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A Mixed-Method Analysis of Scaffolding Patterns of High-, Average-, and Low-Achieving Students when Solving Complex Math Problems in Multimedia Environment*

Kwon, Jung Min
Dept. of Special Education, Ewha Womans University

《 Abstract 》

The purpose of this observational study was two-fold. First, we examined the differences between achievement groups' cognitive strategies in solving a complex math problem in computer-based assessment (CBA). Then we investigated whether the use of strategies have changed after a constructivist instruction. The tests were administered before and after they had participated for four weeks in a video-based math anchored instruction curriculum. Students' activity on screen while problem- solving were recorded and analyzed. Four different scaffolding codes for cognitive strategies were used in the analysis. The results show that, low achieving students used more procedural scaffolding than the higher achieving peers. Students used more problem relevant scaffolding post-instruction than pre-instruction. The data indicate that the cognitive strategies used by the low-achievers have become to resemble more like the high-achievers after EAI. Implications for future research and related practices are discussed.

Key Words : scaffolding, anchored instruction, math, multimedia, low-achieving

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Ⅰ. Introduction

Not only do underachieving students typically show low academic self-concept (Schunk, 1998; Supplee, 1990; Whitmore, 1980), low self-efficacy (Schunk, 1998), low self-motivation (Weiner, 1992), low goal-valuation (McCall, Evahn, & Kratzer, 1992), and negative attitude toward school and teachers (Colangelo, Kerr, Christensen, & Maxey, 1993; Ford, 1996; Rimm, 1995), but they also show differences in cognitive strategies (Floyd et al., 2003; Lian, 1998; McGrew & Hessler, 1995). For example, in Lian's (1998) study, she has found that low-achievers process knowledge differntly from high-achievers. Low-achievers were less thoroughly processing knowledge, took less time to make sense of concepts, took less effort to sort, and group concepts, formed less relevant links to concepts, and organize less into hierarchical structure between the concepts. Wu & Tsai (2005) has also found that low-achievers made less use of knowledge, made less use of metacognitive strategies, and were more reluctant to integrate information into knowledge. However, Wu & Tsai found that students benefited from constructivist instruction in the use of cognitive strategies.

The purpose of this study was two-fold. First, we investigated to find whether there were differences in the use of cognitive strategies when solving problem between high and low achievers. But secondly, we also were interested in whether after a student-directed complex problem solving practices, those differences in the use of cognitive strategies would narrow.

In contrast to the traditional pedagogy of teacher-directed, skills-based education, complex problem-based learning requires students to take an active role in their own learning, which shifts the responsibility of setting learning goals to the student (Hannafin, Hall, Land, & Hill, 1994). To set meaningful goals and take charge of one's own learning, the learner needs to employ cognitive strategies (Ge & Land, 2004). Some of these internal cognitive strategies include self-monitoring of one's problem-solving progress (Iiyoshi & Hannafin, 1998), inquiring and finding of the problem (Ge & Land, 2003), organizing information (Liu & Bera, 2005), finding of what they do not know (Winn & Synder, 1996), goal-setting/attaintment and problem solving (Lee et al, 2006), planning, and selecting appropriate strategies (Hannafin, Land, & Oliver, 1999) to arrive at a solution.

The cognitive strategies that are employed during the meaning-making or learning processes are called scaffolding. Scaffolding refers to the use of tools, strategies, and guides that support students achieve higher level of understanding (Hannafin, Land, & Oliver, 1999). Although the traditional understanding of scaffolding was limited to adult-child social interaction (Vygotsky, 1978), contemporary researchers have begun to study scaffolding as internal cognitive tools. Especially in the study of complex problem-based learning, researchers have found that cognitive scaffolding plays a critical role in student learning. Complex problems that are often ill structured, open-ended, and situated, often demand that students guide their own problem solving strategies and skills (Zydney, 2005).

