peffers et al., 2007; Wyk and Villiers, 2014; Geitz and de Geus, 2019).

A combination of design learning frameworks proposed by Peffers et al. (2007), Wyk and Villiers (2014), and Geitz and de Geus (2019) were adapted according to the suitability of this study. This new design-based research process involves five phases: (i) identify problems in the context of current situations and generate ideas; (ii) define a solution's objectives; (iii) design and development; (iv) demonstration and reflection; (v) communication and evaluation. Specifically, the design-based research process focuses on identifying issues in situations at present and producing innovative ideas to encourage students to design a solution based on their critical-thinking abilities. As the study was conducted in an online learning setting where face-to-face interactions are limited, it is essential to integrate communication and evaluation to allow students to interact with their lecturer and peers as well as examine whether or not the objectives and outcomes of the assignment have been met.

Based on the above discussion, the five phases of the synthesized generic design-based research model were applied in the learning process of university undergraduate students. Additionally, the following research questions were used as guides to explore the experience of students participating in online DBL:

RQ1: How does online DBL benefit students?
RQ2: What are the challenges faced by students in online DBL?

LEARNING ENVIRONMENT

This qualitative study was employed to investigate the benefits and challenges faced by students during online DBL. According to McGrath et al. (2019), qualitative research interviews are appropriate for gathering informative insights into people's experiences and allow in-depth analysis from a small sample size. The participants for this study were 25 second-year science undergraduate students enrolling in the Managing New Technologies course. Managing New Technologies course is the elective program course to provide students with knowledge on the nature of new technologies and the importance of technology management. Throughout the semester, the lecturer explains various concepts and theories related to technology management in the class. This helps students to understand the scenario. Due to the recent COVID-19 pandemic, all teaching and learning activities in the university have shifted to online learning; therefore, the course was entirely delivered online *via* google meets apps.

As a component of their assessment, students were given a group task to design a prototype for solving a real-world problem, focusing on the process of design and the techniques used to come up with innovative ideas. Students were given autonomy to choose their group members. A typical group consists of five members in a group. In the group, they identified the problem they wanted to solve. At the end of the semester, students need to orally present innovative solutions to explain the product, types of innovation they used to develop solutions, and SWOT (strengths, weaknesses, opportunities, and threats) analysis. In other words, the presentation's content should relate the design with the students' theoretical knowledge. **Table 1** describes the framework of the design-based research process applied during the DBL.

Interviews were done a week after the project presentation. Each interview session lasted approximately half an hour to an

hour. Students were informed before the interview that their participation was entirely voluntary and that the interview would not be used to evaluate them. Before the interviews, an informed consent form was given to the students. The interviews were done in groups depending on the project groups of the students. A group interview is an interview method that involves a group of people at the same time, whether in a formal or informal (Fontana and Frey, 2000). Typically, group interviews were performed to reminisce about events that the respondents had in common. This type of data collection is flexible, low in cost, and provides rich data. However, as Fontana and Frey (2000) point out, findings from group interviews cannot be generalized since individuals may dominate the group, resulting in "groupthink."

Some of the open-ended questions that were asked are: (1) What do you like about DBL?; (2) How does DBL contribute to your learning development?, and (3) Please share your experience regarding the online DBL experience. Thematic analysis was used in the data analysis process. To develop similar themes, the coding was done manually following Braun and Clarke's (2006) six-step framework (i.e., familiarizing yourself with the data, creating codes, searching for themes, reviewing themes, defining themes, and writing up). During the coding process, research questions were used as a guide. The coding process began with the generation of initial codes after becoming familiar with the transcripts. Both researchers went through each transcript, coding every section of the transcript that related to the research questions. Both researchers compared the codes and the coded section and discussed how to achieve the agreed codes for the data. Following this, the researchers again coded the coded sections with the agreed codes only. Finally, both researchers grouped the codes into possible themes. Based on Braun and Clarke (2006), the themes were then reviewed to ensure that the coded data was relevant and supported the themes. Five themes were identified from the transcripts: i.e., online learning setting, enhanced creativity, collaborative learning, human interaction, and thinking outside the box. The following section explores these themes.

TABLE 1 | Application of the design-based research process.

Phase	Activities
Identify problems in the context of current situations and generate ideas	• At the beginning of the semester, the lecturer introduced the course, and throughout the semester, the lecturer explained various concepts and theories connected to technology management. This facilitates the students' understanding of the scenario. • Students worked in groups to identify the problem they intended to solve. Students were given the option of selecting their preferred group members. • To create innovative designs, students performed background studies to explore alternative solutions.
Define a solution's objectives	• Students need to specify the solution or the design to be produced. • Students present their idea/proposal and modify their idea based on the feedback from peers and the lecturer.
Design and development	• Students begin designing their prototypes. • The lecturer monitors their progress through online tutorial classes. • Students in groups need to write and verbally report on their progress. • Student design must be completed by the final week.
Demonstration and reflection	• During the final week, students in groups present their designs online and explain how the theories learned in class were applied to the design.
Communication and evaluation	• Question and answer sessions were also held to allow lecturers and peers to understand the design produced. • Students submitted their finished work to an online platform for grading by the lecturer.

RESULTS

Online Learning Setting

The students deemed their online DBL experience enjoyable because it allows for easy access to learning and project materials.

"Accessibility is another advantage of online design-based learning, both in terms of time and space."

"...we can google information and watch videos that help broaden our ideas to increase our creativity."

Nevertheless, the students highlighted the inconsistent internet line as an obstacle to their studies.

