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Problem-based Learning

Effectiveness of Problem-Based Learning on Academic Performance in Genetics

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Gülsüm Araz‡ and Semra Sungur§¶

From the ‡Department of Elementary Education, Faculty of Education, Erciyes University, Kayseri, Turkey and §Department of Elementary Education, Faculty of Education, Middle East Technical University, 06531-Ankara, Turkey

This study aimed at comparing the effectiveness of problem-based learning (PBL)[1] and traditional lecture-based instruction on elementary school students' academic achievement and performance skills in a science unit on genetics while controlling for their reasoning ability. For the specified purpose, two instructional methods were randomly assigned to intact classes of two different teachers. Each teacher had both PBL classes and traditional classes. Although students in PBL classes (n = 126) worked on ill-structured problems cooperatively with the guidance of the teacher, students in traditional classes (n = 91) received instruction based on teacher's explanations, discussions, and textbooks. Genetics Achievement Test was developed by researchers to measure the academic achievement and performance skills. Multivariate Analysis of Covariance results showed that the PBL students had higher academic achievement and performance skills scores (M = 11.44 and M = 2.67, respectively) when compared with those in traditional classes (M = 10.91 and M = 2.20, respectively). This indicated that the PBL students tend to better acquire scientific conceptions related to genetics and integrate and organize the knowledge. Moreover, it was found that the reasoning ability explained a significant portion of variance in the scores of academic achievement and performance skills.

Keywords: Problem-based learning, elementary school, genetics, academic, performance.

Problem-based learning (PBL) is an instructional approach that allows students to interact with their environment while dealing with ill-structured problems. In PBL classrooms, knowledge evolves through social negotiation. Furthermore, problems with no clear-cut solution encourage students to take alternative point of views and strategies into consideration and apply their newly constructed knowledge into new areas [1–3]. In fact, through addressing problems with no single, correct solution, students learn how to assess what they know, identify what they need to know, gather information, and collaborate on the evaluation of hypotheses and ideas based on the data they collected. As students attempt to deal with the problem, the nature and definition of the problem may change. Teachers serve as facilitators, and students are only given guidelines for approaching the problems. Students take responsibility for what is learned and how [4].

PBL was first introduced in the medical schools and has had a major impact on thinking and practice in medical education for the past 30–40 years. This approach has been based on active learning in small groups, with clinical problems used as the stimulus for learning, and it has been evaluated in medical literature for its ability to incorporate realistic experiences in the classroom [5–12]. Apart from the studies conducted in the field of medical education, there are studies in the literature that aimed at adapting PBL for use in elementary and high school settings [13–19]. Results, in general, revealed that PBL creates an environment in which students actively participate in the learning process, take responsibility for their own learning, and become better learners in terms of time management skills, and ability to define topics, access different resources, and evaluate validity of these resources. Moreover, it was found that PBL appears to improve critical thinking, communication, mutual respect, teamwork, and interpersonal skills and increase students' interest in the course and make students apprentice scientists [2, 13, 17, 20–22]. Furthermore, it was suggested that PBL encourages students to identify knowledge deficiencies, coordinate actions and people, realize goals, and continuously monitor understanding [20, 23, 24]. However, at this point, it is important to note that most of the studies in the literature focused on the effectiveness of PBL without making a comparison with other instructional methods. Related studies in elementary and high school levels were mainly descriptive. As a result of this, the number of empirical studies, which compared effectiveness of PBL with other instructional methods, was very limited. To fill this gap in the literature, our study aimed at comparing the effectiveness of PBL and traditional lecture-based instruction on elementary school

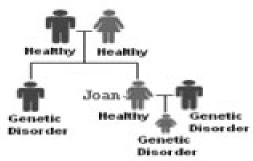
¶ To whom correspondence should be addressed. Tel.: 90-312-210-4066. E-mail: ssungur@metu.edu.tr.