With the development of new technologies, these cognitive scaffolding has been able to be facilitated by embedding cognitive tools(Brush & Saye, 2001) in problem-based multimedia learning environment. For example, in a design based multimedia environment CoMPASS (Puntambekar & Stylianou, 2002), scaffolds were embedded within the multimedia to influence student learning, to help them regulate their learning processes and accomplish their learning goals, through multiple representations, concept mapping, hypertext and text help. Brush and Saye (2001) embedded various scaffolds within a large hypermedia database to support a high-level activity utilizing the database as an information resource. They were able to utilize hyperlinked interactive essays to help students complete tasks, visual prompts to help students explore and focus, and menu to help students linearly index through information. In another hypermedia study by Simons and Klein (2007), hard scaffolds were embedded in the problem-based hypermedia program. These included guiding questions and responses, expert suggestion, hints, cues, and plans. On the other hand, Zydney(2005) focused on scaffolds that support cognitive processing for problem definition. The tools embedded in their problem-solving software were information seeking tools, information presentation tools, knowledge organization tools, knowledge integration tools, knowledge generation tools.

The previous scaffolding studies focus on report of types of scaffolds and their effects on student achievement. However, student characteristics, such as achievement levels, prior knowledge, or disability, were seldom taken into account when they assessed the effects on students. In this study, we were particularly interested how different achievement level students (high-, average-, and low-achieving) engaged in scaffolding while problem solving in multimedia environment. Understanding how students at different achievement levels scaffold could affect the design of instruction and embedded tools to benefit wider range of students, which is one goal of problem-based learning (Gallagher, 1995).

To observe scaffolding patterns, we adopted a curriculum that requires extensive scaffolding activities during learning. The curriculum is called enhanced anchored instruction (EAI), an approach that allows students to solve complex problems in the multimedia environment. EAI is based on anchored instruction (AI) (see Cognition and Technology Group at vaderbilt, 1997), with an additional component of hands-on building activity. EAI problems were especially designed to advance the problem-solving skills of low-achieving students, but they have also been effective in improving the math skills of students across a range of skill levels (Bottge, Heinrichs, Chan, & Mehta, 2002). EAI employs a problem-based learning (PBL) approach, which the core characteristics include: (1) Instructors use probing questions to guide student understanding of authentic-like problems; (2) Students work together in small groups to discuss, test, and find solutions to the problems; and (3) Instructors provide in-depth instruction on skills and concepts as students need them (Bottge et al., 2007).

To assess student learning before and after the EAI, computer based assessment (CBA) is conducted. The CBA was designed to measure the concepts they have learned during the instruction phase, with the potential added benefit of providing students a similar level of interactivity as they had experienced during EAI. This CBA is a good way to observe student scaffolding activity while problem solving in the multimedia environment as all activities need to be done on the screen. In this research, we used the CBA to observe student scaffolding activities while solving multimedia math problems. The purpose of the research was to answer the following questions: How do low achieving, average achieving, and high achieving students scaffold differently when trying to solve a complex math problem in the multimedia environment? What are the natures of these patterns?

To understand student scaffolding patterns in detail, we employed the four constructs of scaffolding by Hannafin, Land, and Oliver (1999). Their model conceptualizes four categories of scaffolds that could be used by students when engaged in technology-supported environment: (a) conceptual, (b) metacognitive, (c) procedural, and (d) strategic.

Conceptual scaffolds are used when students need to determine what to consider when solving a problem. Finding direct or indirect information from within and outisde the problem, to find a solution to the given problem is conceptual scaffolds. This may include finding hints, listening to prompts, and reading key information from problem content. On the other hand, metacognitive scaffolds are less evident. Megacognitive scaffolds support students in managing the underlying processes in learning. Self-management and self-evaluation are examples of this scaffold. It is about the underlying problem-solving skills rather than the content itself. Checking answers, reflecting answers to the current problem to the answers from the previous problems, monitoring one's progress are all considered metacognitive scaffolds. Procedural scaffolds assist students with learning how to use the resources to solve the problem. The "Help" function in Microsoft Word is a good example of this scaffold (Brush & Saye, 2000). Procedural scaffolds help students attain procedural knowledge in solving the problem. It assists students by providing explanation of the kind of functions embedded in the environment, where to find them, and how to use them. Finally, the strategic scaffolds provide students with possible alternate solutions to a problem or different interpretations of given information (Brush & Saye, 2000). This allows the students to find various approaches or techniques to solve a problem rather than just one.

