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ORIGINAL ARTICLE

The Impact of Design-Based Learning on Student Achievement Motivation and Retention in The 7th Grade Science Curriculum: A New Approach to Teaching Chemical Equations

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Ethical Statement
This research was conducted in accordance with Prior to participation, all individuals provided informed consent. Participants were fully informed about the study's objectives, the procedures to be undertaken, potential risks, and possible benefits. They were assured of the confidentiality of their responses and reminded of their right to withdraw at any stage without any adverse consequences. Written consent forms were obtained from each participant, and all data were anonymized to ensure privacy. Ethical approval for the study was obtained from the Ethics Committee for Research in Social and Human Sciences at Fırat University (Approval Number: 01.07.2024-25490).

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Conflict of Interest
The authors declare that there are no conflicts of interest among themselves. Furthermore, the authors confirm that they have no financial or personal conflicts with any individuals orinstitutions that could have influenced the conduct or reporting of this study.

ABSTRACT

This study examines the effects of a Design-Based Learning (DBL) approach on students' academic achievement, motivation toward science, and knowledge retention in the *Pure Substances and Mixtures* unit of the 7th-grade science curriculum. Conducted in the first semester of the 2024–2025 academic year, the research adopted a pre-test/post-test control group experimental design. Data were gathered through two primary instruments: the Academic Achievement Test (AAT-PSM) and the Motivation for Learning Science Scale (MSTLS). To measure long-term retention, the achievement test was administered again to both the experimental and control groups four weeks after the instructional intervention. The findings revealed that the DBL approach significantly enhanced students' academic performance, strengthened their motivation toward science, and improved knowledge retention. The collaborative structure of DBL activities encouraged active participation, which in turn fostered intrinsic motivation. Moreover, engaging students in designing and testing their own solutions cultivated a sense of ownership over the learning process, thereby increasing enthusiasm and engagement in science classes. Notably, although the experimental group reported lower initial motivation levels compared to the control group, they ultimately achieved higher academic performance by the end of the study. These results indicate that DBL not only facilitates conceptual understanding but also sustains student interest and contributes to long-term academic growth. Overall, the study highlights the effectiveness of design-based learning as a pedagogical strategy for promoting deeper and more meaningful learning experiences in middle school science education.

Keywords: Design-Based Learning, Academic Achievement, Motivation, Permanence

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INTRODUCTION

Within the framework of the Science Curriculum, one of the fundamental goals of the science, engineering, and entrepreneurship components is to guide students in identifying real world problems related to the topics studied and in developing practical solutions in the form of tangible products. During the design phase of these products, students are encouraged to consider essential factors such as time, cost, and available materials mirroring processes employed in professional engineering. This emphasis reflects the curriculum's prioritization of engineering competencies and product-oriented thinking.

In line with global educational trends, Turkey has also placed increasing importance on the integration of science, technology, and engineering within its national science education standards. The curriculum aims to foster students' design and engineering skills while encouraging interdisciplinary connections among science, mathematics, and technology to cultivate innovative thinking and practical application (Yapıcıoğlu, 2021).

Design-Based Learning DBL is a pedagogical approach that emphasizes engineering-oriented learning and the cultivation of higher-order cognitive skills. Rooted in inquiry and logical reasoning, DBL supports learners in creating functional systems, products, or solutions to real-life challenges (Gómez Puente, Van Eijck, & Jochems, 2013). It encourages students to design personalized projects based on their experiences, thereby transforming theoretical knowledge into practical applications (Doppelt, Mehalik, Schunn, Silk, & Krysinski, 2008). Furthermore, this instructional model establishes active connections among scientific inquiry, design processes, and engineering disciplines (Demirel & Özcan, 2021; Ercan & Şahin, 2015; Wang & Hannafin, 2005).

The literature includes numerous studies that highlight the value of integrating design elements into science instruction. One pioneering example is the work of Penner et al. (1997), who explored the impact of design-based modeling on primary students' abilities to evaluate models while studying the human elbow. Kolodner et al. (2003) structured DBL around interrelated phases such as "Design/Redesign" and "Research/Explanation." Hynes et al. (2011) proposed a nine-step Engineering Design Cycle adapted for high school learners, promoting the practical use of science and mathematics in engineering contexts. Similarly, NASA (2015) outlined an eight-step iterative process for developing new systems or products to support scientific problem-solving.

