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Learning Mathematics from Examples and by Doing: Enhancing Learning Engagement and Self-efficacy

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Abstract. Purpose: Numerous empirical studies have confirmed that learning from examples and by doing (LFED) can improve learning efficiency; however, its impact on learning motivation is still unclear. Therefore, this study investigated the effects of LFED on students' mathematics learning performance, academic engagement and academic self-efficacy to explore its effect on Learning motivation. Methods: In a cluster randomized controlled trial, 119 seventh-grade students were randomly assigned to either a four-month LFED group (n=59) or a conventional group (n=60). The interventional group was taught by the LFED method, and the other received a traditional teaching method. Both groups were assessed before and after the intervention to measure academic performance in mathematics, learning engagement, and academic self-efficacy. Results: Repeated-measures ANOVA showed a significant group-by-time effect for academic self-efficacy and learning behavior dimension scores; there were no significant group-by-time effects for math academic performance, learning engagement scores, and related dimension scores. Paired-sample t-tests showed no significant change in self-efficacy scores in the LFED group but a significant decrease in self-efficacy and all related dimensions scores in the conventional group. There was no change in cognitive engagement dimension scores in the LFED group but a substantial decrease in the conventional group. Conclusion: As an adaptive learning method originating from artificial intelligence, LFED had an equal impact on math academic performance as traditional teaching methods. However, LFED was feasible and effective in enhancing students' academic self-efficacy and cognitive learning engagement.

Keywords: adaptive production learning methodology; learning from examples and by doing; learning engagement; academic self-efficacy.

1. Introduction

Large-scale survey results show that many Chinese students, especially middle school students, are generally bored with schools[1]. One study even reported that 19.2% of Chinese middle school students may have hidden truancy[2]. Some researchers believe the traditional teacher-centered approach in Chinese classrooms has hindered students' potential and autonomy, leading to passive learning, weariness, and high dropout rates[3]. Learning from examples and by doing (LFED) provides a potential solution to those problems as an adaptive learning method originating from artificial intelligence.

Herbert A. Simon, one of the founders of artificial intelligence, and Professor Xinming Zhu, a psychologist at the Chinese Academy of Sciences, discovered the advantages of using a "Human

Adaptive Production System" in learning mode and proposed LFED. LFED utilizes adaptive production systems to simulate human learning and problem-solving. It represents mathematical knowledge as production rules and designs examples and problems around them. Students expand the scope of problem-solving and improve learning efficiency by actively acquiring new production rules through example examination and problem-solving, which is a proactive, adaptive learning approach [4].

Studies have shown that LFED can achieve equal or better teaching outcomes than traditional methods in less time. Students in the LFED group completed three years of middle school course content in two years and had higher grade point averages than the control group[5].LFED has been successively applied to school mathematics classroom teaching and has produced significant research results[6, 7]. Students with weak foundations benefit more from LFED interventions,e.g., LFED can help students with learning difficulties in application-solving skills and improve their academic performance[8]. Ma et al. (2009) found that LFED significantly enhanced students' learning outcomes with low prior knowledge and working memory breadth compared to traditional teaching methods[6].

According to the cue recognition and cue elaboration theory[9], During LFED, learners can focus on critical problem-solving cues instead of using the means-end approach, which makes it easier to acquire cognitive skills[10, 11] and significantly improves learning efficiency[10, 12, 13]. Although some scholars have proposed that LFED can also improve students' learning motivation and self-confidence[5], researchers have yet to explain the interaction between LFED and learning motivation within the existing theoretical framework.

Various empirical studies based on Self-Determination Theory (SDT) have found that autonomy-supportive (AS) teaching styles facilitate students' engagement in learning and academic performance.[15] Moreover, it reduces students' boredom and actual dropout behavior [15-18]. In the field of example-learning research, some researchers have found that examples can stimulate learning motivation [19]. However, related research has been conducted in tightly controlled laboratories, and empirical studies in natural classroom settings still need to be developed[14].

This study aimed to observe the impact of LFED on student learning outcomes in mathematics, especially on motivation, such as learning engagement and academic self-efficacy. LFED has two key characteristics that make it different from traditional teaching methods. Firstly, it combines learning from example with learning by doing, enabling students to construct their knowledge system independently without relying on teachers and fully engage in the learning process. Secondly, courseware design principles, such as small steps and timely feedback, help students gain success and confidence throughout the learning process. These characteristics compensate for students' motivational issues, such as aversion to learning and difficulties caused by improper teaching concepts and methods. This study can provide new references for autonomous classroom reform in the context of implementing new curricula and new textbooks in China.