Ⅱ. Method

1. Participants

As with most studies that attempts to look into cognitive processes of students, a small group of students to represent each achieving group participated in the study. To utilize a mixed method analysis which particularly involved quantifying qualitative data, we recruited six students that were selected by their math teachers according to their general achievement levels: two low−, two average−, and two high−achieving for the study. Tracking cognitive processes of six students is still considered a large pool as many studies as such are conducted as single case studies (Wu, 1998). Achievement level was based on their recent standardized achievement test scores (TeraNova Test) and teacher judgement on appropriateness of representation for ability groups. As our purpose of the study was to gain detailed observations of student behaviors, the quantified qualitative data from six students yielded quite a large amount of information to be analyzed. <Table 1> describes the demographic information of the six students. Both of the low−achieving students, who were receiving regular education, were reported to show difficulties with math. In addition, one of the low−achieving student (L2) was low−achieving in reading as well.

2. Procedures for Data Collection

All students took a pretest, either in paper mode or computer mode, then they participated in same a four−week−long mathematics instruction along with the rest of the classmates. Students learned fractions during the instruction phase using Fraction of the Cost (Bottge et al., 2002) and Hovercraft Challenge (Bottge et al., 2002). The instruction involved solving complex real life−like problems, such as measuring wood, finding the most economic way to use wood boards, and figuring out tax and money problems. After students solved the problems in Fraction of the Cost, they used real materials (PVC pipes) and electric tools to build a 3-D life-size object, in this case a hovercraft. After four weeks of instruction, all students took a post test, in the same mode they took the pre test- either paper or computer. While each of these 6 students were taking the computer-based assessment, a r recording system was set up to record their activity on screen directly from the computer. All students took a pre-test before the instruction began. After four weeks of fractions EAI instruction, all students took a post-test. Students were recorded on both tests. The video data on digital videotapes were digitized and compressed into 14.25 GB in MPEG-1 encoding format and then merged into video analysis software called vPrism. vPrism is a video analysis software that can link transcripts to video although we used only the coding feature for this study. Altogether, including both pretests and posttests, a total of 1440 hours of video was captured.

〈Table 1〉 Student Demographic Information

Student	Gender	Age	Difficulty	TeraNova % Rank	Fraction of the Cost Computer Test	
					Pre	Post
H1	M	13	-	82.00	15	30
H2	F	13	-	83.00	18	33
A1	M	12	-	56.00	11	30
A2	F	12	-	61.00	16	29
L1	M	12	in Math	9.00	7	15
L2	M	13	in Math and Reading	4.00	6	17

Note) H1 and H2: high-achieving; A1 and A2: average-achieving; L1 and L2: low-achieving

3. Testing Materials

The EAI computer test was largely composed of three sections. The main section is the problem solving section. It is the backbone of the software and other "information" revolve around these problems. There are seven questions in total, each question being cumulative of the previous.

The second sections are the information pieces where the user can find necessary information to solve the problem. These are hyperlinked at the top of the screen all throughout the problems, enabling the users to access them anytime at any stage. The seven hyperlinks to different information needed to solve problems are: the video that provides context and information to solve the problem, 2-D plans of a skateboard ramp, bank statement, materials list for the skateboard ramp, a hardware store advertisement, information about who is who in the video, and a 3-D tracking device. To solve the problem, it was necessary to access five of the seven hyperlinks. The two hyperlinks ("3-D tracking" and "who's who") were there to help students solve the problem in a more efficient way but did not provide any critical information.

The third major part of the software was the "Help" function available for each of the questions. When the user clicks on the hyperlink to Help function, it reads the directions and shows how to use the buttons in each problem.

4. Data Analysis

Using vPrism, researcher coded the video data of student problem-solving activity into four categories of scaffolding. The codes were set up to identify scaffolding activities and problem answering activities. The scaffolding activities were then identified in four different categories, adapting Hannafin, Land, and Oliver's(1999) four categories of scaffolds in technology-supported environment: (a) conceptual, (b) metacognitive, (c) procedural, and (d) strategic.

