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The Study Of The Effectiveness Of Design-Based Engineering Learning (DBEL): The Mediating Role Of Cognitive Engagement And The Moderating Role Of Modes Of Engagement

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ABSTRACT

Aim: Design-based engineering learning (DBEL) offers a potentially valuable approach to engineering education, but its mechanism of action has yet to be verified by empirical studies. Accordingly, the present study aimed to establish whether DBEL produces better learning outcomes, thereby building a strong, empirically grounded case for further research into engineering education.

Methods: To build a more comprehensive model of design-based engineering learning, the variables of cognitive engagement (the mediator) and modes of engagement (the moderator) were introduced to build a theoretical process model. Questionnaires and multiple linear regression analysis were used to verify the model.

Results and discussion: All four features of DBEL (design practice, interactive reflection, knowledge integration, and circular iteration) were found to exert significant and positive effects on learning outcomes. Moreover, cognitive engagement was found to both fully and partially mediate the relationships between these features and the outcomes of engineering learning; under two different modes of engagement, the positive effects of the learning features on cognitive engagement differed significantly.

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Conclusions: The paper concluded the following: (1) a design-based learning approach can enhance engineering students' learning outcomes, (2) cognitive engagement mediates between design-based engineering learning and learning outcomes (3) a systematic mode of engagement produces better learning outcomes than a staged modes of engagement.

Conference Key Areas: Engineering Education Research

Keywords:Design-based Engineering Learning; Learning Outcomes; Cognitive Engagement; Modes of Engagement.

1 INTRODUCTION

In the early 21st century, design-based learning (DBL) was introduced to the literature (Doppelt, 2009). In DBL approaches, teachers take a bottom-up approach, posing real-world problems that encourage students to construct meaningful knowledge while completing design tasks. As they work toward a final product that meets task requirements, the students iteratively deepen their theoretical and practical topic knowledge (Goel et al., 1996; Kolodner, 2002; Mehalik and Schunn, 2010; Feiran et al., 2022). DBL is widely viewed as a model that supports innovative learning and has been combined with engineering education practice to evolve into design-based engineering learning (DBEL).

1.1 DBEL AND ENGINEERING LEARNING OUTCOMES

Eisner (1979) introduced the concept of learning outcome to denote the result of the learner's engagement in learning, including not only intentional but also unintentional outcomes. Kuh and Hu (2001) subsequently defined learning outcome as the student's ability to demonstrate evidence of competence in knowledge, skills, and values after completing a training component or full program. The outcomes of engineering learning programs include the enhancement of subject-specific knowledge, skills, and competencies (OECD, 2012; Jia, 2015; Jiang, 2015). DBEL's direct impacts on the learning outcomes of engineering students have been widely corroborated by researchers (Zhang et al., 2021; Gupta, 2022; Gutierrez-Bucheli et al., 2022). Scholars have pointed out that engineering design activities and tasks center on a cyclic, iterative process of "design–inquiry–redesign," in which learners' knowledge and abilities develop in an upward "spiral" pattern (Vincenti, 2001; Xiang, 2015, 2016). However, in the field of engineering learning, few empirical studies have examined the relationship between design-based engineering learning and learning effectiveness. To address these issues, a theoretical model of DBEL learning effectiveness was developed (see Figure 1, below). Thus, the initial hypotheses proposed in this study were as follows:

Hypothesis 1: Design-based engineering learning has a positive effect on engineering students' learning outcomes.

1.2 THE MEDIATING ROLE OF COGNITIVE ENGAGEMENT

Scholarly work has taken two perspectives on cognitive engagement: one that emphasizes the psychological involvement of learning; and another highlighting the application of learning strategies (Moliterni et al., 1990). Cognitive engagement stems from the perception that learners actively mobilize cognitive, motivational, and emotional aspects when learning, which leads to better outcomes and improves academic performance (Tinto and Pusser, 2006).

Contextual cognitivism views knowledge not as a static intellectual structure confined to the brain, but as a cognitive process that includes people, tools, other people in the environment, and knowledge-building activities (Misra, 2021). Thus, engineering science knowledge is understood as contextual, practical, and produced through collaboration (Brown et al., 1993; Streveler et al., 2008). When classrooms are characterized by clear instructional objectives, sound instructional evaluation, and effective pedagogies, learners tend to adopt deep cognitive engagement and produce better results (Ramsden et al., 2017).Based on the above analysis, this study anticipated that DBEL would provide an effective contextual learning model in which cognitive engagement plays a crucial mediating role and influences learning outcomes:

Hypothesis 2: Different aspects of design-based engineering learning positively influence engineering learning outcomes by promoting engineering students' cognitive engagement.