[1] The abbreviations used are: PBL, problem-based learning; SD, standard deviation.

students' academic achievement and performance skills in a science unit on genetics. However, because understanding of genetics requires an abstract level of thinking, it is necessary to consider students' reasoning abilities while predicting their genetics achievement. Actually, Lawson and Thompson [25] reported that to overcome prior misconceptions and establish scientifically acceptable biological conceptions concerning genetics and natural selection, formal reasoning ability was necessary for the seventh-grade students. Moreover, Cavallo [26] showed that reasoning ability best predicted 10th grade students' achievement in solving genetics problems. Therefore, in this study, students' reasoning ability was used as a covariate to control the variance in achievement and performance skills scores due to this variable.

In summary, given the insufficiency of empirical research on the comparative effect of PBL instruction and traditional instruction, the current study aimed at comparing effectiveness of these two instructional methods in terms of students' academic performance. For this specified purpose, two instructional methods were randomly assigned to classes using quasi-experimental design and it was hypothesized that there would be a significant difference between the effectiveness of two instructional approaches with respect to students' achievement and performance skills scores when the variance in the scores due to reasoning ability was removed.

The following pedigree belongs to Joan and her family.



As it is shown in the pedigree, although Joan and her parents are healthy, her brother has a genetic disorder. When Joan got married to a man with the same genetic disorder, she gave birth to a daughter having the disease. What can be the genotype of Joan?

a) AA
b) Aa
c) aa
d) it is impossible to make an inference

FIG. 1. **Sample Multiple-Choice item.**

Direction: Read the case carefully and answer the questions.

Mr. and Mrs. Robinson have an 8-month baby named Peter. They brought Peter into hospital due to bleeding in his mouth. His parents told doctor that there was no apparent reason for bleeding. He was not injured and did not have any accidents. His parents were thinking of teething as a possible reason for bleeding.

As a result of discussion with parents, it was come out that similar instances occurred previously with other family members even some resulting in death. For example, Mrs. Robinson reported that one of her cousins (son of her mother's sister) suffered from bleeding that lasts a long time from an accident or other injury or bruised easily even after minor traumas. She added that her uncle (her mother's brother) who lived in a village had an accident years ago. Although, he had minor injuries, he died of heavy bleeding. However, other people having the same accident with similar minor injuries survived from the accident. She remembered no more similar events in her family.

Mr. Robinson, on the other hand, reported no cases of bleeding problems.

1) Write the information obtained from the case
2) Write your opinion of the problem based upon all of the findings. (Explaining your answers to the questions below in detail using the information given in the case and the information you gathered from the resources you used).
a) What might be the reason for Peter's illness?
b) Malfunctioning of which body system may lead to the instances given in the case?

FIG. 2. **Essay-type item.**

METHOD

Sample

Participants of the study were 217 eight-grade students (99 boys and 118 girls), attending an elementary school in an urban area. Students were from intact classes of two teachers, and intact classes were randomly assigned to one of the two modes of instruction, namely, PBL instruction and traditional instruction. Each teacher had both PBL classes ($n = 126$) and traditional classes ($n = 91$). Students in both types of classes received identical syllabus-prescribed learning content. The mean age of the students was 14.08 years ($SD = 0.36$, range 13–15). Students were from middle-class families. In the school where the study was conducted, there were two science laboratories, one computer laboratory with internet connection and one multimedia room. In addition, there was a library with books on different disciplines. All students had access to these resources.

Instrument

Genetics Achievement Test—This instrument was developed by the researchers taking elementary school science curriculum into consideration. The test included 20 multiple-choice items and one essay-type item to measure the students' academic achievement and performance skills, respectively. Items in the test were related to Mendelian Genetics. Essay-type item was prepared in accordance with a PBL approach aimed at measuring the students' performance skills such as ability to use relevant information in addressing the problem, articulate uncertainties, organize concepts, and interpret information. A sample of multiple-choice and the essay-type items are presented in Figs. 1 and 2, respectively.

