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In this study, the effect of problem-based learning on students' academic achievement and performance skills in a unit on the human excretory system was investigated. Sixty-one 10th grade students, from two full classes instructed by the same biology teacher, were involved in the study. Classes were randomly assigned as either the experimental or the control group and were pre- and post-tested to determine their academic achievement and performance skills before and after the treatment. The experimental group was taught with problem-based learning while the control group received traditionally-designed biology instruction. Results showed that although there was no pre-existing difference between two groups, students instructed with problem-based learning earned significantly higher scores than those instructed with traditionally-designed biology instruction – in terms of academic achievement and performance skills. Students in the experimental group appeared to be more proficient in the use and organisation of relevant information, in constructing knowledge and moving toward better conclusions.

Key words: Problem-based learning; Achievement; Performance skills; Biology; Excretory system

Introduction

We live in a dynamic society in which social, political and technological conditions are changing continuously. So educators should analyse and evaluate the trends, in order to decide on appropriate curricula and methods of instruction which will make students ready for real life situations. Today, it is recognised that every person must be empowered to wonder, to suggest possible explanations, to propose ways to test personal or class hunches, to collect and interpret data obtained, to communicate the process and results to others (Yager, 2000). People who can think, solve problems, and make decisions based on evidence and reasoning are needed. Accordingly, today's science education must include providing students with a classroom environment where they experience the richness and excitement of knowing about and understanding the natural world, and where they use appropriate scientific processes and principles in making personal decisions. Problem-based learning (PBL), involving real or simulated problems, can produce the changes in knowledge, skills or attitudes necessary for making wise decisions on problems (Rangachari and Crankshaw, 1996). In PBL environments, students act as professionals and are confronted with problems that require clearly defining an ill-structured problem, developing hypotheses, accessing, analysing, utilising data from different sources, revising initial hypothesis as the data collected developing and justifying solutions based on evidence and reasoning (Gallagher *et al*, 1995; Barrows, 1986).

Ill-structured problems are those where there is no single right solution and as new information is gathered the problem definition changes. So, a student in a problem-based classroom learns while dealing with ill-structured problems, and is responsible for seeking, accessing his or her own learning material, and developing skills to communicate acquired knowledge to other students and the teacher (Rosing, 1997). In fact, the study carried out by Krynock and Robb (1996) showed that PBL does increase higher-level thinking skills of eighth grade students by requiring them to think about a problem critically and analysing data to find the solution. Also, based on students' opinions, they reported that PBL students tend to work better in group and are able to do better research on a topic.

Moreover, Achilles and Hoover (1996) proposed that PBL was an effective model for addressing varied learning styles, improved general classroom behaviour and achievement, and made learning experiences more exciting at elementary and secondary grade levels. In addition, they suggested that this model encouraged life skills such as communication, mutual respect, teamwork, and responsibility. In addition, the results of the study carried out by McBroom and McBroom (2001) indicated that PBL enhanced secondary school students' knowledge level, attitude, and self-confidence. Gordon *et al*, (2001) found that PBL helped students develop interpersonal skills, critical thinking and information seeking.

To sum up, PBL as an instructional method appears to improve interpersonal skills, critical thinking, information seeking, communication, mutual respect and teamwork. Students involved in PBL tend to have more positive attitudes toward the course and better performance in tests. However, as reported by Dochy *et al*, (2003), the effects of the PBL are moderated by the way the knowledge and skills are assessed, so this current study investigated the effect of problem-based learning on students' academic achievement and performance skills through multiple choice and an essay type exercise (which can be considered as an individualised version of the small group PBL activity).

Given the general lack of research on the comparative effect of problem-based and traditional approaches on high school students' learning, this paper addresses the research question: "Are there differences in the effectiveness of PBL and traditionally-designed biology instruction on tenth-grade students' academic achievement and performance skills in a unit on the human excretory system?"

