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Using Problem-Based Learning in Sustainable Design Education

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Abstract: This study investigates whether problem-based learning (PBL) can further enhance interior design students' sustainability learning. It compares the learning environment of a conventional lecture-based approach and PBL in sustainable design education. This study differs from the existing design literature on sustainable design education in that; (i) it implements PBL into interior design education to overcome the limitations of sustainability teaching in a conventional lecture-based instruction, and (ii) it proposes a new way of organising classes based on learner-centric features of PBL to increase student awareness toward sustainability. To achieve these two aspects, the two instructional modes of learning were applied during the two years of a sustainability module. In the first year, sustainability has been taught in a conventional lecture-based environment, and in the second year, in a PBL environment. It is possible to conclude that different than the other design topics, sustainability teaching and problem solving require a more learner-centric approach rather than an instructor-centric instruction to further enhance critical solving abilities of design students. Moreover, sustainability learning in the PBL setting is more effective when compared with the learning outcomes in the conventional lecture-based setting.

Keywords: *problem-based learning (PBL); sustainability; learner-centric; interior design*

1 Introduction

This study investigates whether problem-based learning (PBL) can further enhance interior design students' sustainability learning. PBL, which is an increasingly popular way of presenting a problem scenario, was first introduced in medical education (Wijnia et al., 2014). In the last decade, it has been implemented in various education curricula, such as business, engineering studies, law, and nursing (Hung, Jonassen and Liu, 2008). PBL is a learner-centric instructional approach rather than instructor-centric. It is based on an active exploration process of real-world problems, which consists of the following three key phases: (1) initial discussion phase, (2) self-study phase, and (3) a reporting phase (Savery, 2006; Schmidt, 1983). However, the implementation of PBL in interior design education is not common (Galford, Hawkins & Hertweck, 2015). Since PBL requires complex thinking and cognitive activities (analysis-synthesis-evaluation), it could have potentially unique benefits for interior design context, which is also most commonly explained in the literature under analysis-synthesis-evaluation model (Lawson, 1990; Roozenburg & Eekels, 1994). Both rely on a reflective questioning process through creative experimentation (Barrows, 1986; Schön, 1987). The initial discussion, self-study and reporting phases of PBL are very similar to the studio-based learning model in interior design education that generally requires exploring precedents of architectural space and form, studying appropriate materials and construction techniques, developing design solution alternatives and presenting them in the form of drawings and 3D models (Afacan, 2016). As problems become more ill-defined and complex in both PBL and interior design, formulating problem explanations and developing solution alternatives require more cognitive effort (Rourke & Sweller, 2009). Moreover, determining the relevance of sources for such problems is a difficult task for both novice and expert designers (Rouet et al., 1997). Hence, eliminating redundant information and engaging with appropriate knowledge become very crucial in PBL to lead to better learning outcomes, increase creativity and improve the quality of design solutions (Douchy et al., 2014; Wijnia et al., 2014). Thus, the present study aims to overcome the gaps in sustainability education by effective learning models. It proposes PBL as an instructional strategy to eliminate the high cognitive demand on sustainability learning and to integrate it as a core component of design curricula (Afacan, 2016; Shields, Verga & Blengini, 2016).

2 Sustainability in Interior Design Curriculum

The concept of sustainability has become an overarching principle in many national and international studies since the publication of the United Nations' Brundtland Report (1987) and the 1992 Rio Earth Summit. Sustainable design is a philosophy that aims to maximise the quality of the built environment while minimising or eliminating the impact on the natural environment. A sustainable interior environment provides better sanitation (sewers and trash collection), better indoor air quality (IAQ) (daylighting, ventilation, heating and cooling), energy-efficient water and effective energy services, innovative and ecological materials with improved living standards (Afacan & Demirkan, 2016). The growing concern and increasing interest in sustainable environments are changing the interior design education agenda. Sustainability teaching is not a trend; it has become a necessity in interior design education (Zuo, Leonard & Beach, 2010). Interior design is a major player of sustainable architectural development, and thus appropriate sustainability design teaching must be incorporated into design education to prepare students for the real world. According to Council for Interior Design Accreditation (CIDA) (2011), interior design students' work must demonstrate "comprehension of the concepts, principles and theories of sustainability as they pertain to building methods, materials, systems and occupants" (p.13).