Conceptual scaffolds are used when determining what is needed to solve a given problem. This included student viewing the embedded video, listening to the actors' comments, reading the plans, understanding bank statements, and using the ad to buy the needed materials from the material list. Viewing the answers to the previous questions was also coded as conceptual scaffolds. Any scaffolding activity to obtain information to solve the problem was considered conceptual scaffolds. The conceptual scaffolds were then coded again to determine whether the scaffold was directly related or indirectly related to the solution of the problem. Metacognitive scaffolds support the underlying processes in solving a problem. Although the nature of metacognitive scaffold may be somewhat less visible, for coding purposes, only what was visible was coded. One metacognitive scaffolding strategy that the participants employed was going back to previous questions to check answers. The test, as well as the EAI instruction and software, was structured in a way that all problems were related to each other, making impossible to solve one problem without knowing some of the other. Students had to constantly go back and check their previous answers to solve other problems.

Another metacognitive scaffold involved keeping track of wood pieces using the 3-D tracking device which was embedded in the software. Visualization of the number of length of wood they had cut in the test was necessary for students to self-monitor their whereabouts in the problem-solving procedure. The 3-D tracking device was embedded in the software to help students with the visualized follow-up.

Procedural scaffolds assist students with learning how to use the resources to solve the problem. In this study, clicking the "Help" button to hear the directions and see how to use the functions embedded in the software was the only procedural scaffolds available to students.

Finally, strategic scaffolds support students with possible alternate solutions. In this study, alternate solutions were possible in questions 5 and 6 where students can try ways to cut the wood pieces in the most economic way. However, because this could be separated from problem solving activity, strategic scaffolds were first coded as a part of problem answering activity and then later coded to count how many times the student tried different solutions.

The rest of the activities such as measuring, typing the answer, reading the problem were considered problem answering activities. Student activity on screen was observed and coded for duration for each scaffolding activities. All of the activities except for strategic scaffolds were coded in both time-length and count. Strategic scaffolds were only coded in terms of count.

Ⅲ. Results

Results were analyzed in three different variables ? time duration, access count, and relevancy. First, we looked at the time duration for problem answering activities and each scaffolding activities. The results are as shown in <Tables 2>, <Tables 3>, <Tables 4>, and <Tables 5>.

<Table 2> % of time spent on problem answering and each type of scaffolding

Student	Concept		Procedure		Metacognitive		Strategic		Problem	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
H1	21.36	30.10	0	0	0	2.62	-	-	76.15	62.09
H2	27.15	25.75	2.02	0	3.19	2.61	-	-	55.38	69.78
A1	18.35	14.56	.76	0	0	0	-	-	75.90	80.90
A2	31.98	26.35	.72	0	0	.67	-	-	55.09	70.81
L1	32.66	20.75	7.18	4.44	1.23	.71	-	-	47.76	70.04
L2	14.44	24.29	5.60	6.65	2.59	1.41	-	-	64.20	57.24

Results indicate that the high and average achievers spent slightly more time on problem answering activities than the low achievers, though the access count does not necessarily increase with time duration. For instance, the high achieving student H1 spent less time on problem but access count increased from pretest to posttest. From our observation, we could see that this student knew exactly what to do and where to go at the time of posttest. Shorter time on problem at posttest meant the student spent less time reading the problem and thinking about how to solve it.

We also analyzed how many times each user accessed or tried problem answering activities and each scaffolding activities. The results are as shown below.

<Table 3> % of access count on problem and each type of scaffolding

	Concept		Procedure		Metacognitive		Strategic		Problem	
Student	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
H1	47.69	45.45	0	0	0	10.91	(1)	(0)	52.31	62.09
H2	45.19	37.93	.96	0	9.57	8.62	(4)	(5)	42.79	69.78
A1	50.00	50.00	.75	0	0	0	(0)	(0)	48.51	48.25
A2	52.11	40.54	.70	0	0	6.08	(1)	(4)	44.37	41.89
L1	40.52	41.55	6.54	4.93	6.54	4.93	(0)	(0)	44.44	45.78
L2	33.06	47.02	5.79	3.57	11.57	1.79	(0)	(0)	47.94	47.02

Note) Numbers in ( ) show the actual number of how many times rather than the percentage

Access count to the problems increased at posttest because the student was able to fluently use the scaffold tools as well as solve more number of problems compared to the pretest. On the other hand, a low achieving student (L1) spent less time on problem in the pretest because he spent more time at browsing through the tools. As observed, we could see that students who are high achievers seemed to be anchored to the problems, while low- achieving students seemed to be less focused on problem tasks. However at post test, the low achievers' time spent on problem increased to the level of other students of high and average achieving.