Wendell et al. (2010) suggested a DBL model that begins with a core design challenge. At this stage, aligned with problem identification, teachers introduce the main task, while students assess their prior knowledge, identify knowledge gaps, and define relevant design criteria and constraints. The next stage involves generating initial ideas or mini-designs that facilitate knowledge acquisition. In the evaluation phase, students collaboratively use decision matrices based on predetermined criteria to select the most viable solution. The chosen idea is then prototyped, tested, and refined. Throughout the process, teacher-guided discussions play a critical role in deepening students' understanding and promoting reflection.

In the Turkish context, DBL practices have been associated with positive outcomes across various domains, including academic performance (Bakırcı & Kaplan, 2021; Özcan & Koca, 2019; Yıldırım & Altun, 2015), decision-making skills (Ayaz & Sarıkaya, 2021), attitudes toward engineering (Ergün & Kıyıcı, 2019), scientific process skills (Şimşek, 2019; Yamak, Bulut, & Dündar, 2014), attitudes toward science (Özkızılcık & Cebesoy, 2020), and perceptions of scientific knowledge (Asal Özkan & Sarıkaya, 2023). In addition, several studies have examined students' perspectives on DBL (Bozkurt Altan & Karahan, 2019; Hacıoğlu, Yamak, & Kavak, 2016; Sarı & Yazıcı, 2019; Yıldırım, 2018). The purpose of this research is to implement the "Pure Substances and Mixtures" unit from the 7th-grade science curriculum using a DBL approach, and to examine its impact on students' academic achievement, motivation toward science, and knowledge retention. To guide the instructional process, the Engineering Design Cycle developed by Wendell et al. (2010) was selected due to its suitability for middle school learners and its structured, classroom-friendly design tailored for effective implementation.

Research Problem

Does the implementation of the DBL approach in the "Pure Substances and Mixtures" unit influence the academic achievement, motivation toward science, and knowledge retention of 7th-grade students?

Sub-Problems

1. To what extent do the pre-and post-test scores on the Academic Achievement Test on Pure Substances and Mixtures (AAT-PSM) differ significantly within the experimental group?
2. Does the comparison of pre- and post-test scores on the AAT-PSM show a statistically significant change for students in the control group?
3. Are there statistically significant differences between the pre- and post-test scores of the Motivation for Learning Science Scale (MSTLS) within the experimental group?
4. Do the MSTLS scores of the control group show any statistically significant change from pre- to post-test?
5. Is there a significant difference between the post-test and retention test scores on the AAT-PSM within the experimental group?
6. Do the AAT-PSM post-test results reveal a statistically significant interaction effect between group membership (experimental and control) and gender?
7. How do the academic achievement gains, as measured by differences in pre- and post-test AAT-PSM scores, compare between the experimental and control groups?
8. Is there a statistically significant correlation between AAT-PSM and MSTLS post-test scores within both the experimental and control groups?

METHOD

Research Design

This study employed a pre-test–post-test control group experimental design, a widely used model in quantitative research to determine causal relationships between variables. Experimental research enables the investigation of the effects of manipulating at least one independent variable on one or more dependent variables (Creswell & Creswell, 2018).

Participants

The study included a total of 46 seventh-grade students, equally distributed by gender (23 males and 23 females), enrolled in Classes A and B at a public middle school affiliated with the Ministry of National Education in Elazığ, during the 2024–2025 academic year. Participants were selected using simple random sampling, ensuring that each student had an equal chance of being included in the sample.

Data Collection Instruments

Academic Achievement Test for Pure Substances and Mixtures (AAT-PSM):

This multiple-choice test, developed specifically for the study, consists of 20 items aligned with the objectives 7th grade science curriculum unit "Pure Substances and Mixtures." The test was designed to be both valid and reliable and was scored out of 100 points. It was administered three times: as a pre-test, to measure initial group equivalence, as a post-test, to evaluate the effect of the instructional intervention and as a retention test, applied four weeks later to assess long-term knowledge retention.

Motivation Scale Toward Learning Science (MSTLS):

The MSTLS was used to measure students' motivation in science education. Originally developed by Glynn and Koballa (2006) and adapted into Turkish by Yılmaz and Çavaş (2007), this scale was administered both before and after the instructional process to identify any changes in motivation levels.

Research Procedure

At the beginning of the study, both the experimental and control groups completed the AAT-PSM and MSTLS as pre-tests, allowing for baseline comparisons in academic performance and science motivation. The intervention phase lasted for six weeks:

- The experimental group received instruction through the DBL approach.
- The control group followed the traditional curriculum based on the Ministry of National Education's guidelines.

