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Effects of Hands-on Inquiry-Based Learning Using LEGO® Materials on the Learning of Eighth-Grade Physics Students*

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Physics instruction methods have long been a challenge for front-line teachers and instructors. To improve physics instruction, we have developed an innovative physics instruction method that uses LEGO® to facilitate the teaching of mechanics in middle-school physics classes. We expect the students to learn through construction and hand-on inquiry-based learning using LEGO® materials. After completing the curriculum design, lesson design, and other instruction-involved designs, we have conducted tests on two eighth-grade classes from junior middle schools in Beijing to verify the effect of the LEGO® instruction. The preliminary experiments have revealed improvements in physics study attitudes ($t = -3.099$, $p < 0.005$), physics learning motivation ($t = -3.794$, $p < 0.001$), and inner study motivation ($t = -2.243$, $p < 0.05$) of every member of the pilot study class comprising 35 students. On the basis of these results, we have revised our instruction designs and subsequently conducted experiments on the experimental class totaling 33 students. The physics grades of lower-grade ($t = -6.154$, $p < 0.000$) and middle-grade ($t = -4.971$, $p < 0.001$) students improved significantly. Moreover, attitude, usability ($t = -4.062$, $p < 0.000$), cognitive effectiveness ($t = -4.062$, $p < 0.000$), and LEGO® study attitude ($t = -2.384$, $p < 0.05$) improved remarkably. This article gives an account of the proposed innovative physics instruction design and makes an analysis of its effectiveness using the acquired data. A discussion on the teaching methods for innovative physics class instruction is also included.

Keywords: hand-on inquiry based learning; LEGO® materials; physics instruction

1. Introduction

Education represents the future of a nation, and hence jurisdictions worldwide implement regulations concerning education. In China, high-school students are under great pressure to learn physics. Mandating a similar curriculum as its U.S. equivalent, the Chinese Ministry of Education requires students to be taught a broad base of knowledge. Currently, the main model of teaching in Chinese primary and secondary schools remains traditional, with teachers teaching students through auditory learning. In this model, knowledge is usually taught in an abstract way. However, there still remain plenty of problems to be solved during the implementation of an inquiry-based education reform, which include teachers' lack of knowledge about and experience with inquiry-based instruction [1] as well as the universality and the implementary continuity of the inquiry-based instruction philosophy.

Furthermore, there still exist obstacles to the teaching of physics experiments in elementary and secondary schools. First, because of a lack of time and given the intense effort necessary for developing new teaching methods in addition to the pressure associated with teaching the new content, teachers do not have enough resources to invest in learning and implementing education reforms; hence, they continue with traditional teaching methods, despite the demand for educational reform. Additionally, despite the current education system having been in operation for nearly a hundred years, it still cannot effectively promote student passion and interest in studying, especially in physics. Furthermore,

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teachers rarely attach enough importance to teaching physics experiments, and teaching objectives tend to be utilitarian; consequently, teachers often fail to guide students on their learning attitude. The most fundamental teaching objective of physics experiments classes should be letting students acquire subject knowledge, while the most important objectives of the experiments should be promoting students' abilities to explore, think deeply, and acquire knowledge. Other important objectives include stimulating student interest in experimental exploration and related natural science subjects. However, teachers' current cognition about experiments mainly centers on ensuring that students can execute the test content during the experiments, which is an inverted teaching approach. There is, as discussed above, an urgent need for teaching aids and instruction designs that can not only ensure that students obtain relevant knowledge but also facilitate their manipulative abilities while stimulating their interests.

An integrated teaching and learning (ITL) program was initiated in 1992 and the ITL laboratory was built later in 1997. This could be a convincing example to show the essential status of ITL. With decades of development, the ITL laboratory is in its second round of full-time operation now. The driving force is the excitement of students regarding learning by doing [2].

Lopes et al. argues that engineering students should start getting prepared for their profession demands from the early introductory courses, while introductory physics courses often have little connection to the real world of engineering. LEGO® can fully arouse students' manipulative desire and help improve introductory physics instruction which lacks practicability. Besides, LEGO® construction is like an interesting game, so it's generally attracted to students, the result of which is that it meets the needs of physics teaching for an incremental improvement on both historically low pass rates and students' satisfaction [3].