Access count of conceptual scaffolds for high- and average- achievers decreased slightly (H1, H2, A2) or stayed the same(A1) at posttest whilst both the low-achievers' increased at posttest. This indicates that students who are high and average achieving became efficient in terms of finding relevant information from the scaffold tools. Students needed less clicks to search for the information they need because they became familiar with the software. Also, there was less need for repeated access to the information. With the exception of the student H1 and L1, all other students' time spent on conceptual scaffolding decreased in the posttest. Students who are low achievers made more trips to the conceptual scaffolding in the posttest. The length of time spent on these scaffolds did not necessarily increase with trip counts. However, from our observation, the low achieving students knew better at posttest where to search for relevant information.

Also note that the lower achievers used more procedural scaffolds than their higher achieving peers. Procedural scaffolds in this study was using the "Help" function. There were seven problems all together hence seven "Help" buttons all together. The pretest shows that both the lowest achieving students almost always used the help function though in the posttest both the time duration and the access count have dropped. From observation, both of the low- achieving students went directly to the help button as the page loaded during pre test, without reading the problems while high and average achieving students rarely went for help.

It is interesting to note that H2 and A2, who were both and the only females in this study, used strategic scaffolds while most of their male peers did not. Strategic scaffolds were students trying to find alternate solutions for the problem. Female students tried to move the wood boards around to consider alternate ways to combine the woods to make most economical use of them.

In addition, for the conceptual scaffolds, we looked at the relevancy of those scaffolds to the problems the students were working on(see <Table 4> and <Table 5>). Direct relevancy means that the information they were seeking were immediately related to the problem, whereas indirect relevancy means that it was not in the most immediate relation to the problem though not wrong. The results show that directly related scaffolds have increased in the posttest, both in terms of time duration and access counts for four students (students H1, A1, A2, and L2). For students H2 and L1, the high, average, and low achievers in direct and indirect concept scaffolding.

<Table 4> % of time duration of conceptual scaffolds directly and indirectly related to the problems

	Direct	Indirect
H1		
Pre	97.17	2.83
Post	97.81	2.19
H2		
Pre	29.54	70.46
Post	80.31	19.69
A1		
Pre	80.39	19.61
Post	65.02	34.98
A2		
Pre	90.06	9.94
Post	98.31	1.69
L1		
Pre	92.45	7.55
Post	60.52	39.48
L2		
Pre	83.43	16.57
Post	95.06	4.94

<Table 5> % of access counts of conceptual scaffolds directly and indirectly related to the problems

	Direct	Indirect
H1		
Pre	51.75	48.25
Post	82.67	17.33
H2		
Pre	19.15	80.85
Post	46.97	53.03
A1		
Pre	80.60	19.40
Post	70.18	29.82
A2		
Pre	51.35	48.65
Post	91.17	8.33
L1		
Pre	77.42	22.58
Post	71.19	28.81
L2		
Pre	72.50	27.50
Post	82.28	17.72

Ⅳ. Discussion

This study investigated scaffolding times and patterns of high-, average-, and low-achieving students when solving a complex math problem in a multimedia environment. We have found that the lower achievers are more in need for procedural scaffolding than their higher achieving peers. Hearing the directions and visually being shown how to answer the problem seem to have been an important part of approaching the problem for the low achieving students. The lower achievers accessed the Help button during both pre and post tests whereas the higher achieving students did not. There are two possible reasons for this result. Many students with math disabilities are known to have low reading skills (Bottge, 2001) which leads to poor word problem solving. When solving word problems, or other math problems, especially at assessment, procedural scaffolds are seldom provided. With this computerized assessment, such procedural scaffolds were immediately at the students' access. Another possible explanation could be due to students' attitude of low self-efficacy (Bandura, 1994) in academics. Repeated failures in the past may have contributed to the students' self belief that they need "help" when solving academic problems. The results of this study suggest procedural scaffolds may be in immediate need for some low achievers and that procedural scaffolds may help students achieve at higher levels.

We have also learned from the results that pre-instruction and post-instruction scaffolding display slightly different patterns. During the pre-instruction scaffolding, indirect scaffolding tended to be higher than during post-instruction scaffolding. This is natural because students are exploring the new software during the pre-instruction phase. After the instruction was given, students were familiar with the context and the need for exploration of the software decreased. Students knew where to go to retrieve the information required to solve the problem. In other words, their practices have become more similar to the high-achievers.