1.3 MODERATING ROLE OF MODES OF ENGAGEMENT

This study introduces the construct of modes of engagement to characterize design-based engineering learning in different contexts (Lina, 2022). Based on the literature, these modes of engagement are, in fact, two specific contexts in which students are engaged in design-based engineering learning, labeled here as staged and systematic engagement. The former refers to the implementation of design-based engineering learning through short-term courses and projects, which often have clear implementation goals, such as a practical project for a particular course or a graduation design. The latter denotes students' participation in two or more interrelated design-based engineering learning course modules, which occupy an important place in the four-year undergraduate engineering curriculum.

Hypothesis 3: In design-based engineering learning, systematic modes of engagement have a stronger positive impact on students' cognitive engagement than staged modes of engagement.

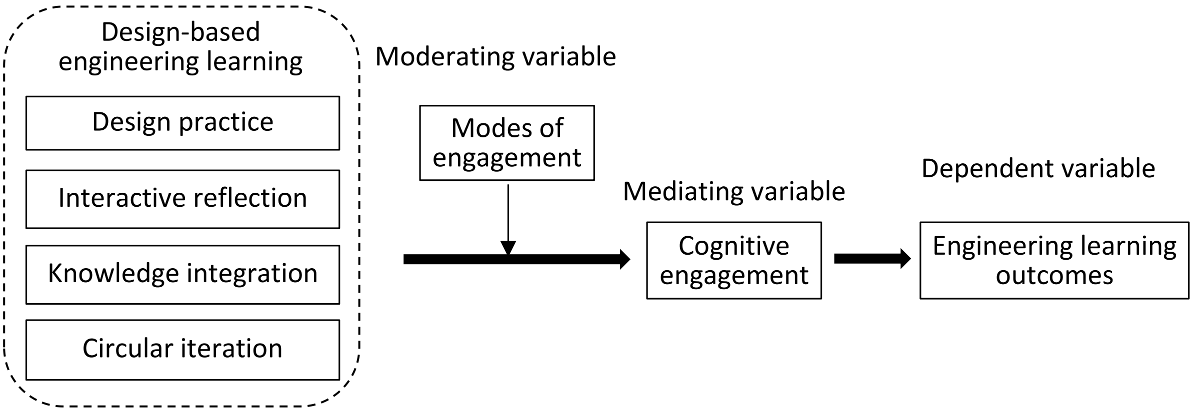

Figure. 1 Diagram of the design-based engineering learning research model

2 METHODS

2.1 DATA COLLECTION

The data for this study were collected by surveying a sample of engineering students. A total of 2590 questionnaires were distributed between September 2021 and January 2022, of which 2210 were returned, a recovery rate of 85.32%. Among these, 560 invalid questionnaires were excluded, leaving 1650 valid questionnaires, 74.7% of the total and well above the minimum rate specified for this study. All respondents had completed at least one design-based engineering learning project or course.

2.2 MEASUREMENT OF VARIABLES

The main variables measured in this study included engineering learning outcomes (the dependent variable), design-based engineering learning characteristics (the independent variable), cognitive engagement (the mediating variable), and modes of engagement (the moderating variable). The questions used to measure the dependent variable were based on earlier research carried out by Berggren et al. (2003), Pearce and Hadgraft (2011), Kolmos (2011), and Jacob and Pearce (2015). To measure the multi-dimensional features of DBEL, we referred to studies conducted by Berggren et al. (2003), Kuh (2003), Wang (2018), and Wei (2022) while the measurement questions for the mediating variable were based on work conducted by Stefanou et al. (2013) and Greene (2015). Finally, we referred to Tai et al. (2020) and Wei (2022) to set the measurement questions for the moderating variables. In addition, gender, school, grade, major, and GPA score were included in the regression model as control variables, after previous studies by Lotus Zhu (2019), Lian (2020), and Lv (2020). The questionnaire responses were measured using a 5-point Likert scale, (1 = very non-conforming, 5 = very conforming).