Method

Subjects

Sixty-one 10th-grade students (n=39 boys and n=22 girls) in two complete classes instructed by the same biology teacher were involved in this study. The majority of the students were from middle to upper class families. Two instructional methods (PBL and traditionally-designed biology instruction) were randomly assigned to the classes as experimental and the control groups using the static-group comparison design (Fraenkel and Wallen, 1996). The number of students in the experimental group was 30 while that of in the control group was 31. The mean age of the students in both groups was 16.3 years. Previous biology grades of the students in both groups were comparable: 4.6 out of 5 in the experimental group and 4.7 out of 5 in the control group. Topics related to the excretory system were covered as part of the regular classroom curriculum in the biology course. During the four-week period, each group received an equal amount of instruction – four 40-minute periods.

Instruments

The Pre/Post Human Excretory System Achievement Test (HESAT)

This was developed by the researchers by taking related literature into consideration. The test included 25 multiple-choice questions and one essay to measure students' academic achievement and performance skills respectively. All the items in the test were related to the structure and function of the excretory system and its relation to other organ systems. Multiple-choice questions required the students to recall definitions and facts as well as to integrate their knowledge of different topics in biology and other subject areas such as chemistry. The reliability of the multiple-choice part of the test was found to be 0.70. Sample items from the test are presented in the Appendix.

The essay, devised in line with the problem-based learning approach, aims at measuring students' performance skills such as the ability to: use relevant information in addressing the problem; articulate uncertainties; organise concepts; and interpret information. Each item in the Human Excretory System Achievement Test was examined by a group of experts in the field of science education, biological sciences and by biology teachers for content validity and format.

Problem Based Learning Feedback Form

This was adapted from the end-of-course evaluation form used by Mierson (1998). It consisted of two parts. In the first part, including 14 Likert-type items, students were asked to respond to statements concerning PBL on a five-point scale. In the second part, including seven open-ended items, students were asked to give their opinions regarding PBL. This instrument was administered to students after the treatment to get their opinions about the PBL

Treatment

The traditionally-designed biology instruction was based upon lessons employing lecture/questioning methods to teach concepts. Teaching strategies relied on teacher explanations, discussions and textbooks. Students were required to read the related section from the textbook before the class. The teacher structured the entire class as a unit, wrote notes on the chalkboard about the definition of concepts and drew figures of structures related to the excretory system. After the teacher's explanation, the concepts were discussed, directed by the teacher's questions. The majority of the time was devoted to instruction and discussions stemming from the teacher's explanation and questions. The remaining time was taken up with the worksheet study. The direction of communication in the classroom was from teacher to student.

The PBL Task

In the experimental group, before the treatment five heterogeneous groups of six students were formed: these had different learning styles and academic performance and were of mixed gender composition. Then, students and the teacher were trained to use PBL.

During the treatment, students worked in small groups and dealt with ill-structured problems based upon patients' experiences. Every member of the group had some expected roles and responsibilities; students were supposed to participate actively in the group discussion. They had to express their ideas, feelings and share their knowledge and experience with each other. Each of them had to be sensitive to the needs and feelings of other group members. Apart from the group work, each student had to conduct an independent study and evaluate his/her learning at both individual and group levels. Students were asked to select their own learning issues and decide upon the appropriate depth for study.

Students also took specific roles which included the doctor, the patient, the reader, the reporter, and the presenter. For example, the reader read the pages distributed by the teacher, which provided increasing amounts of information about the patient's problem. The reporter wrote down the facts, ideas, hypotheses and learning issues identified by the group. The doctor interviewed the patient, asking the questions determined as a result of group discussion. During the interview, the patient answered the questions based on the information just provided to him/her about patients' medical history, history of current illness, socio-economic status, etc. The group then discussed the patient's problem, generated ideas, made predictions, identified learning issues and determined what further information was needed to better understand the problem – additional information such as physical exam results, laboratory test results was then given to the students. Each PBL session ended with both self-evaluation and a time in which groups evaluated their effort and made suggestions improving their performance.

Outside the classroom, students conducted independent study addressing the learning issues determined in the group session. In the following session, the presenter (selected by lottery from each group) summarised the previous session's work by describing relevant case data. In this way, the presenter provided a link between the two sessions. Students discussed their new knowledge and revised their previous ideas and hypotheses based on the new knowledge. These processes continued until the groups were satisfied that sufficient basic science was learned.