The two packages developed by faculty members at Tufts University allow teachers to teach engineering with both LEGO bricks and LabVIEW to students from 5 to 50 years old. Students can design, build and optimize their projects using these packages which will motivate them to learn the math and science. This use of LEGO® doesn't only extend learning age but also promote the internal motivation of learners [4].

McKenna and Agogino confirmed that three-dimensional LEGO® models can help students improve their mechanical reasoning [5]. Marulcu and Barnett reported that in physics classes on simple machines, teachers were surprised to discover that engineering activities using LEGO® materials hold students' attentions for a long time [6]. Similarly, Moundridou and Kalinoglou, who investigated the effects of LEGO® Mindstorms® on engineering study [7]; Hadjiachilleos et al. [8], who explored how LEGO® teaching tools prepare science teachers in elementary schools and Kammer et al. [9], who studied the use of LEGO® Mindstorms® for facilitating computer programming instruction have all reported favorable results. Additionally, LEGO® tools have been reported to play a positive role in classes on various subjects, such as engineering, science, and computer programming.

Therefore, we propose an innovative physics instruction method that uses LEGO®. LEGO® is used for constructing models of objects, an activity that has a close connection with mechanics in physics. Additionally, project-based study utilizing LEGO® tools can improve students' manipulation, scientific inquiry, and group cooperation abilities. Therefore, development of an innovative physics instruction design through praxis and improvement is feasible. This article focuses on the design, implementation, improvement, and innovation during teaching using LEGO®. Moreover, data analyses and the advantages and current drawbacks of the proposed innovative LEGO® instruction are reported.

2. Research method

2.1 Pilot study

Research subjects: We chose one class as the pilot study class (hereafter, Class B). There were 35 students (23 boys and 12 girls). The average age was 14 years. The research objective was to teach them using LEGO® and to direct activities without teaching any physics knowledge points. The main goal was to observe whether their attitudes changed after using LEGO®.

Test process: First, students built a LEGO® car in groups. They then let the car slide down a ramp so that they could explore how to make the car slide further. The content of this activity was related to physics knowledge points but we did not directly teach the students any physics. We used an attitude scale to measure the changes in their attitudes to physics study to verify the validity of the initial LEGO® innovative teaching.

In the pilot study, the physics learning attitude ($t = -3.099$, $p < 0.005$), external motivation ($t = -3.794$, $p < 0.001$), and internal motivation ($t = -2.243$, $p < 0.05$) improved in all 35 students (Table 1). However, the usability of the LEGO® materials did not improve. A possible reason is that this was the first time that the students had used LEGO®,

Table 1. Pilot study result

Dimension	Mean	Std. Deviation	Std. Error Mean	t	df	Sig
LEGO® usability	–0.91429	3.50941	0.59320	–1.541	34	0.133
Physical learning attitude	–2.31429	4.41769	0.74673	–3.099	34	0.004
External motivation	–2.05714	3.20792	0.54224	–3.794	34	0.001
Internal motivation	–1.42857	3.76740	0.63681	–2.243	34	0.031

and they did not have enough time to become accustomed to it; consequently, they found using LEGO® difficult. Thus, students should be given more time to become accustomed to using LEGO®. Overall, in the pilot study, some dimensions improved, which inspired us to probe further and conduct the formal experiment.

2.2 Formal study

Research subjects: We randomly chose another class as our formal test class (Class A). There were 33 students in Class A (22 boys and 11 girls). The average age was 14 years. The study aim was to observe and record students' changes in attitude and exam grade after the new innovative LEGO® instruction was implemented.

Process: To ensure ecological validity, we chose Class A for the formal study. First, instructors administered pretest questionnaires and rating scales. Subsequently, the students participated in activities under instructors' guidance. Simultaneously, the instructors observed and recorded the students' behavior. At the end of the experiment, instructors administered posttest questionnaires and rating scales to test the changes in attitude and exam grade after the innovative LEGO® instruction. Finally, we interviewed the students.