The literature on sustainable design education incorporates many studies ranging from sustainability teaching methods in design studio and non-studio courses (Afacan, 2014; Fletcher & Dewberry, 2002; Gurel, 2010; Lee, 2014) to student experiences on sustainability awareness and perception (Brundiers & Wiek, 2011; Stark, Gyu & Park, 2016). It is not the scope of this study to list the literature contributing to sustainability integration in design curricula, rather it tries to overcome the following three knowledge gaps in sustainability education specific to the interior design context (Fischer & McAdams, 2015). Firstly, interior design education has lagged in integrating some aspects of sustainability, such as solar energy use, which is not taught in detail (Zuo et al., 2010). Secondly, there is a heavy focus on the technical-solution driven approach, which means adopting only prescribed solutions from available green design standards (Lee, 2014), rather than letting students formulate their own answers based on a critical analysis-synthesis-evaluation process. Thirdly, most of the studies on and concerns for sustainability in interior design explore curriculum and student awareness issues (Fischer & McAdams, 2015), and do not address instructional models, such as how to endow students with real-world sustainability skills, including effective reasoning process, self-directed learning, critical awareness of physical, social and economic dimensions of sustainable design and innovative project development. To date, little has been done to specifically integrate problem- and project-based learning into sustainability programs. Thomas (2009) highlighted the commonalities of sustainable education and PBL. According to Thomas (2009), there is a need for the critical thinking of PBL across all the disciplines in sustainable education. Zuo et al. (2010) integrated performance-based design as a new teaching pedagogy for sustainability awareness at the beginning of interior design education. They have focused only on passive solar energy use among various sustainability principles, such as water, energy, indoor air quality, innovative process, material use. Their results showed that performance-based design enhanced student understanding of the mutual relationship between interior and exterior and between built and natural environment. Wiek et al. (2013) presented Arizona State University (ASU)'s School of Sustainability as a successful first initiative to implement problem and project-based learning at undergraduate and graduate level in sustainability teaching with all its principles. However, based on their survey analyses and observations, there is a need for further development of instructional strategies. Stark, Gyu and Park (2016) also reported that many interior design educators have difficulty understanding how to incorporate and teach sustainable design in a systematised and integrated manner to achieve desired learning outcomes. Thus, sustainability in interior design education needs to be urgently re-examined with a focus on enhanced instructional approaches and student-centred pedagogies (Thomas, 2009).

This study differs from the existing design literature on sustainable design education in that; (i) it implements PBL into interior design education to overcome the limitations of sustainability teaching in a conventional lecture-based instruction and (ii) it proposes a new way of organising classes based on learner-centric features of PBL to increase student awareness toward sustainability.

To achieve these two aspects, the two instructional modes of learning were applied during the two years of a sustainability module. In the first year, sustainability has been taught in the conventional lecture-based environment, and in the second year in the PBL environment. Specifically, this study addresses the following three research questions:

1. Does PBL enhance interior design students' sustainability learning? The study's hypothesis is that there will be a statistically significant difference between the sustainability learning outcomes of the two interior design student groups with respect to their instructional modes (Hypothesis 1).
2. Are there any differences between the two instructional modes in terms of specifying design goals? The study expects that there will be statistical differences between the groups in specifying design goals during sustainable problem solving (Hypothesis 2).
3. Are there any differences between the two instructional modes in terms of the required mental effort? The third hypothesis is that students' mental effort ratings of sustainable problem-solving process in a conventional lecture- based environment will be higher than to the scores in a PBL environment (Hypothesis 3).

3 Study

3.1 Participants and Procedure

200 third year interior architecture students participated in the study (54 male, 146 female). Two different semester offerings of the same course, IAED 342- Sustainable Design for Interiors, at Bilkent University, Turkey, were used to compare the two instructional approaches. The same faculty member, the author, taught the courses first in the Spring semester of 2014-2015 academic year using conventional lecture-based approach (100 students; 22 male and 78 female), then in the following year, the Spring semester of 2015-2016 academic year using PBL approach (100 students; 15 male and 85 female). Both semesters were composed of 14 weeks of teaching.