Upon completion of the instructional phase, both groups were re-administered the AAT-PSM and MSTLS as post-tests. Four weeks later, the AAT-PSM was applied again to assess retention of knowledge.

Implementation of the Design Process

The experimental group (Class 7/B) was divided into six heterogeneous teams: five groups consisted of four students, and one group consisted of three students. The DBL implementation was based on a structured version of the Engineering Design Process, consisting of the following stages:

1. Problem Identification
2. Needs Assessment
3. Defining Design Requirements
4. Generating Alternative Solutions

5. Selecting the Most Viable Option
6. Developing and Testing a Prototype
7. Evaluating and Refining the Solution
8. Presenting the Final Product

Throughout the design process, instructional tools such as the course textbook, interactive smartboard, animation software, and the science laboratory were used. These resources supported both conceptual understanding and hands-on learning during the design tasks.

Data Analysis

Data were analyzed using SPSS statistical software. The following tests were applied: Paired Samples t-Test, One-Way Repeated Measures ANOVA, Two-Way ANOVA for Independent Samples, Two-Way Mixed ANOVA and Correlation Analysis. Effect sizes for group comparisons were interpreted according to the criteria provided by Üstün and Eryılmaz (2014), while correlation coefficients were evaluated based on the guidelines outlined by Taşpınar (2017).

Limitations

- The sample of the study was limited to two seventh-grade classes selected from a public middle school affiliated with the Ministry of National Education in the Kovancılar district of Elazığ province.
- The scope of the study was limited to the topics included in the *"Pure Substances and Mixtures"* unit, and the Design-Based Science Teaching approach was implemented only within these topics.
- The research process was limited to the 2024–2025 academic year.

RESULTS AND DISCUSSION

Findings for the first and second sub-problems are presented in Table 1.

Table 1 Paired samples t-test results for pre-test and post-test mean scores of AAT-PSM in the experimental and control groups.

Groups	Tests	N	$\bar{X}$	SS	sd	T	p	η^2
Experimental	Pre	23	6.65	2.06	22	-8.371	.001	.45
	Post	23	12.22	3.79				
Control	Pre	23	6.44	2.78	22	-4.572	.001	.23
	Post	23	10.39	4.06				

P<.05

A paired sample t-test was conducted to evaluate the difference between the pre-test and post-test test mean scores of the Pure Substances and Mixtures Academic Achievement Test AAT-PSM of the students in the experimental and control groups. In the experimental group, a significant improvement was observed between the pre-test ($\bar{X}$=6.65; SS=2.06) and post-test ($\bar{X}$=12.22; SS=3.79), ($t_{(22)}$=-8.371; p<.05), with a large effect size (η^2=.45). These results suggest that the design-based science instruction significantly enhanced students' academic performance. Similarly, the control group exhibited a statistically significant increase from pre-test ($\bar{X}$=6.44; SS=2.78) to post-test ($\bar{X}$=10.39; SS=4.06), ($t_{(22)}$=-4.572; p<.05), with a moderate effect size (η^2=.23). Although the traditional instruction also contributed to increased academic achievement, the improvement was more pronounced in the experimental group. These results align with previous research findings (Aksoy, Özcan & Çeken, 2023; Apedoe, Reynolds, Ellefson & Schunn, 2008; Fortus, Dershimer, Krajcik, Marx & Mamlok-Naaman, 2004; Mehalik, Doppelt & Schunn, 2008).

The results for the third and fourth sub-problems are presented in Table 2.

Table 2 Paired samples t-test results for pre-test and post-test mean scores of the MSTLS in the experimental and control groups.

Groups	Tests	N	$\bar{X}$	SS	sd	T	p	η^2
Experimental	Pre	23	48.39	7.36	22	-2.201	.001	.01
	Post	23	50.78	7.14				
Control	Pre	23	81.61	17.38	22	-4.730	.001	.32
	Post	23	83.44	16.02				

P<.05

The paired samples t-test also evaluated differences in students' motivation scores MSTLS. The experimental group showed a statistically significant increase from pre-test ($\bar{X}$=48.39; SS=7.36) to post-test ($\bar{X}$=50.78; SS=7.14), ($t_{(22)}$=-2.201; p<.05), though the effect size was small (η^2=.01). The control group similarly showed significant gains (($t_{(22)}$=-4.730; p<.05), with a moderate effect size (η^2=.32). These results indicate that Design-Based Science Instruction positively influenced student motivation, a finding supported by earlier studies (Aydın, Atalay & Göksu, 2017; Uzun & Keleş, 2012; Yenice, Saydam & Telli, 2012).