Content validity of each item in the test was determined by a group of experts in biology, biology education, and measurement and evaluation. The classroom teachers also analyzed the relatedness of the test items to the instructional objectives. Internal consistency reliability coefficient was found to be 0.63 for multiple-choice items, and interrater reliability was found to be 0.91 for the essay-type item.

The Test of Logical Thinking—This instrument was developed by Tobin and Capie [27] to measure the formal reasoning ability of the students. The test consists of 10 items. Students responded to each item by selecting a response and reason for selecting that response. For an item to be scored correct, the student must choose the best answer and the best justification. The Cronbach alpha internal consistency for the test was found to be $r = 0.85$.

Treatment

This study was carried out over 5 weeks during 2005–2006 fall semester with a permission granted from the Ministry of Education. During the study, the topics related to genetics were covered as a part of regular classroom curriculum in the science course. The classroom instruction was four 40-minute sessions per week.

In the PBL classes, small heterogeneous groups were formed, so that the interaction among students with different learning styles, academic performance, and gender was optimized. Groups dealt with ill-structured problems relating to monohybrid cross and genetic diseases. Problems were introduced to students as cases, and case information was distributed over several pages and presented one at a time. In this

TABLE I
Descriptive statistics

	PBL classes		Traditional classes	
	M	*SD*	*M*	*SD*
Academic knowledge	11.44	3.36	10.91	3.32
Performance skills	2.67	1.41	2.20	1.45

TABLE II
Univariate ANOVA results

Source	Dependent variable	*df*	*F* value	*p* value
Reasoning ability	Academic achievement	1	54.92	0.000
	Performance skills	1	6.08	0.014
Treatment	Academic achievement	1	4.44	0.036
	Performance skills	1	7.14	0.008

way, an increasing amount of information about the problem was provided to the students as they needed. Students brainstormed and generated ideas and hypotheses related to the problem and identified the learning issues. Then, each student in a group conducted independent study outside the classroom. The purpose of the independent study was to seek for information regarding learning issues in relation to problematic situations. Next, in the classroom, students shared the information that they acquired during independent study with other students in their groups. Students discussed new knowledge and revised their previous ideas and hypotheses based on the new knowledge. These processes continued until the groups thought that sufficient basic science was learned. Actually, during these processes, teachers acting as facilitators stressed that the purpose was not to find a quick solution to problems but to learn about underlying concepts and principles. At the end of the PBL implementation, a guest speaker from science education department at a university was invited to provide students with an opportunity to share their knowledge with an expert from the field and discuss some points that they were unclear about. In this way, it was intended that the students' concern about missing important points to be learned can be overcome and students become aware of important learning issues and what they learned during PBL.

On the other hand, in the traditional classes, instruction was based on lessons with lecture/questioning methods and teaching strategies depended on teacher's explanations, discussions, and textbooks.

RESULTS

Descriptive statistics concerning mean (*M*) and standard deviation (SD) for PBL and traditional classes with respect to academic knowledge and performance skills was presented in Table I. As shown in the table, PBL students appeared to have higher scores on both variables.

Multivariate Analysis of Covariance was conducted to investigate the relative effect of PBL and traditional instruction on elementary school students' academic achievement and performance skills in the unit of genetics while controlling for reasoning ability. Results showed a statistically significant mean difference between the PBL and the traditional classes with respect to the collective dependent variables of academic achievement and performance skills. The multivariate η^2 based on Wilk's Λ showed that 4% of multivariate variance of the dependent variables was associated with the treatment. Univariate ANCOVA results for each dependent variable further indicated that there were significant mean differences between two groups with respect to each of the dependent variables (see Table II). η^2 values as a measure of effect size for the academic achievement and performance skills were 0.02 and 0.03, respectively. When the mean scores on academic achievement and performance skills scores were examined, it was found that the students in the PBL classes had higher mean scores ($M = 11.44$ and $M = 2.67$, respectively) when compared with those in the traditional classes ($M = 10.91$ and $M = 2.20$, respectively). So, PBL students appeared to have higher levels of academic achievement and performance skills. In addition, results showed that there was a significant relationship between reasoning ability and collective-dependent variables. The multivariate η^2 based on Wilk's Λ showed that 21% of multivariate variance of the dependent variables was associated with the reasoning ability. When the results for the dependent variables were considered separately, it was found that there was a significant relationship between reasoning ability and each of the dependent variables. η^2 values for the academic achievement and performance skills were 0.20 and 0.03, respectively.