The conventional lecture-based approach consisted of two-hour lecture sessions twice a week, during which seven sustainability topics (sustainable strategies, water systems, waste water and its reuse, toilet design, energy conservation, heating and cooling) were introduced every two weeks. The assessment of learning outcomes was done through the following methods; (i) seven homework assignments, one for each topic; (ii) one midterm for evaluating content learning and (iii) one final project for assessing critical thinking and problem-solving abilities. Each method was assessed based on four criteria: application of appropriate sustainability knowledge; consideration of proper spatial arrangements and layouts; usage of sustainable products, furniture and materials, and integration of innovative strategies. A score of 1 point was given for each satisfied criterion, and a score of 0 was assigned if the solution did not satisfy the criterion. Students, who received a total mean score between 2 and 4 points, were considered to have satisfactorily completed the requirements of each assessment type. Thus, the study defined these students as successful in terms of weekly learning grade and the other students, who received below the score of 2, were considered as unsuccessful.

The PBL also consisted of two-hour lecture sessions twice a week, but incorporated five key features of PBL (Newman, 2005):

1. The instructor as a facilitator to deliver the learning content;
2. The ill-structured problem solving in the form of a designed script;
3. Integration and contextualisation of learning by the ill-structured problem solving;
4. Collaborative learning
5. Learning assessment in relation to the objectives of learning.

In the introductory lecture of the first week, the instructor introduced a set of learning objectives regarding each topic. At the beginning of each week, an ill-structured real problem along with a set of resources was presented in the online course management system at Bilkent University. At the first hour of the two-hour lecture session, the students were divided into predetermined groups of 5 to 6 students, who worked on the problem for the entire lecture hours. The instructor guided them by asking questions and discussing their answers, similar to a brainstorming process. In the second hour, each group presented how they approached the problem and what they critically proposed as a solution alternative. An exemplary problem from the hot water week was as follows: "A residential building with 10 flats has recently been renovated, and all the water distribution systems (cold and hot) have been renewed. The hot water system, which was previously local, is now central. Describe in detail the possible sustainable hot water solution alternatives in terms of different heat source types and different climate conditions".

3.2 Instruments

To observe the impact of PBL, data was collected by comparing student learning outcomes and their specified goals during problem solving of the final project. Learning outcomes in each semester was defined in terms of student overall course grade obtained as the mean value of the seven homework scores in the conventional lecture-based instruction and seven weekly learning scores in PBL, the midterm grade, final project grade. Students who received a C (Grade> 2, 00/ 4, 00) or a higher grade were considered to have satisfactorily completed the course. Thus, the study defined these students as successful and the other students, who received below C (Grade< 2, 00), as unsuccessful. These mean values from each instructional mode were compared in the Result section to test Hypothesis 1.

The same final project was given in both semesters to test *Hypothesis 2*. The final project was designing a sustainable energy-efficient table unit. In both conventional-based lecture approach and PBL environment, only a single sentence was given to the students at the beginning: "You are asked to design a sustainable table unit and state your reason for your design goal by selecting only one of the given relevant explanations" (Table 1). In all two instructional modes, the same specified design goals were asked. In both modes of instruction, the same instructor and two guest jury members did the evaluation of projects. A successful project was defined according to the mathematical average of the three-jury members' grades.

Table 1. Design goal categories with their explanations.

Categories	**Explanations**
☐ Form	Shape, and other external visual appearance of the source example.
☐ Symbolism	Other objects, contexts or designs that the participant associated with.
☐ Structure	The relationship among the elements of source example.
☐ Function	The way the source example will benefit or serve its users.
☐ Aesthetic	Sense of form, art, or visual pleasing sensation that source invokes.
☐ Experience	Similar project has been done or observed by the participant.
☐ Green character	The relationship to energy efficiency, recycling, reusing material and colour.
☐ Adaptability	Being long lasting to accommodate changes in later use.
☐ Ecology	Natural, organic and local resources.
☐ Usability	Inclusivity for all people regardless age, ability and size.
☐ Design and construction process	Innovative and sustainable methods, such as recycling and technological advances.
☐ Novelty	Associated with new, creative and original.

Mental effort during the course was also assessed based on a student self-evaluation questionnaire to test Hypothesis 3. The questionnaire was inspired by Paas's (1992) study on the cognitive load theory to problem solving skills. The cognitive load theory was proposed by Paas and Van Merrienboer in 1993 to compare the effects of different instructional approaches on learning. Cognitive load theory is mainly concerned with the learning of complex cognitive tasks, where the number of information elements that need to be processed simultaneously before meaningful learning can commence often overwhelms learners and their interactions (Kostons, Gog & Paas, 2012; Paas, Renkl & Sweller, 2004). At the end of each semester, the students were asked to evaluate their invested personnel effort to the course (homework assignments/weekly sustainable problem-solving sessions, midterm and final project) on a 9-point scale, ranging from 1 (very, very low mental effort) to 9 (very, very high effort). So, a high mental effort meant a negative outcome.