Suggestions: For teachers using LEGO®, we recommend the following: (1)Allow students participating in activities a reasonable time. Too short a time will result in no effect, and too long a time will lead to slow progress. (2)Ensure efficient LEGO® instructional design. Design a proper instructional process that can take complete advantage of LEGO®; the use of worksheets can facilitate students' independent exploration. (3) Give different students different rewards. The experimental results revealed large differences in the learning characteristics among lower-, middle-, and higher-grade students, as explained in the following section; for example, LEGO® teaching is inefficient when applied to higher-grade students but significantly improves the educational attainment of lower-grade students. Figure 1 shows students using LEGO® materials in physics classes through the hand-on inquiry based learning.

3. Data analysis

3.1 Total grade improvement

To determine the effect of our instruction method, we redistributed the questionnaire after the experiment. We used SPSS 16.0 to analyze the pretest and posttest achievement distribution (Table 2). The average pretest and posttest scores of Class A were approximately 43 and 65, respectively, which indicated that student performance improved after the experiment. For verifying this result, we conducted a paired-sample t-test. The pretest and posttest scores differ significantly and that the proposed teaching method is effective in improving the student scores.

3.2 Grade improvement by student level

To further study the relationship between the improvement in posttest grades and pretest grades by student performance level, we defined three grade levels according to pretest grades in the experimental class (Table 3): higher-grade (those whose pretest grades were in the top one-third), middle-grade (those whose pretest grades were in the middle one-third), and lower-grade (those whose pretest grades were in the bottom one-third).

First, we analyzed the data of the lower-grade students by using a paired-sample t-test. The average pretest and posttest scores for this level were 33.4 and 55.4, respectively, which differ significantly ($p < 0.001$).

Subsequently, we conducted paired-sample t-tests for the other two levels. For the middle-grade level, the average pretest and posttest scores were 41.5 and 62, respectively, which too differed sig-

Table 2. Paired-sample t-test of pretest and posttest scores of Class A

	Mean	Std. Deviation	Std. Error Mean	t	df	Sig
Pretest and posttest of Class A	–22.4849	14.20634	2.47301	–9.092	32	0.000

Table 3. Results of the paired-sample t-test for low-, middle- and high-grade students

Pre-post	Mean	Std. Deviation	Std. Error Mean	t	df	Sig
low grade level	–22.0000	11.85749	3.57517	–6.154	10	0.000
Middle-grade level	–20.5455	13.70667	4.13272	–4.971	10	0.001
high-grade level	–7.36364	13.50017	4.07045	–1.809	10	0.101

nificantly ($p < 0.001$). The average pretest and posttest scores for the higher-grade level were 54 and 61.3, respectively; this difference was nonsignificant ($p > 0.05$).

On the basis of these analyses, we conclude that the proposed innovative teaching methods using LEGO® materials are effective in improving the grades of middle- and lower-grade students in their physics learning. This result may relate to learning attitude. We next analyze students' learning attitudes in detail.

3.3 Analysis of attitude scale data in the experimental class B

On the basis of a literature review, we chose an attitude scale and appropriately revised it. The modified attitude scale comprised 31 questions across six categories: LEGO® ease-of-use [10], cognitive validity, LEGO® learning attitude, physics learning attitude [11], physics learning motivation, and internal learning motivation [12]. We conducted a reliability analysis of each construct and the entire questionnaire, the Cronbach's Alpha coefficient for the questionnaire reached at 0.8, suggesting that the questionnaire is reliable. Then, we administered the pretest and posttest attitude scale before and after implementing the proposed innovative teaching method, respectively. We paired the data by dimensions and analyzed it using a paired-sample t-test (Table 4).

(a) Ease of use of LEGO®

The significance value of the difference in the pretest and posttest scores was approximately 1.47×10^{-4} ($p < 0.001$), which indicates that the ease of use of LEGO® improved significantly. This result proves that the proposed curriculum design is easy to use.

(b) Cognitive validity

The significance value of the difference in the pretest and posttest scores was approximately 0.035 ($p<0.05$), which indicates that cognitive validity improved significantly. This result clarifies that the proposed method can facilitate middle-school students' understanding of difficult and important topics in physics textbooks.