Often in the real world of problem solving, novice problem solvers become experts through participating in apprenticeship (see Lave & Wenger, 1991). An apprenticeship allows novices to acquire skills through interaction with experts that takes time and practice. Through apprenticeship, novice learners' act of working becomes similar to the expert's. In some ways, the nature of scaffolding is similar to this idea of apprenticeship learning (Lajoie, 2005). The novice learner participates in cognitive apprenticeship to become like experts by learning to use cognitive tools such as planning, self-management, and information organizing. The results from this study sheds light upon the possibility of the participating low-achievers' change of scaffolding patterns to assimilate high-achievers. However, we acknowledge that data from our study is too limited to fully support this argument at this time.

Additionally, the results suggest that the lower achievers scored low in comparison in spite of knowing where to go for information. The lower achievers' conceptual scaffolding pattern did not show great distinction from the higher achievers. This finding suggests that providing scaffolding may not be the only significant solution to help students achieve. Our findings from previous research supports that prior knowledge also plays a significant role in student achievement in problem solving environments (Hung, 2005). Also, as for practical applications for low-achievers, we suggest that additional strategies be taught to low-achievers such as self-monitoring. Self-monitoring is a strategy that experts and high-achievers often employ for effective and self-directed learning (Agran, King-Sears, Wehmeyer, & Copepland, 2003). Researchers report that self-monitoring of one's learning or information seeking processes is helpful in maintaining awareness of learning goals throughout the learning activities (Agran, King-Sears, Wehmeyer, & Copepland, 2003; Reid, 1996; Seong & Lee, 2009). It is our suggestion for future research to examine the effects of self-monitoring strategy on low-achieving students in complex multi-media problem solving environment.

Finally, the findings from the study need to be taken with caution. Although tracking six students' cognitive strategies yielded to a large amount of data, it still is considered a small group of participants to draw a statistical conclusion, making it dangerous to generalize the findings of this research to other students, curriculum areas, and cultures. We acknowledge this limitation and this study should be understood as a need for further research involving more participants for statistical significance in the future.

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멀티미디어 환경에서의 스캐폴딩 패턴에 관한 질적 연구
: 우수, 평균, 학습부진 학생들의 수학문제 해결을 중심으로

권 정 민
이화여자대학교 특수교육과

<요 약>

본 연구의 목적은 두 가지였다. 첫째, 학생들이 컴퓨터 기반 시험 환경에서 복잡한 수학 문제를 풀 때 사용하는 인지 전략의 시간과 패턴이 성취수준에 따라 다른지 알아보고자 함이었고, 둘째, 구성주의적 수학 교수 후 이러한 전략 사용의 변화가 있었는지 알아보고자 함이었다. 성취 수준에 따른 6명의 학생(고성취 2명, 평균 수준의 성취 2명, 저성취 2명)이 본 연구의 대상이었으며, 학생들은 4주 동안 진행된 수학교수에 참여하였고, 수업은 앵커드 수학교수방법을 사용한 수업이었다. 모든 학생들을 대상으로 4주 동안의 수업이 이루어지기 전과 후에 사전-, 사후-검사를 실시하였다. 학생들이 시험 보는 동안의 문제 풀이 활동을 스크린에서 녹화되었으며, 인지 전략의 사용을 알아보기 위해 네 가지의 스캐폴딩 코드를 사용해 분석하였다. 분석 결과, 학습부진 학생은 우수 학생보다 과정적 스캐폴딩을 많이 사용한 것으로 드러났다. 또한 모든 학생들은 교수 전보다 교수 후에 문제와 직접적으로 관련 있는 스캐폴딩을 더 많이 사용한 것을 알 수 있었다. 특히 학습 부진 학생들의 인지 전략이 구성주의적인 교수 후 우수학생들의 전략 사용 패턴과 비슷해진 것을 알 수 있었다. 본 연구 결과에 대한 논의와 함께, 향후 연구 및 교육현장에서의 실제를 위하여 제안이 이루어졌다.

주제어 : 스캐폴딩, 앵커드 교수, 수학교육, 멀티미디어, 저성취, 학습부진

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