4 Results

To test the hypotheses, the grades and questionnaire data from two semesters of 200 participants (100 students from each semester) were obtained. Descriptive analyses and analyses of variance (ANOVA) tests were conducted. The ANOVA is for explicitly testing equality of means of values between two or more groups. Differences between student groups were considered significant at a level of 95% ($p=0.05$). For statistical analysis, IBM SPSS Statistics version 21 was used.

4.1 Learning Outcome

ANOVA test (One-Way ANOVA) was performed to see if there were any differences between two student groups in terms of the course grade, weekly learning grade and final project grade (Hypothesis 1). Post-hoc comparison test using the Tukey procedure was carried out to determine exactly where the differences between the groups existed. According to Hsu (1996), Tukey is the best for all possible pairwise comparisons with exact P-values, such as Bonferroni, Duncan and Scheffe, when sample sizes are big and the numbers within the groups are equal. Table 2 illustrated descriptive statistics for course grade. In the study, successful students based on the explanations in the previous section, were coded as 1 and unsuccessful students as 2. According to the means and standard deviations, the number of successful students was increased in the PBL environment. The results of ANOVA (Tables 3 and 4) indicated that there is statistically significant differences in overall course grades for the two student groups ($F(2,297) = 13.975$, $p = .000 < .05$). Subsequent post hoc Tukey indicated that students who were taught in PBL were more successful than students in the conventional-based learning (PBL vs. conventional-based: Mdiff = -.19000, p = .007,one-tailed).

Table 2. Descriptive statistics for course grade between student groups.

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Min.	Max.
					Lower Bound	Upper Bound		
Conventional_based	100	1.4800	.50212	.05021	1.3804	1.5796	1.00	2.00
PBL	100	1.1500	.35887	.03589	1.0788	1.2212	1.00	2.00
Total	300	1.3150	.43049	.04305	1.2296	1.4004	1.00	2.00

Table 3. ANOVA result for course grade.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	5.487	2	2.743	13.975	.000
Within Groups	58.300	297	.196		
Total	63.787	299			

Table 4. Tukey HSD test for course grade.

(I) InstructionMode	(J) InstructionMode	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Conventional_ based	PBL	.19000*	.06266	.007	.0424	.3376

*. The mean difference is significant at the 0.05 level.

The same multiple comparison analyses were conducted to analyse the differences between student groups in relation to their mean grades of weekly learning for each semester. The means and standard deviations indicated that the number of successful students was increased in the second semester (M_conventional-based = 1.5900, SD = .49431; M_PBL = 1.0500, SD = .21904). The results of ANOVA revealed significant group differences in weekly learning grades as well ($F(2,297) = 48.131$, $p = .000 < .05$). According to the comparative analysis using the Tukey HSD test, the mean learning grades of students in conventional lecture-based learning differed significantly compared to the grades in PBL at 0.05 significance level (conventional lecture-based learning vs. PBL: Mdiff = .54000, p = .000, one-tailed). Similar to the course grade results, students who were taught in PBL mode were more successful in terms of weekly learning than students in the conventional lecture-based learning. Moreover, in terms of both course grade and weekly learning grade, success in the PBL environment has been significantly increased.

The results of ANOVA indicated that there exist statistically significant differences in final project grades for the two student groups ($F(2,297) = 18.927$, $p = .000 < .05$). Subsequent post hoc Tukey indicated that students who taught in PBL mode were more successful than students in the conventional lecture-based learning (PBL vs. conventional-based learning: Mdiff =. -35000, p = .000, one-tailed). As indicated, the difference in mean scores is relatively high. So, Hypothesis 1 was confirmed by the results. As expected, there is a statistically significant difference between the sustainability learning outcomes of interior design student with respect to their instructional modes.