During the PBL sessions, the teacher organised the groups and created a comfortable atmosphere. The teacher ensured that students had control of the discussion. When guidance was needed, the teacher asked open-ended, very general questions and gave ample opportunity to students to focus on the goal. The teacher encouraged critical thinking. At the end of PBL implementation, students evaluated each other with respect to participation, preparation, interpersonal skills, and contribution to group progress. In this way, it was expected that students would become aware of the extent to which they behaved as intended - both individually and as a group. Students' learning was evaluated by using multiple choice and essay questions.

Data analyses

To test the null hypothesis – that there was no statistically significant, mean difference between students taught with PBL and those taught with traditionally-designed biology instruction with respect to a collective-dependent variable of academic achievement and performance skills – a Multivariate Analysis of Variance (MANOVA) was conducted. Students' academic achievement and performance skills were measured by multiple-choice questions and an essay respectively. Each multiple-choice item was given a numeric value of 1 if response was correct, and 0 if incorrect. Accordingly, scores ranged from 0 to 25. Students' essays were evaluated by two independent raters, using a rubric adapted from Lynch and Wolcott (2003). Students were rated according to four main performance skills, namely, identifying, exploring, prioritising and envisioning, on a scale from 1 to 5 (Table 1).

A rating of 1 corresponded to a weakness in all four performance skills. Those students approached the problem using very limited information (mainly facts and definition) and proceeded as if the goal was to find the single correct answer. A rating of 5 was given to students who were strong on all four performance skills. They showed complex awareness of ways to minimise uncertainties and proceeded on the basis that the goal was to strategically construct knowledge and to move toward better conclusions. Two independent raters evaluated the students' responses to the essay. Similarities and differences between the ratings of the two raters were discussed with the authors until a consensus was reached and a high inter-rater reliability obtained (r = 0.94).

Table 1. Rubric for essays

Score for skills performance skills	Criteria for scoring
1	presents the information but does not interpret; proceeds as if the purpose were to find a single, correct answer; does not provide any information or evidence that supports his/her claim about the problem.
2	uses evidence logically to support conclusions but jumps to conclusions as if the goal were to stack up evidence and information to support conclusions
3	organises knowledge; presents the problem in a coherent and balanced way; attempts to interpret the information and evaluates evidence from different viewpoints
4	approaches the problem as if the goal is come to well-founded conclusions using evidence and principles and considering different viewpoints
5	uses a complex, coherent discussion of own perspective; proceeds as if the goal is to strategically construct knowledge, and to move toward better conclusions taking different aspects of the problem and different viewpoints into consideration.

Results

Mean scores and Standard Deviations for both academic achievement (AA) and performance skills (PS) are given in Table 2.

At first sight, it appeared that students in the experimental and control groups had similar responses for those items requiring simple recall (*Mean* = 9.6 and *Mean* = 9.7 respectively). However, students in the experimental group could better integrate and organise the knowledge on different topics in biology and on different subjects such as chemistry (*Mean* = 9.6 and *Mean* = 11.4 respectively). For example, 100% of the students in the experimental group and 96.6% of the students in the control group correctly answered a question which required them to remember the definition of tubular reabsorption as one of the basic renal processes. However, striking differences were apparent between the experimental and the control groups on the majority of items measuring ability to integrate and organise knowledge. For instance, the item asking students to combine their knowledge of the excretory system, circulatory system, endocrine system and homeostasis required them to identify the factor leading to an increase in urine volume. To answer this question, students had to understand the relationship between the blood volume, plasma osmotic pressure, and glomerular filtration rate. Moreover they had to recognise the role of antidiuretic hormone in the regulation of fluid balance in the body acting on tubular cells. They had to infer that a decrease in sodium reabsorption, ultimately, leads to a decrease in extra-cellular blood volume, increasing the volume of urine formation. About 48% of students in the control group responded to this item correctly, making the connections between their knowledge of different biological concepts. On the other hand, the percentage of students who answered this item correctly in the experimental group was 93.3, indicating that experimental group students were more successful in integrating knowledge.