2.3 DESCRIPTIVE STATISTICS OF THE VARIABLES

Table 1 displays the means, standard deviations, skewness, kurtosis, and Pearson correlation coefficients of the main variables. The means ranged from 3.06 to 4.02, with standard deviations of between 0.211 and 0.987, and there were positive correlations among the variables.

Table 1. Descriptive statistics of the main variables measured by the formal questionnaire

Variables	**DP**	**IR**	**KI**	**CI**	**CE**	**ELO**	**PM**
DP	1						
IR	0.533**	1					
KI	0.542**	0.505**	1				
CI	0.500**	0.517**	0.536**	1			
CE	0.062*	0.061*	0.041*	0.134**	1		
ELO	0.525**	0.544**	0.530**	0.592**	0.144**	1	
PM	0.139**	0.151**	0.234**	0.147**	0.139**	0.121**	1
Mean value	3.98	4.02	3.87	3.84	3.06	3.79	0.41
Standard deviation	0.845	0.867	0.961	0.987	0.211	0.722	0.392

Note: ** $p \leq .01$ (bilateral); * $p \leq .05$ (bilateral)

3 MULTIPLE LINEAR REGRESSION

3.1 EFFECT OF DESIGN-BASED ENGINEERING LEARNING ON ENGINEERING LEARNING OUTCOMES

Table 2 reports the regression results for the linkages between various features of DBEL and engineering learning outcomes. The results show that design practice had a significant positive effect on these outcomes ($\beta = 0.365$, $p < 0.001$), as did interactive reflection ($\beta = 0.103$, $p < 0.001$), knowledge integration ($\beta = 0.198$, $p < 0.001$), and circular iteration ($\beta = 0.313$, $p < 0.001$). Therefore, hypotheses 1a, 1b, 1c, and 1d were supported.

Table 2. Regression analysis of the effect of DBEL on engineering learning outcomes

	Dependent variable: engineering learning outcomes				
	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**
Gender	-0.004	0.005	0.008	0.010	0.006
Grade	0.037	0.012	0.003	-0.025*	-0.022*
Types of universities	0.122***	0.062***	0.044***	0.033**	0.024*
Major	0.018	-0.026	-0.015	-0.010	-0.010
GPA	0.134***	-0.006	-0.010	-0.037*	-0.001
Design practice		0.831***	0.437***	0.390***	0.365***
Interactive reflection			0.498***	0.348***	0.103***
Knowledge integration				0.228***	0.198***
Circular iteration					0.313***
Adjusted R^2	0.036	0.669	0.779	0.792	0.805
F-value	13.481	616.541	594.667	104.192	113.109
VIF value	1.070-1.197	1.070-1.199	1.070-2.372	1.071-2.482	1.071-3.072
VIF average value	1.109	1.105	1.465	1.720	1.960

Note: *p < 0.05; **p < 0.01; ***p < 0.001.

3.2 MEDIATING EFFECTS OF COGNITIVE ENGAGEMENT

3.2.1 Test for mediating effects of cognitive engagements

To decide how to test these hypothesized relationships, we consulted related studies such as Wen et al. (2022), Jiang (2022), Fang et al. (2023), and Baron and Kenny (1986). Stepwise regression and bootstrapping were used to test the mediating effect of cognitive engagement.Model 6 showed that design practice, interactive reflection, knowledge integration, and circular iteration imparted a significant positive effect on the cognitive engagement of the engineering students (see Table 3) while model 9 demonstrated that cognitive engagement had a significant positive effect on learning outcomes. Comparing models 8 and 9, it was noted that the coefficients of design practice, knowledge integration, and circular iteration with engineering students' learning outcomes changed significantly after the mediating variable of cognitive engagement was introduced while the effect of interactive reflection on the engineering students' learning outcomes became insignificant.

Table 3. Test of the mediating effects of cognitive engagement on the relationship between multidimensional learning features and engineering learning outcomes

	Dependent variable: cognitive engagement	Dependent variable: engineering learning outcomes		
	Mode 6	**Mode 7**	**Mode 8**	**Mode 9**
Gender	-0.024	-0.004	0.006	0.016
Grade	-0.026*	0.037	-0.022*	-0.011
Types of Universities	0.011	0.122***	0.024*	0.019
Major	0.000	0.018	-0.010	-0.010
GPA	0.046***	0.134***	-0.001	-0.017
Design practice	0.362***		0.365***	0.214***
Interactive reflection	0.116***		0.186***	0.022
Knowledge integration	0.193***		0.198***	0.150***
Circular iteration	0.308***		0.313***	0.184***
Cognitive engagement				0.419***
Adjusted R^2	0.828	0.016	0.047	0.053

F-value	123.744	5.238	13.439	14.131
VIF value	1.071-3.072	1.070-1.152	1.071-3.072	1.019-3.190
VIF average value	1.960	1.12875	1.960	1.963

Note: *p < 0.05; **p < 0.01; ***p < 0.001.