4.2 Specified Design Goals

ANOVA test (One-Way ANOVA) was performed to see if there were any differences between the two student groups in terms of specifying design goals during sustainable problem-solving process. The results of ANOVA revealed significant group differences in specified design goals ($F (2,297) = 15.728$, $p = .000 < .05$). Most of the students in the conventional lecture-based instruction mode stated sustainability definitions as the basis for their solution alternatives- green character stated by 37 participants out of 100; adaptability by 27 participants out of 100 and ecology by 20 participants out of 100. The rest of the students explained their specified goals under structural (6 out of 100), aesthetical (5 out of 100) and functional considerations (5 out of 100). None of the students in the conventional lecture-based instruction mode chose symbolism, experience or design and construction process as their specified goals. However, in the PBL environment, rather than the more direct sustainability concepts, experience become the most important explanation as their design goals. Experience was stated by 25 students out of 100; green character by 22 participants out of 100; adaptability by 18 participants out of 100; ecology by 17 participants out of 100 and design and construction process by 18 students. Similar to the conventional lecture-based instruction mode, none of the students stated symbolism as their specified goal. This suggested that the use of PBL during sustainability learning process had an impact on the student specified design goals as well. Figure 1 illustrates one of the successful design solution examples in PBL based on form as the specified design goal.

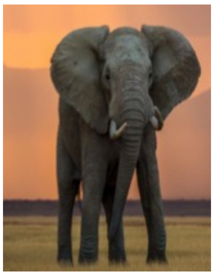
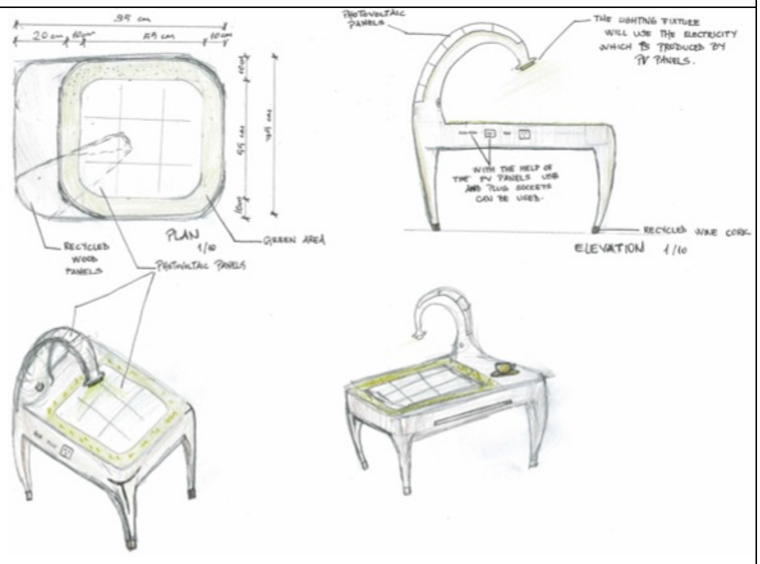
Source Selection	Specified Design Goal	Example
	Form	

Figure 1. One of the successful design solution examples in PBL based on form as specified design goal.

4.3 Mental Effort

The third hypothesis was that mental effort ratings of students in the conventional lecture-based environment would be higher compared to the scores in the PBL environment. The adapted cognitive load mental effort survey evaluated invested personnel effort of students on the following four items: (i) understanding the resources of homework/the source domains of weekly problems; (ii) solving homework/sustainable problems of each week; (iii) understanding final project; (iv) solving final project. Reliability results of the survey in each semester were respectively α (conventional lecture-based learning) = .808 and α (PBL) = .816. There was a statistically significant mental effort difference between student groups in terms of understanding the resources of homework/the source domains of weekly problems (two-tailed, $p = .000$). There was also a significant mental effort difference between student groups in terms solving homework in the conventional lecture-based instruction mode (two-tailed, $p = .000$). According to the pairwise comparisons, mental effort differed significantly in the conventional lecture-based learning environment (M_rank_conventional-based = 243.07; M_rank_PBL = 141.90). Figure 2 illustrates the instructional differences on mental effort rankings for solving weekly homework/sustainability problems.