Furthermore, students' responses in the essay revealed that students in the experimental group could better use relevant information in addressing the problems, interpret the information and use the principles to judge objectively. Here, a case based on a particular patient was given to students and they were asked to write a comprehensive essay in the light of questions about the patient's situation. Approximately 66%

Table 2. Statistics for AA and PS scores

	Control group		Experimental group	
	Mean	SD	Mean	SD
AA	17.75	2.43	21.03	1.81
PS	1.49	0.68	2.39	0.95

of students wrote their essays just listing the case information, and they ended their essays with one sentence indicating that patient was suffering from an illness related to excretory system. Only 23.3% of students in the experimental group approached the problem this way, though. There was only one student whose essay was scored 5 by one of the raters. This student was in the experimental group and approached the problem as if the goal was to move toward better conclusions, taking different aspects of the problem and different viewpoints into consideration.

In general, students' responses revealed that experimental group students could better identify what they knew and its relation to the patient's case. They were better at using, integrating and interpreting relevant information while proposing solutions. They could make better interpretations based on the evidence. Accordingly, they first outlined what they knew about the patient in their essays and, based on the patient's complaints and laboratory test results, they indicated that most probably there was something wrong with his kidneys. They supported their claim by providing information on kidney function. Then they tried to explain the symptoms in relation to possible consequences of kidney malfunction.

Prior to treatment, the Human Excretory System Achievement Test was administered to students in the experimental and the control groups to determine whether a statistically significant, mean difference existed between the two groups, with respect to previous academic achievement and performance skills. One-way Multivariate Analysis of Variance (MANOVA) results revealed that there was no statistically significant, mean difference between the two groups with respect to the collective dependent variables of previous academic achievement and performance skills, Wilks' Lambada = 0.99, $F(2,53) = 1.11$, $p = 0.90$.

After the treatment, the effect of PBL on students' academic achievement and performance skills was determined by conducting one-way MANOVA. The findings showed that there was a significant mean difference between the experimental and the control groups with respect to collective dependent variables of academic achievement and performance skills, Wilks' Lambada = 0.42, $F(2,56) = 38.57$, $p = 0.00$. The multivariate η^2 based on Wilk's Lambada was strong, 0.58, implying that the magnitude of the difference between the groups was not small. In fact, this value indicated 58% of multivariate variance of the dependent variables was associated with the treatment.

In order to determine the effect of the treatment on academic achievement and performance skills separately, univariate ANOVA's were run. The ANOVAs on the academic achievement scores and performance skills scores were significant – $F(1,57) = 69.19$, $p = 0.000$, $\eta^2 = 0.55$ and $F(1,57) = 18.75$, $p = 0.000$, $\eta^2 = 0.25$, respectively – indicating that there was a statistically significant, mean difference between the groups with respect to these two variables. An inspection of the mean scores indicated that experimental group students performed better on the test in terms of academic achievement and performance skills (see Table 2).

Student opinions on PBL

Students' responses to some of the items presented in problem-based learning feedback form are given in Table 3. It was found that students appreciated the value of PBL on their learning. Most of the students said that acquiring necessary skills and attitudes to access information and deciding on which resources to use, working cooperatively, and realising the practical applications of the knowledge contributed to their learning. Many students thought that they had a good understanding of basic principles and concepts and they could apply the general principles they had learned to other topics. Furthermore, students indicated that they did out-of-class searches, and tried to learn more about the topics because they were curious about the patient's case and wanted to understand it deeply.

However, their responses showed that, although they are aware of their expected roles and appreciated the importance of them, they had difficulty in adapting to them. They found it difficult to deal with uncertainties and unknowns. They wanted more teacher participation and guidance. They suggested that the teacher should provide answers to their questions and that brief lectures could be integrated into the PBL sessions.

Discussion

Results revealed that PBL instruction caused a significantly better acquisition of scientific conceptions than the traditional instruction. PBL students appeared to be more proficient in the use and organisation of relevant information, in construct-

Table 3. Student opinions about PBL

	Agree (%)	Undecided (%)	Disagree (%)	Mean	SD	Range
PBL helped me learn to obtain information from a variety of sources	83.4	13.3	3.3	4.13	0.90	1-5
I am comfortable with working in groups	80.0	16.7	3.3	4.37	0.89	2-5
I feel comfortable sharing information with others	93.3	3.3	3.3	4.33	0.71	2-5
I feel comfortable in asking help from others	83.3	6.7	10.0	3.77	0.68	2-5
I can evaluate new information and reassess my knowledge	93.4	3.3	3.3	4.17	0.65	2-5
If given an opportunity, I would like o take another PBL class	40.0	43.3	16.7	3.37	0.93	2-5
I have a good understanding of basic principles and concepts	86.7	6.7	6.6	3.77	0.68	1-4
I feel that I can apply the general principles I learned to other topics	83.3	16.7	0.0	3.83	0.38	3-4

ing knowledge and moving toward better conclusions. However, based on the mean scores, it seemed that the difference between PBL students and students in the control group was not apparent on the items requiring simple recall.