(c) LEGO® learning attitude

The significance value of the difference in the pretest and posttest scores was approximately 0.023 ($p < 0.05$), which indicates that the LEGO® learning attitude improved significantly. This result shows that LEGO® materials can increase students' interests in physics and that teaching using LEGO® is accepted and supported by students.

(d) Physics learning attitude

The significance value of the difference in the pretest and posttest scores was approximately 0.065 ($p > 0.05$), indicating that there is little (nonsignificant) improvement in physics learning attitude. This may be because the students had a positive attitude to physics learning even before the proposed method was implemented. Alternatively, the results indicate that our curriculum design needs further improvement.

(e) Physics learning motivation and internal learning motivation

The significance value of the difference in the pretest and posttest scores of physics learning motivation was approximately 0.827, whereas that of internal learning motivation was approximately 0.076. This result reflects the difficulty in increasing students' learning motivation. Future studies can focus on increasing students' interest in exploring

Table 4. Attitude analysis of data from the formal experiment

Dimensions	Mean	Std. Deviation	Std. Error Mean	t	df	Sig
Ease of use of LEGO®	–2.15	3.04	0.53	–4.06	32	0.000
Cognitive validity	–1.00	2.61	0.45	–2.20	32	0.035
LEGO® learning attitude	–0.88	2.12	0.39	–2.38	32	0.023
Physics learning attitude	–0.97	2.91	0.51	–1.91	32	0.065
Physics learning motivation	–0.09	2.36	0.41	–0.22	32	0.827
Internal learning motivation	–0.67	2.09	0.36	–1.84	32	0.076

and gaining knowledge, which is likely to improve their motivation for learning.

4. Discussions

We implemented the proposed teaching method using LEGO® materials in a preliminary experiment and measured the learning attitude of students after the experiment. All thirty-five students in the preliminary experiment class showed a significant improvement in physics learning attitude, physics learning motivation, and internal learning motivation. Thus, although we didn't associate the proposed teaching process with the physics knowledge in the junior high-school textbook, students displayed a positive attitude toward physics learning. Teaching junior-high-school physics using LEGO® materials is therefore feasible. Additionally, we found that the ease of use of LEGO® did not significantly improve, which indicates that the proposed LEGO® teaching format is not easy for students to adapt to. Therefore, on the basis of the results of the preliminary experiment, we revised the proposed curriculum design by adding detailed graphic and text instruction to worksheets and including specialized activities for teaching the proposed LEGO®-based method appropriately.

In the formal experiment, comparing the pretests to the posttests of the physics knowledge, students made a remarkable progress in the tests, which is consistent with the results of Williams et al. [13] who reported LEGO enhanced students' physics content knowledge. In addition, we found that students who were in the middle-grade and lower-grade levels showed significant improvement in their grades, whereas higher-grade students did not. Lindh and Holgersson [14] also found that the pupils with medium scores benefited more than pupils with high scores.

We can infer that innovative teaching with LEGO® makes difficult knowledge easier to understand and that students can learn a broader range of knowledge through hand-on inquiry based learning methods compared with the traditional method. Higher-grade students did not exhibit significant progress.

Regarding learning attitude, LEGO®'s ease of use, cognitive validity, and LEGO® learning attitude showed significant improvement, which reflects that students become interested in learning with LEGO® after implementing the hand-on inquiry based learning method. The students also reported that the proposed teaching method makes difficult knowledge easier to understand. Additionally, after our curriculum revision, students find LEGO® materials easier to use than flexible physics equipment. However, in this case, students' physics learning attitude, motivation, and internal learning motivation did not show significant improvements, which is consistent with the results of Jing, et al [15]; this can be further examined in further research.

5. Conclusions

This article focuses on the proposed innovative physics instruction design and goes further to analyze its effectiveness using the acquired data. Its preliminary experiments have revealed improvements in physics study attitudes, physics learning motivation, and inner study motivation of every member of the pilot study class. And the formal experiment has shown that the physics grades of lower-grade and middle-grade students rose significantly. Moreover, attitude, usability, cognitive effectiveness, and LEGO® study attitude have been improved remarkably. Therefore, it concludes that innovative physics instruction design by using LEGO® material is efficient.

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