3.2.2 Bootstrap test analysis for the significance of the mediating effect

Based on the preliminary results, basic bootstrap resampling was conducted using Stata16 software to empirically analyze the mediating effects of cognitive engagements. In this study, 2000 bootstrap resampling analyses were conducted based on the 1650 samples to obtain the standard deviation, significance, and 95% confidence intervals of the direct, indirect, and total effect unstandardized path coefficients of the model path analysis. The test results are shown in Table 4.

Table 4. Results of the analysis of the bootstrap test for the significance of mediation effects

Intermediary model	Total effect	Direct effect	Indirect effect [95%, CI]
DBEL→CE→ELO	0.882***	0.477***	0.405***[0.317，0.503]
DP→CE→ELO	0.749***	0.242***	0.509***[0.448，0.565]
IR→CE→ELO	0.787***	0.269***	0.517***[0.437，0.594]
KI→CE→ELO	0.668***	0.206***	0.462***[0.406，0.517]
CI→CE→ELO	0.790***	0.289***	0.501***[0.422，0.583]

Note: *p < 0.05; **p < 0.01; ***p < 0.001 (N = 1650)

The investigation of the mediating role of cognitive engagement showed that its mediation of the relationship between design-based engineering learning and engineering learning outcomes was significant, with an indirect effect value of 0.405 ($p < 0.001$) and a 95% confidence interval of [0.317, 0.503]. Cognitive engagement also significantly mediated the effects of the following aspects of DBEL on engineering learning outcomes: design practice (0.509, $p < 0.001$, 95% CI [0.448, 0.565]), interactive reflection (0.517, $p < 0.001$, 95% CI [0.437, 0.594]), knowledge integration (0.462, $p < 0.001$, 95% CI [0.406, 0.517]), and circular iteration (0.501 $p < 0.001$, 95% CI [0.422, 0.583]). In summary, hypotheses 2a, 2b, 2c, and 2d were tested and all four were verified.

3.3 MODERATING EFFECT OF MODES OF ENGAGEMENT

Following Fang et al. (2022), group regression and interaction terms were then used to test the moderating effect of modes of engagement. The sample was divided into two groups according to the type of modes of engagement (systematic vs. staged), and group regressions were randomly conducted using SPSS (see Table 5).

Table 5. The moderating effects of modes of engagement and cognitive engagement in DBEL

Dependent variable: cognitive engagement	Model 10	Model 11	Model 12
	Staged engagement	**Systematic engagement**	
Gender	0.032	0.022	0.006
Grade	-0.023	-0.045	-0.022
Types of Universities	0.023	0.012	0.021

Major	-0.054	0.005	-0.010
GPA	0.017	0.017	-0.010
Design practice (DP)	0.159**	0.450***	0.368***
Interactive reflection (IR)	0.097*	0.104*	0.190***
Knowledge integration (KI)	0.152	0.115*	0.117***
Circular iteration (CI)	0.587***	0.308***	0.306***
DP×PM			0.049*
IR×PM			0.081**
KI×PM			0.005
CI×PM			0.024
Adjusted R^2	0.772	0.871	0.906
F-value	218.262***	388.540***	577.597***
VIF value	1.070-3.123	1.070-2.868	1.070-2.973
VIF average value	1.967	1.816	1.903

Note：*$p < 0.05$；**$p < 0.01$；***$p < 0.001$.

In model 10 (systematic engagement in design-based learning), design practice, interactive reflection, knowledge integration, and circular iteration had significant positive effects on engineering students’ learning outcomes. However, in model 11 (the staged engagement model), only the first three of these had significant positive effects on learning outcomes while the effect of knowledge integration was insignificant.

Finally, the systematic and staged engagement modes were set to 0 and 1, respectively and their interactions with design practice, interactive reflection, knowledge integration, and cyclic iteration were tested. The results showed positive and significant interaction terms for the mode of engagement and the two variables of design practice ($\beta = 0.049$, $p < 0.05$) and interactive reflection ($\beta = 0.081$, $p < 0.001$). However, the corresponding terms for knowledge integration and circular iteration were not significant ($\beta = 0.005$, $p > 0.05$; $\beta = 0.024$, $p > 0.05$).