The results related to the fifth sub-problem are presented in Table 3 and Table 4.

Table 3 Descriptive statistics of the experimental group's pre-test, post-test and retention test scores on the AAT-PSM.

Tests	N	$\bar{X}$	SS
Pre	23	6.65	2.06
Post	23	13.09	4.04
Retention	23	12.22	3.79

Table 4 One way repeated measures ANOVA results for the experimental group's pre-test, post-test and retention test scores on the AAT-PSM.

Source of Variance	Sum of Squares	Sd	Mean Square	F	p	Significant Difference	η^2
Between-subjects	544.986	22	24.772			1-2	
Process	560.696	2	280.348	55.075	.001	1-3	.72
Error	223.971	44	5.09			2-3	

p<.05; 1=pre test, 2 =post test, 3=retention test

The results of the repeated measures ANOVA indicated a statistically significant difference among the three test scores ($F_{(2, 44)}$=55.075; p<.05). A post-hoc Bonferroni test was conducted to determine the source of the difference, revealing that all paired comparisons (pre to post-test, pre to retention test and post to retention test) were statistically significant at the p<.05 level. An examination of the mean scores shows that the post-test average ($\bar{X}$=13.09) was higher than both the pre-test ($\bar{X}$=6.65) and the retention test ($\bar{X}$=12.22). This suggests that the instructional method employed during the intervention substantially improved student performance. Moreover, the significant difference between (post and retention) test scores indicates a degree of knowledge loss over time. Nonetheless, the higher retention test score compared to the pre-test implies that students were able to retain a considerable portion of what they had learned. Additionally, the large effect size (η^2=.72) underscores the strong influence of the instructional approach on students' science achievement. Comparable findings have been noted in the literature, where student-centered instructional strategies led to significant improvements in retention test scores in favor of the experimental groups (Şengül & Demir, 2024).

The findings addressing the sixth sub-problem are presented in Table 5 and Table 6.

Table 5 Descriptive statistics of students' post-test scores AAT-PSM according to class and gender.

Class	Male			Female			Total		
	N	$\bar{X}$	SS	N	$\bar{X}$	SS	N	$\bar{X}$	SS
7A	11	8.36	3.98	12	12.25	3.28	23	10.39	4.06
7B	12	10.67	3.31	11	13.91	3.67	23	12.22	3.79
Total	23	9.57	3.75	23	13.04	3.50	46	11.30	3.99

Table 6 Two way ANOVA results for students' post-test scores AAT-PSM by class and gender.

p<.05; ** 1=7A male; 2=7A female; 3=7B male; 4=7B female

Source of Variance	Sum of Squares	Sd	Mean Square	F	p	Tukey Significant	η^2
Gender	145.830	1	145.830	11.505	.002		.22
Class	45.048	1	45.048	3.554	.006	1-2, 1-3, 1-4, 2-3, 2,4	.08
Gender * class	1.190	1	1.190	.94	.761		.02
Error	532.371	42	12.676				

The results of the two-way ANOVA revealed a statistically significant difference in post-test achievement scores based on gender ($F_{(1,42)}$=11.505; p<.05). Female students ($\bar{X}$=13.04) scored higher than male students ($\bar{X}$=9.57) on the post-test. The calculated effect size for gender (η^2=.22) indicates a strong impact of gender on academic achievement within the design-based science instruction framework. Similarly, there was a statistically significant difference in students' scores based on class level ($F_{(1,42)}$=3.554; p<.05). Students in class 7B ($\bar{X}$=12.22) achieved higher post-test scores compared to those in class 7A ($\bar{X}$=10.39). The effect size for the class variable was η^2=.08, suggesting a moderate influence of class context on student success in design-based science learning environments. Although the interaction between gender and class was not statistically significant ($F_{(1,42)}$=.94; p>.05), the descriptive statistics and Tukey test results revealed some important trends. Notably, female students in class 7B ($\bar{X}$=13.91) outperformed all other subgroups, including male students in the same class and both genders in class 7A. Across both classes, female students ($\bar{X}_{7Bfemale}$=13.91; $\bar{X}_{7Afemale}$=12.25) consistently showed higher academic achievement than their male peers ($\bar{X}_{7Bmale}$=10.67; $\bar{X}_{7Amale}$=8.36). Among male students, those in class 7B scored better than those in class 7A. The interaction effect size (η^2=.02) suggests a low-to-moderate combined influence of gender and class on learning outcomes in design-based science education. Previous research has also noted the importance of reporting gender-based distributions using frequency and percentage values when analyzing subgroup performance (Satar & Doğru, 2022). The findings addressing the seventh sub problem are presented in Table 7 and Table 8.