DISCUSSION

This study investigated the comparative effectiveness of PBL instruction and traditional lecture-based instruction on elementary school students' academic achievement and performance skills in a science unit on genetics controlling for reasoning ability. Results showed that the students instructed by PBL had higher mean scores on the genetics achievement test aimed at measuring academic achievement and performance skills. At this point, it should be noted that many of the multiple-choice items measuring academic achievement on the test were at the comprehension and application levels. For this reason, students had to realize interrelationships among the concepts and apply their knowledge on genetics to be able to respond to the items correctly. Moreover, essay-type item measuring performance skills required students to identify relevant information in addressing the problems, use and interpret the information, and take different viewpoints into consideration. Therefore, it appeared that the students instructed with the PBL approach could better integrate and organize the knowledge. When the characteristics of the PBL instruction are considered, these findings can be considered as expected outcomes, because in the PBL model, students are actively involved in the learning process and acquire new information without specific readings or content assignments. In PBL classes, it is the process of learning, not the memorization of the isolated bits of information, that is emphasized. Students work in small groups cooperatively to deal with a common problem in an analytical way with facilitators whose role is to facilitate the discussion rather than disseminating knowledge. Therefore, PBL is assumed to increase higher order thinking skills during the process of dealing with ill-structured problems with no single solution, working in groups, and being guided by teachers and peers [1, 28]. Actually, Karabulut [23] proposed that PBL allows students to take responsibility for their own learning promoting time management skills, and the ability to define leaning issues and to variety of resources.

In fact, what makes PBL different from other instructional strategies is its focus on students as active learners dealing with authentic, ill-structured problems [17]. As Savery and Duffy [29] pointed out, in PBL, students are considered as constructors of knowledge in a context similar to that in which they would make use of that knowledge. Accordingly, in PBL classes, both critical and creative thinking are encouraged. In addition, social negotiation of meaning is considered as an important aspect of group process. In line with this idea, Dennen [30] suggested that web-based conferencing software can be used to promote more collaborative and successful group process in PBL environments. According to him, documenting group process and work such as brainstorming and idea generation activities enable facilitators to know who is actively contributing to the group process and to be sure that all students have the opportunity for substantive input. Therefore, technology can be integrated into PBL classes to promote the effectiveness of the PBL approach. In fact, integration of technology to PBL can be useful for the students to learn especially abstract topics such as genetics, because the use of special software programs can help students visualize and explore some important processes and terms related to abstract topics. Accordingly, use of these programs can help students with the lower levels of formal reasoning ability to understand the concepts in a more meaningful way. Actually, this study showed that there was a significant relationship between reasoning ability and academic performance. Thus, it is suggested that the PBL instruction should be integrated with special computer programs to enhance students' learning.

In summary, our study appears to support the idea that PBL encourages the development of skills necessary for critical evaluation and acquisition of new knowledge interacting with the environment. However, it should be noted that the current study was limited to the implementation of PBL in a science unit on genetics and to eight-grade students from one school. Moreover, content of the genetics achievement test was limited to eight-grade science curriculum with 20 multiple-choice items and 1 essay-type item. Reliability of the multiple-choice test was 0.63. Therefore, there is a need for replicating the study with a larger sample size and more reliable instruments. Moreover, since the effects of PBL are moderated by the way knowledge and skills are assessed [30], in further studies, students should be evaluated not just by paper–pencil exams but also during learning process by making observations, using checklists, and collecting portfolios.

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