These findings were in agreement with the literature. In their meta-analysis, Dochy *et al* (2003) showed that students in PBL has slightly less knowledge, but remembered more of the acquired knowledge and applied it more efficiently. Moreover, they reported that the effects of PBL are moderated by the way the knowledge and skills are assessed. Similarly, in the current study PBL students outperformed on the items requiring higher order thinking skills and could better use relevant information in addressing the problems, interpret information and use the principles to judge objectively. In fact, Krynock and Robb (1996) stated that PBL does increase higher-level thinking skills by requiring students to think about a problem critically and analyse data to find the solution. Nowak (2001) reported that the PBL increases critical thinking skills, problem solving skills, and decision-making skills. According to Karabulut (2002), 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, ability to identify learning issues and ability to access resources.

Actually, what makes PBL different from other instructional strategies in the development of these skills is that it places students in the centre of an authentic, ill-structured problem with no one right answer (Sage, 1996). The problem stimulates students to carry out investigations to satisfy their needs to know, then link the new knowledge into their thinking and decision-making processes (Gordon *et al*, 2001).

As pointed out by Savery and Duffy (1995), in PBL the focus is on learners as constructors of knowledge, in a context similar to that in which they would use this knowledge. They are encouraged to think both critically and creatively and to monitor their own understanding.

Social negotiation of meaning is an important aspect of group process. The learners have the ownership of the problem and all of the learning occurs as a result of consideration of the problem. Facilitation is focused on meta-cognitive processes. Therefore, PBL allows students to interact with their environment and with their peers; in a typical PBL class, students work in groups cooperatively which allows evolvement of knowledge through social negotiation. The ill-structured problems posed lead students to apply their newly constructed knowledge and to take alternative points of views and strategies into consideration. These properties of PBL may have caused better academic achievement and performance skills when compared to traditional instruction.

Educational implications

This study provides evidence to support the claim that student-centred classrooms – in which students work on open-ended tasks cooperatively by identifying knowledge deficiencies, generating appropriate learning issues, accessing different resources, and monitoring understanding – lead to the development of lifelong learning skills. Therefore, it is suggested that instructional methods promoting high level cognitive processing such as PBL should be integrated into the curriculum.

Since the teacher plays a vital role in the implementation of such instructional methods – as a coordinator of activities, as a model of an expert learner, as a facilitator, and as an evaluator (Cooper, 2002) – they should undergo extensive training. Moreover, implementation of PBL or other student-centred methods should start at earlier grade levels so that cognitive and meta-cognitive learning skills, time and environment management skills, and critical thinking skills begin to develop at an early age. In this way, students become more proficient, for example, in accessing and using different resources when they are at secondary school. Classrooms should be designed so that students can work in groups effectively, and they can access different resources such as books, educational CDs, and a computer with internet connection.

In this study, during implementation, most of the students indicated that they had difficulty in making use of a variety of resources due to the overloaded curriculum. However, if they were used to doing out out-of-class searches, or if there were more resources available for them in the school library, it would be easier for them to access different resources and to make use of them.

Since the effects of PBL are moderated by the way knowledge and skills are assessed, assessment strategies in appropriate alignment with the PBL should be used.

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Appendix. Sample items from the multiple-choice test

1. One would expect to see an increased volume of urine formation following:
   - a rise in ADH secretion
   - a fall in plasma volume
   - an increase in plasma osmolarity
   - severe sweating
   - inhibition of tubular sodium reabsorption

2. In the kidney, movement of substances from the filtrate into the blood capillary is termed:
   - tubular reabsorption
   - autoregulation
   - glomerular filtration
   - micturition
   - tubular secretion