2. Method

2.1 Sampling

A sample of 119 seventh-grade students from a middle school in Linyi, Shandong Province, were selected as the participants aged 12~14 (M age = 12.58, SD = 0.53) of this study. Randomly divide the two parallel classes into an LFED group (n = 59, M age = 12.58, SD = 0.50) and a conventional group (n = 60, M age = 12.58, SD = 0.56). All participants took part in both the pre-test and post-test assessments. However, only the LFED group students participated in the intervention experiment. The same content and exams were taught to both groups of participants without any differences.

2.2 Measurement

2.2.1 Math Learning Engagement Scale

The Math Learning Engagement Scale was developed by Wang et al. (2016)[20] and revised by Liu[21]. This study used the revised version to measure the level of engagement in math learning. This scale contains 26 items and is scored on a 5-point scale (1 = completely disagree, 5 = agree), evaluating social engagement (e.g., I try to work with others who can help me in math), behavioral engagement (e.g., I try to learn more about the topics we cover in class), emotional engagement (e.g., I feel good when I am in math class), and cognitive engagement (e.g., I try to understand my mistake when I get something wrong). Six of the items were reverse-scored. In this study, the Cronbach's α was 0.93.

2.2.2 Academic Self-efficacy Scale

The Chinese version of the Academic Learning Engagement Scale was developed by Pintrich and De Groot (1990) and revised by Liang. This study used the revised version to measure students' ratings of their ability to learn math on a 5-point scale[21]. This scale contains learning ability (Questions 1 to 11, e.g., I believe I can do well in my studies.) and learning behavior (Questions 12 to 22, e.g., When studying, I always like to check if I have mastered what I have learned by asking myself questions and answers). Learning ability assesses a student's ability to achieve excellence in learning and avoid academic failure on time. Learning behavior refers to students' assessment of whether their efforts can lead to good results and learning outcomes. The sum of the scores from these two dimensions is also the scale's total score. Higher scores indicate higher student academic self-efficacy in math. In the current sample, the Cronbach's α was 0.95.

2.2.3 Measurement Statistical Analysis

All statistical analysis was conducted using SPSS 24.0. Intervention effects (Group ×Time interactions) were examined using repeated measure ANOVA, testing the difference of change from pre-test to post-test between the LFED and conventional groups. Pre-test-to post-test changes were analyzed within each group using a paired sample t-test. Cohen’s d and η2 were used to calculate an effect size.

3. Result

3.1 Intervention Effects on Math Score

Repeated measure ANOVA showed that there was no significant interaction between group (LFED group, conventional group) and time (pre-test, post-test) for math score (TABLE I). As further paired-sample t-tests showed, math scores declined significantly in both the LFED group (M Post-test – M Pre-test = -6.54, t = -3.24**, Cohen’s d = -0.32) and conventional group (M Post-test – M Pre-test = -5.98, t = -4.29***, Cohen’s d = -0.31).

3.2 Intervention Effects on Learning Engagement

Repeated measure ANOVA showed no significant interaction between group and time for learning engagement and its dimensions (TABLE I). Further, paired-sample t-tests showed that in the intervention group, scores on learning engagement and each of its dimensions increased from pre-test to post-test, except for the cognitive engagement dimension, but did not show a statical difference. While in the conventional group, all the scores decreased, and the score of the cognitive engagement dimension showed a significant decrease (M Post-test – M Pre-test = -1.65, t = -3.34***, Cohen’s d = -0.45).

3.3 Intervention Effects on Academic Self-efficacy

Repeated measure ANOVA showed a significant interaction between group and time for academic self-efficacy ($F = 4.16$, $p < 0.05$, Partial $\eta 2 = 0.034$) and its learning behavior dimensions ($F = 4.11$, $p < 0.05$, Partial $\eta 2 = 0.34$, TABLE I), indicating different changes from pre-test to post-test in the two groups. Further, paired-sample t-tests indicated that the conventional group had significantly lower scores on the post-test than the pre-test (M Post-test – M Pre-test = -4.77, t = -3.04**, Cohen's d = -0.31), while the LFED group had higher scores on the post-test than on the pre-test (M Post-test – M Pre-test = 0.31). On the learning ability dimension, both groups scored lower in the post-test than in the pre-test. However, it showed a statistical difference in the conventional group (LFED Group: M Post-test – M Pre-test = -0.28; Conventional Group: M Post-test – M Pre-test = -2.50, t = -2.74**, Cohen's d = -0.29). On the learning behavior dimension, the post-test scores of the conventional group are significantly lower than those of pre-test (M Post-test – M Pre-test = -1.19, t = -2.51*, Cohen's d = -0.24), while the post-test scores of the LFED group are than those of pre-test (M Post-test – M Pre-test = 0.57), but not significantly.