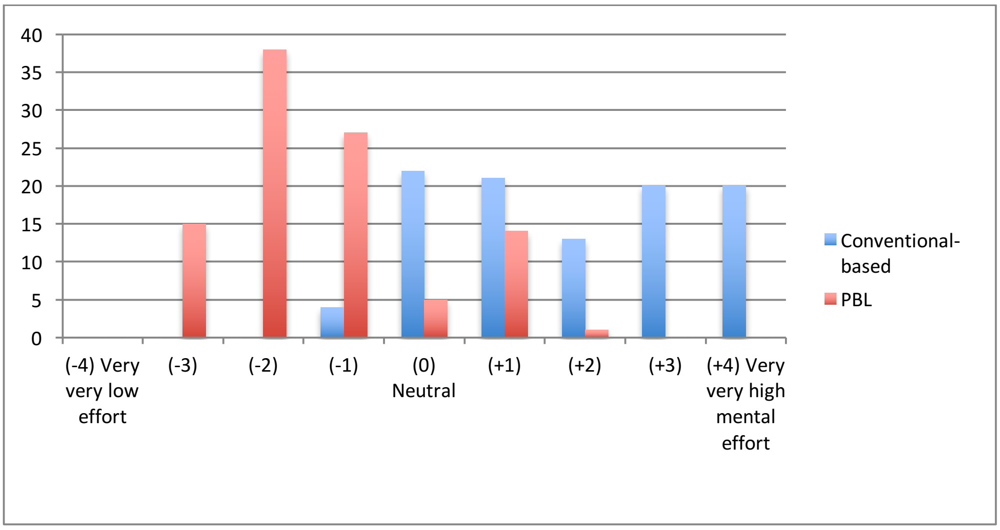


Figure 2. Differences on mental effort rankings for solving weekly homework/ sustainability problems.

Thirdly, there was a significant mental effort difference between the student groups in terms of understanding final project (two-tailed, p = .000). According to the pairwise comparisons, the difference in mean ranks was also relatively high (M_rank_conventional-based = 238.89; M_rank_PBL = 146.74). Finally, mental effort required for solving final project differed also significantly between the student groups (two-tailed, p = .000). Again, pairwise comparisons found a significant mean rank difference (M_rank_conventional-based = 225.68; M_rank_PBL = 159.27). So, Hypothesis 3 was confirmed by the results. As expected, mental effort ratings of students on solving final project in the conventional lecture-based environment were statistically different compared to the ratings in the PBL environment. Figure 3 illustrates these instructional differences on the mental effort rankings.

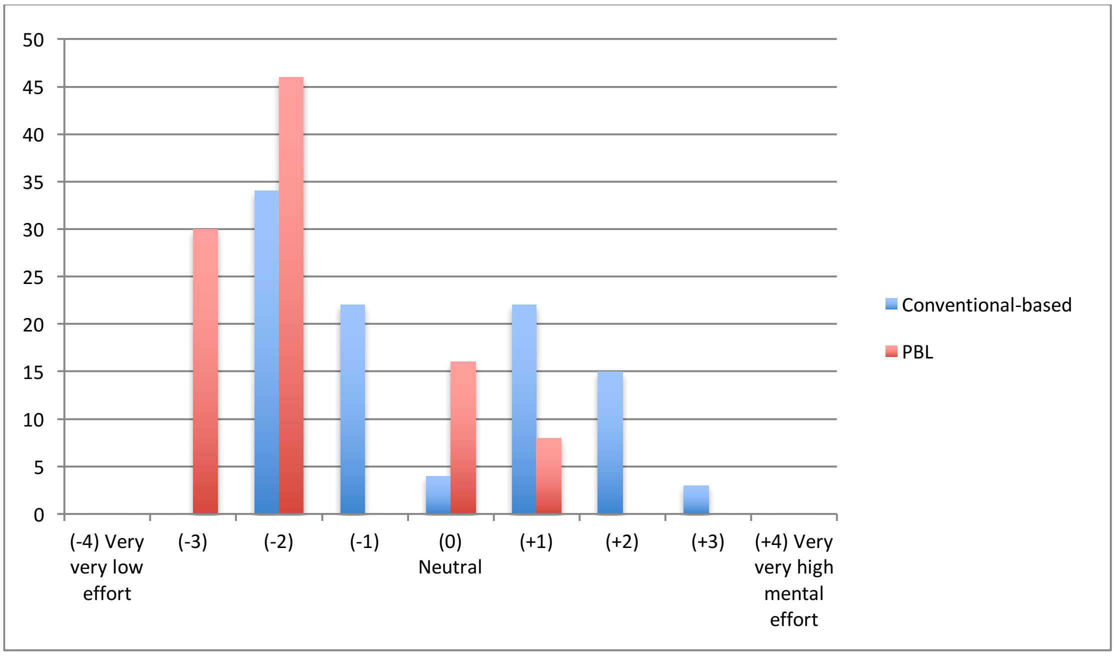


Figure 3. Differences on mental effort rankings for solving final project.