4 MAIN FINDINGS

4.1 DESIGN-BASED ENGINEERING LEARNING EFFECTIVELY ENHANCES ENGINEERING STUDENTS’ LEARNING OUTCOMES

This study empirically tested the significant positive effects of four learning characteristics on learning outcomes through multiple regression analysis. First, the test results showed a significant positive effect of design practices on engineering students’ learning outcomes. Task-specific problem situations appear to stimulate learners’ engagement, in turn improving their learning outcomes. The findings of this study affirmed the important role of design practices in enhancing engineering students' learning outcomes and believed that specific learning tasks could help deconstruct complex knowledge systems and enhance learners’ cognitive engagement, to some extent.Second, interactive reflection significantly and positively affected engineering students’ learning outcomes. There are two reasons why interactive reflection improves engineering students’ learning outcomes: first, interactive reflection offers a crucial way for learners to communicate with the outside world and transform the information they gain into their own knowledge; second, interactive reflection can construct a discourse of mutual understanding and facilitate the application and implementation of technology.Third, the empirical test results show that knowledge integration exerted a positive effect on engineering students’ learning outcomes. Knowledge integration demonstrates learners’ ability to coordinate and integrate key resources. It also enables the smooth flow of scientific thinking and disciplinary knowledge across boundaries, promotes efficient communication within organizations, and enhances the learning outcomes of engineering students.Fourth, circular iteration was found to positively affect the learning outcomes of engineering students. In student-centered engineering, circular iteration may gradually be marginalized with students' initiative and motivation assuming greater prominence in pedagogy.

4.2 COGNITIVE ENGAGEMENT MEDIATES THE RELATIONSHIP BETWEEN DESIGN-BASED ENGINEERING LEARNING AND LEARNING OUTCOMES

The test of mediating effects revealed that cognitive engagement partially mediated the relationships between design practice, knowledge integration, circular iteration, and engineering students' learning outcomes while fully mediating the link between interactive reflection and learning outcomes. These results were further confirmed by bootstrap resampling, demonstrating that cognitive engagement was an important mediator of the DBEL mechanism and enhanced engineering students' learning outcomes.

4.3 THE MODERATING EFFECTS OF MODES OF ENGAGEMENT ON THE RELATIONSHIP BETWEEN DESIGN-BASED ENGINEERING LEARNING AND COGNITIVE ENGAGEMENT

Modes of engagement were found to significantly moderate the relationship between design-based engineering learning and cognitive engagement. In DBEL, a systematic modes of engagement was more likely to enhance engineering students' learning outcomes than one that is stage-based.

5 CONTRIBUTION TO THE LITERATURE

This study used a large sample to empirically test the effects of four design-based learning characteristics of engineering education on student learning outcomes. Its in-depth investigation of the characteristics of DBEL and their mechanisms of action has addressed several limitations of existing theories. Our holistic framework connects the key aspects of design-based engineering learning to modes of engagement, cognitive engagement, and engineering learning outcomes (see Figure 1). Taking a dynamic perspective, we focused on the characteristics of DBEL in colleges and universities and analyzed its mechanism of effect in more detail. By proposing and rigorously testing a model of DBEL, we have extended the boundaries of research into engineering learning and revealed the systematic correlations among the features of engineering learning under the design paradigm, thereby providing a conceptual and empirical basis for the model. The research establishes an empirical basis for reforming and implementing a design-based engineering learning model in colleges and universities. By examining two different modes of engagement, we show that systematic design-based programs of engineering learning in colleges and universities can improve students' learning outcomes. The study highlights the need for colleges and universities to address the institutional and cultural barriers to providing adequate support for DBEL.

6 LIMITATIONS AND PROSPECTS

This empirical study has several shortcomings. The distribution of the sample may not be fully balanced since, among the 1650 engineering undergraduates who returned valid responses, 46% were from 985 universities, 32.12% were from 211 universities, and 21.88% were from ordinary undergraduate universities.Different universities have different educational resources and students' quality, which may affect the implementation effect of DBEL. Future studies should investigate the effects of institution type on the different dimensions of engineering students' learning performance, as well as any variations that occur according to modes of engagement.

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