Table 1. Each Indicator Scores Before and After Intervention In Two Groups

Index	**LFED Group (*n* = 59)**				**Conventional Group (*n* = 60)**				***F***	***Partial η²***
	Pre-test	*Post-test*	*t*	*Cohen'd*	*Pre-test*	*Post-test*	*t*	*Cohen'd*		
Original Math Scores	78.64±18.99	72.66±19.04	**-4.29*****	-0.31	79.36±21.55	72.83±19.70	**-3.24****	-0.32	0.05	0.000
Learning Engagement	102.36±17.48	102.88±14.08	0.25	0.03	101.80±15.64	98.00±18.54	-1.81	-0.22	2.15	0.018
Social Engagement	23.07±4.44	24.17±3.79	1.83	0.27	23.08±4.50	22.45±5.51	-0.84	-0.13	3.26	0.027
Behavioral Engagement	30.92±6.01	30.75±4.86	-0.24	-0.03	31.48±4.77	30.82±5.89	-1.04	-0.12	0.27	0.002
Emotional Engagement	29.12±5.24	29.41±4.64	0.47	0.06	28.37±5.67	27.52±5.67	-1.14	-0.15	1.38	0.012
Cognitive Engagement	19.25±4.13	18.54±3.23	-1.31	-0.19	18.87±3.51	17.22±3.84	**-3.34*****	-0.45	1.63	0.014
Academic Self-efficacy	78.37±18.67	78.68±12.98	0.16	0.02	78.07±14.83	73.30±15.87	**-3.04****	-0.31	**4.16***	0.034
Learning Ability	39.92±10.08	39.64±8.25	-0.27	-0.03	38.67±8.08	36.17±8.95	**-2.74****	-0.29	2.66	0.022
Learning Behavior	38.46±9.47	39.03±5.78	0.54	0.07	39.04±8.11	37.13±8.14	**-2.51***	-0.24	**4.11***	0.034

4. Discussion

The study's results found that after the LFED intervention, the scores of self-efficacy and learning behavior dimensions increased significantly in the LFED group. In contrast, the conventional group significantly decreased self-efficacy scores and all dimensions. The results suggested that LFED had a substantial increase in self-confidence in one's ability to adopt some learning behaviors to achieve a specific goal (learning behavior dimension) and maintained self-confidence in one's ability to cope with academic tasks (learning ability dimension) compared to the conventional group, which is in line with some of the results of previous studies related to example learning[5, 22]. However, related studies have mainly been conducted in tightly controlled laboratory environments, and empirical studies in natural classroom settings still need to be included. The present study provides new evidence that the exemplar rehearsal pedagogy enhances students' academic self-efficacy in authentic classroom contexts. There may be two reasons for this result: from the perspective of cognitive load and information processing, in example-drill teaching, students use examples to make analogies, discover the ins and outs of knowledge, and find ways to

construct knowledge[23, 24]. Learning by doing helps them to realize knowledge transfer, and variant training allows them to broaden the breadth of their thinking. For most students, the learning method becomes traceable. When they master learning and metacognitive strategies, they can build up the confidence to learn mathematics well and make them more willing to obtain self-efficacy in learning behavior through independent learning[25]. From the perspective of the intervention mode, in the learning mode through the teacher's explanation, students are in the position of passive acceptance of knowledge, while the material design of LFED is to provide some examples, create certain problematic situations, inspire students to think actively, and require students to learn through intellectual operations such as analyzing and comparing, analogical generalization, and searching in the problematic space, which is the active heuristic learning with operative solid properties, and thus dramatically improves motivation and self-confidence in learning[3].