Table 7 Descriptive statistics of experimental and control group students' AAT-PSM pre- and post test scores.

Measurements	Experimental			Control			Total		
	N	$\bar{X}$	SS	N	$\bar{X}$	SS	N	$\bar{X}$	SS
Pre test	23	6.65	2.06	23	6.43	2.78	23	6.54	2.42
Post test	23	12.21	3.79	23	10.39	4.06	23	11.30	3.99
Total	46	9.43		46	8.41		46		

Table 8 Two way mixed ANOVA results for experimental and control groups' AAT-PSM pre- and post test scores.

Source of Variance	Sum of Squares	Sd	Mean Square	F	p	η^2
Group	24.011	1	24.011	1.648	.021	.04
Error	640.957	44	11.567			
Time	138.793	1	138.793	1.281	.026	.03
Time*group	9.141	1	9.141	.084	.047	.02
Error	4765.565	44	108.308			

P<.05

The mixed-design ANOVA results revealed a statistically significant difference between the mean scores of the experimental groups and control groups ($F_{(1,44)}$=1.648; p<.05). Specifically, students in the experimental group ($\bar{X}$=9.43) outperformed those in the control group ($\bar{X}$=8.41). Although the effect size (η^2=.04) suggests a relatively small impact, it still indicates the influence of instructional group on students' performance.

When the impact of time pre- and post test was analyzed independently of group membership, a significant difference emerged between the two testing occasions ($F_{(1,42)}$=1.281; p<.05). The average score on the pre-test ($\bar{X}$=11.30) was considerably higher than on the pre-test ($\bar{X}$=6.54), indicating that the instructional period led to learning gains. The effect size for the time variable (η^2=.03) points to a moderate effect. Additionally, the interaction between group and time was also statistically significant ($F_{(1,44)}$=.084; p<.05), suggesting that the degree of change from pre to post-test varied depending on the instructional approach. Specifically, students in the experimental group improved more substantially ($\bar{X}_{pre\ test}$=6.65; $\bar{X}_{post\ test}$=12.21) than those in the control group ($\bar{X}_{pre\ test}$=6.43; $\bar{X}_{post\ test}$=10.39). This supports the conclusion that the design-based instructional method contributed more effectively to academic growth than traditional teaching methods. The interaction effect size (η^2=.02) reflects a modest, yet meaningful, contribution of the teaching method to performance gains.

The findings addressing the eighth sub problem are presented in Table 9.

Table 9 Correlation between AAT-PSM and MSTLS post-test scores for experimental group and control group.

		AAT-PSM	MSTLS
AAT-PSM	r	1	.417
	p		.001
	N	46	46
MSTLS	r	.417	1
	p	.001	
	N	46	46

p=.01; r=pearson correlation

Correlation analysis revealed a moderate and statistically significant positive relationship between students' scores on the Academic Achievement Test for the Pure Substances and Mixtures Unit AAT-PSM and their scores on the Motivation Scale Toward Learning Science MSTLS, with ($r=.417$ and $p<.05$). This indicates that as students' motivation toward science increased, so did their academic achievement highlighting the interdependence between motivation and learning outcomes.

RECOMMENDATIONS

1. DBL approach is a student-centered learning method in which knowledge is concretized, students use their imagination, and produce their own designs. Since it has been clearly demonstrated that even students with low motivation toward science achieve increased academic success through this approach, it can be stated that all science teachers may apply the DBL approach at different grade levels and across different units.

2. The study revealed that retention emerged at a statistically significant level in the class where the DBL method was implemented. This finding is of great importance, especially for students preparing for centralized examinations. As the level of information recall is known to be critical for solving exam questions, it is recommended that this method be used in all courses in alignment with learning outcomes.

3. The DBL method should be particularly preferred across all courses in accordance with learning outcomes, as it promotes cooperative learning through group work and enables students to directly experience the excitement of learning. Since this teaching method incorporates cooperative learning, it has been observed to influence students' daily lives and encourage even introverted students to communicate with their peers. In terms of developing social relationships in everyday life, the use of this teaching method in other courses is also recommended.

4. A researcher who wishes to conduct a study on the DBL approach may first identify a group with high motivation toward science learning and continue the research accordingly, which may lead to higher statistical results in terms of positive academic achievement.

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