"An online class is a bit stressful because some students have internet connection problems, so we cannot focus during our lecture due to the surrounding noises that can disturb our concentration."

"Online learning only left us sitting for hours in front of the screen, expecting us to focus and complete all our assignments, which can be ridiculous sometimes."

Enhanced Creativity

Based on the data, online DBL enhances students' creativity by allowing them to use their imaginations in the project and helping the students broaden their ideas about innovation.

"It (online DBL) makes us more creative, and we find that, nowadays, it is important to have designing skills. Besides that, design-based learning helps broaden our idea about innovation."

"It (online DBL) is unlike any other assignments that we have done so far as it boosts our creativity skills and offers a different approach to learning technologies."

"We get to apply the theory we learned more creatively."

"We also like that we were given a chance to design our very own product according to our likings."

Collaborative Learning

According to the students, the advantage of online DBL is that they no longer need to travel anywhere for a discussion. The students also said they could share tasks and learn from their team members because every team member has different necessary skills to design the prototype.

"We can communicate and collaborate with our group members and brainstorm among ourselves."

"So, by having a team, they (team members) can share the task and complete it together."

"(Online DBL) Allowing students to tackle more complex problems than they could on their own — to delegate responsibilities."

Nonetheless, although working in a group has its advantages, some students mentioned the difficulties in collaborating online. According to the students, they quickly became bored during online group discussions due to being in front of the screen for an extended period. Some team members might also be left behind due to connectivity problems, which causes discomfort to the group. Moreover, online group discussions can also increase the possibility of being distracted by other online sites.

"Internet connection differs from one student to another, which means that during group work (discussions), a team member may get left behind while others are busy discussing the matter."

"(It is) Difficult for students to discuss desired products and design with their group members online or *via* a video call because not all of them have a good internet connection."

"We also find it hard to focus in class since there are a lot of distractions such as an unstable internet connection. In fact, we do not have face-to-face classes — this makes it easier for us to lose focus because there is not too much engagement."

Human Interaction

The students claimed that online platforms as a means of communication are not practical due to insufficient interaction time and misunderstanding of information. Besides, according to the students, it is challenging to stay focused during learning without the actual presence of their lecturers and classmates. The students also reported that they lack motivation and feel isolated due to this limitation.

"With traditional learning, communications between students and lecturers as well as among students will be easier. Students can easily ask lecturers any questions and have effective communication."

". . .it is hard for us to focus in class since there are a lot of distractions such as an unstable internet connection. In fact, since we do not have a face-to-face class, it is easier for us to lose focus because there is not too much engagement."

". . .it is harder (for us) to concentrate in class during online learning due to the lack of human interaction, body language, and physical learning atmosphere."

Think Outside the Box

According to the students, DBL allows them to view objects beyond their physical appearances. In fact, such a pedagogy helps students go beyond their typical learning and stimulate their thinking.

"(Online DBL) Helps us to think outside the box and be more observant of our daily life."

"(Online DBL) Indirectly explains that every problem has a solution where we are required to identify a problem and a solution for it."

"We will not see a product as just one product, but we will see a product as an achievement in fulfilling all the aspects involved."

"It (online DBL) makes us creative, and we find that it is important to have designing skills nowadays. Besides that, design-based learning helps us broaden our ideas about innovation. . .."

"(Online DBL is) Interesting and fun because we get to challenge our creativity and certain skills such as critical thinking skills."

DISCUSSION

Overall, most of the students had a positive experience in online DBL and acknowledged its benefits. Based on the findings, the students deemed their online DBL experience enjoyable and exciting because the pedagogy takes a distinct learning approach. Design-based activities also permit them to develop products based on their interests, thus allowing them to employ their imaginations in the creation process while broadening their understanding of innovation and managing new technology. Ultimately, DBL develops students' metacognitive skills and enables them to see objects beyond their physical appearances. This finding was aligned with a study by Joordens et al. (2012), who stated that DBL improves students' creativity and imagination.

Meanwhile, working in a team implies both advantages and disadvantages in this situation. Even though teamwork encourages responsibilities and learning with complementary skills possessed by each individual in the team, collaborative learning is not easy for some of the team members because some of them might be left behind, for instance, due to connectivity issues. Besides, collaborative learning tasks are not only focused on getting the job done but also on the experiences and decision-making of the team members; hence, their commitment from the beginning of the project is necessary.

Nonetheless, the students highlighted the challenge of remaining engaged in learning without the physical presence of their lecturers and classmates. Even though online learning offers borderless online activities, it tends to hinder lecturer-student interactions, thus making the students feel isolated and demotivated. This is agreed to in the study by Alawamleh et al. (2020) that showed online learning has a negative effect on lecturer-student interactions.

Evidently, DBL is a type of pedagogical learning that allows students to apply prior knowledge and problem-solving abilities. Simultaneously, it enhances students' talent and creativity through gathering information from various resources and developing solutions through a design. While the findings of this study suggest that students recognize the advantages of DBL, most of the challenges related to DBL could still be attributed to online learning. Indeed, the online environment hinders their collaborative learning and self-motivation.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Chairperson, Malaya Research Ethics Committee (Non-medical). The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

SA wrote and refined the introductory, result, and discussion sections. NA wrote and refined the study's background, design, and conclusion sections. SA and NA wrote and refined the description of the design-based research methodology section. Both authors involved in preparing the manuscript.

FUNDING

This research was funded by the UM-Liter Grant, 2021, the Academic Enhancement & Development Centre (ADeC), Universiti Malaya (RU013R-2021).

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