The results of this study found that although there was no significant intervention effect in the LFED group in terms of learning engagement and scores on the dimensions, the conventional group had more decreases in these indicators and even a moderate reduction in the cognitive size, suggesting that LFED has a positive effect on maintaining students' learning engagement compared to the conventional group. The significant downward trend in the conventional group is also in line with the findings of previous studies on secondary school students' learning engagement in mathematics. As the difficulty and depth of math learning content increase, students feel increasingly overwhelmed by learning. They are prone to a mismatch between learning input and learning outcomes, showing fear of difficulty, losing motivation and interest in learning, resulting in low learning engagement, and even giving up learning[26]. Under the premise of increasing the intensity and difficulty of math learning, the intervention group was still able to maintain the learning state due to the material design principles of LFED, such as "low steps, small steps, and strengthening the learning of production conditions," which reduce the burden on students' cognitive system.

The results of this study found no significant difference in academic achievement between the two groups, suggesting that LFED based on adaptive learning theory is on par with the effects of the current pedagogy, which is in contrast to the findings of Zhu et al.[5] Ma, S. et al.[6], and Zengzhuan, Zhang, et al.[7].who found that LFED significantly improved students' math. The possible reason for the different findings of the conventional group is the enhancement of the teaching philosophy and methods. The conventional group in the study used the traditional teacher-centered teaching method. Still, after more than two decades of the new curriculum reform, the concept of student-centered teaching has been deeply rooted in people's minds and has been implemented in many schools in China[27]. It has been proved that the student-centered classroom teaching model can improve classroom teaching efficiency and enhance students' subjectivity to a certain extent[27, 28], which is in common with the LFED's emphasis on highlighting students' subjectivity in the learning process. However, there is a big difference between the conventional and intervention groups' teaching methods. The conventional group highlights inquiry learning, emphasizes students' hands-on practice, self-directed exploration, and cooperative communication, and requires higher teaching ability and experience of teachers. At the same time, LFED mainly adopts the example-learning and doing-learning methods of adaptive learning, which emphasizes guiding students to acquire knowledge and skills by general cognitive laws and has less reliance on the teacher [29].

5. Conclusion

In summary, this study shows that the LFED model had an equal impact on math academic performance as traditional teaching methods. However, LFED was feasible and effective in enhancing students' academic self-efficacy and cognitive learning engagement. Compared to traditional teaching methods that mainly rely on teacher lectures, LFED has several unique and advantageous aspects. First, from the perspective of student subjectivity, teaching methods put

students in a passive position. At the same time, LFED allows students to actively learn through examples and problem-solving, stimulating motivation and reflecting a student-centered approach. Second, from the perspective of learning speed, LFED advocates promoting individual learning and tutoring instead of a unified learning schedule in the classroom. Every student can fully improve, avoiding the weaknesses of traditional teaching and achieving unified teaching objectives. Third, from the student development perspective, LFED combines knowledge acquisition, learning ability cultivation, and motivation stimulation. It promotes diligent thinking habits and autonomous learning abilities through problem-solving. The cognitive design principles of LFED enhance students' sense of success and confidence while improving their knowledge acquisition, ability, and motivation. The LFED method is a self-learning approach that utilizes adaptive production learning as its foundation. It represents mathematical concepts as production and aligns with students' cognitive processing characteristics through learning by example and doing. This approach is centered around the student and has proven highly efficient and effective. In the classroom, teachers serve as auxiliary support, providing timely encouragement and individual guidance. This approach is a valuable resource for the latest curriculum reform, particularly in building students' motivation to learn and boost their self-efficacy. Furthermore, the LFED principles for courseware design, including small steps, timely feedback, and strengthening condition recognition, can be essential references for textbook reform.

6. Limitations

The present study is an LFED intervention study. Although it has good ecological validity and practical significance, the mechanisms involved, especially the mechanisms by which the intervention plays a role in motivational factors such as engagement in learning and self-efficacy, are still not precise, e.g., according to the theory of Self-system Processes[30], essential people can affect learners ' emotional experiences. Teachers, as important people for students, provide autonomy support that can lead to more positive emotional experiences and less negative emotional experiences[31] and engage in learning with full enthusiasm. Therefore, teacher autonomy support may significantly impact the emotional dimension of academic engagement and relatively less on the cognitive and behavioral dimensions. However, the results of the present study found that LFED had a more significant impact on the cognitive dimension than on the emotional and behavioral dimensions, and more in-depth investigations on the effect of LFED on the different dimensions of academic engagement can be carried out in future related studies. In addition, although LFED is based on an in-depth analysis of individual learning mechanisms, there is still room for further exploration of the scope of application of LFED and how to design reasonable examples and classroom teaching boards with specific contexts.

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