4.4 Student Attitudes

Most of the students (80) had a positive attitude towards PBL and found PBL as an effective way of sustainability learning in terms of (i) multi-dimensional analysis (ii) self-study and (iii) creativity. 55 of 100 students stated that by integrating information from multiple literature resources with the aim of finding an answer to the learning of sustainability issues, they could approach sustainability from different perspectives and analyse it in a multi-dimensional way, which they couldn't achieve on their own. 20 students found brainstorming sessions very helpful: through these sessions they could share different ideas, collaborate, discuss and make use of each other's experiences. Since creative design is a matter of working out all solution variants, according to 25 students, PBL developed their creativity skills by giving them autonomy to actively construct their own solutions:

> You can learn more efficiently by self-directed learning rather than being directed by the instructor (Student, #75).
>
> You can enjoy project more if you have the freedom to choose my own literature resources (Student, #22).
>
> We study sustainability because the tasks are interesting and motivating for future (Student, #88).
>
> Brainstorming helped us to learn something different and develop creative designs (Student, #45).
>
> PBL provides variety of solutions and self-motivation (Student, #3).
>
> We put less mental effort in the PBL environment, because we don’t feel to be forced by others (Student, #19).

However, 12 students had very negative responses to PBL as they reported having frustrations and uncertainties during the brainstorming sessions, source selection and integration of that literature in self-study. Some students could have difficulty with the activities undertaken during self-study and creative process, and might learn better when given a defined task, like homework assignments in the conventional lecture-based instruction mode:

> Self-study places high demand on working memory (Student, #15).
>
> Brainstorming session and integrating the ideas obtained from that session could be frustrating (Student, #73).

5 Discussion

The findings indicated that the three stages of PBL process, which are initial discussion, self-study and reporting (Schmidt, 1983), could enrich learning outcomes of sustainable design education. Compared to the conventional lecture-based learning, in PBL both the number of successful course grades and final projects have increased through the collaborative process of discovery; learning before and during the brainstorming session in class; visualising and conceptualising solutions by analysing the relevant real-world case examples and presenting a solution alternative. Concerning the mental effort ratings in PBL, this study suggests that PBL required less mental effort in all assessment types than the conventional lecture-based instruction. This nature of PBL could lead to better understanding and consolidation of acquired sustainability knowledge. Thus, it is possible to discuss the results in terms of two points of view: the learning process and critical reflection. There is a significant correlation between the amount of effort spent on sustainability learning and success of the learning outcomes. Higher grades in all assessment types (homework/weekly learning and final project) were obtained with lower cognitive load investment of self-study during sustainability learning and problem solving. Critical reflection may not be the case in all instances, but in this study, the importance of student’s active role and self-study to understand and solve is emphasized in the construction of their own knowledge. Furthermore, in terms of the specified design goals, students in the conventional lecture-based instruction were more concerned with direct sustainability concepts, such as green character or ecology, to find a solution alternative. However, in PBL, because of the improved critical thinking sessions throughout the semester, students had the opportunity to consider their experiences and the construction process to solve the problems.

6 Conclusion

The study explores a PBL environment to further enhance interior design students’ sustainability learning. When results from the two semesters and two different modes of instruction are considered together, it is possible to conclude that sustainability teaching and problem solving requires a more learner-centric rather than instructor-centric instruction strategy to increase knowledge acquisition and critical solving abilities. Even though sustainability learning in the PBL setting is more effective compared to learning in the conventional lecture-based setting, but it could be further developed based on the following strategies: (i) letting students find their own source domains and solution alternatives and (ii) integrating information across multiple design resources during the self-study phase. Thus, the results of this study is significant in terms of highlighting the importance of eliminating the search of irrelevant design resources, and so, overcoming the challenges of sustainable problem solving as a cognitively demanding task.

It should be noted that the two instruction modes are specific to the current sample and may also be impacted by the course syllabus and type of the final project. The success and mental effort findings could be different under different design experiment conditions. Usage of online learning environments and/or blended learning rather than face-to-face could also influence student-instructor interaction and the process of PBL. Moreover, the expertise level of students has also impact on the use of PBL.

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