Problem-Based Learning: Development Of Knowledge And Reasoning Strategies

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Abstract

Problem-based learning (PBL) reflects new conceptions of learning that have grown out of theory and research in cognitive science. PBL has been used in medical schools to enhance the development of clinical reasoning skills and to promote the integration of basic biomedical sciences with clinical applications. In this study, the effect of PBL on the development of clinical reasoning strategies, use of scientific knowledge, and accuracy are examined on a causal explanation task. Students in problem-based curricula were compared with students in traditional medical curricula. The results indicate that PBL plays a role in facilitating the development of expertise. In PBL, students learn through the transfer of hypothesis-driven reasoning skills that result in more coherent explanations. The PBL students are better able to apply their science knowledge than nonPBL students, leading to greater accuracy of hypotheses.

Problem-based learning

Learning from cases has been proposed and implemented in several forms to help students learn complex, ill-structured domains (e.g., Barrows, 1985; Williams, 1993). Learning from cases situates knowledge in the context of use (J. S. Brown, Collins, & Duguid, 1989). One type of case-based instruction is problem-based learning. In medical schools, problem-based learning (PBL) is becoming widely used to replace the first 2 years of science courses. Instead of the traditional lecture-based format, students learn biomedical science through solving problems. This study examines the cognitive effects of traditional and problem-based medical curricula on first-year medical students. The effects examined are related to the cognitive goals and activities that take place in PBL classrooms.

PBL includes among its goals 1) developing scientific understanding through cases and 2) developing clinical reasoning strategies. Cognitive theories of situated cognition and transfer-appropriate processing suggest that these goals should be met (J. S. Brown et al., 1989; Schmidt, 1993). At a general level, the expectation is that PBL will produce physicians who, when faced with a novel or difficult case, can use their basic science knowledge to assist them in understanding the problem. In some regards then, PBL may be viewed as a design experiment that tests situated theories of learning (A. Brown, 1992). The next section of this paper will describe PBL in more detail followed by a discussion of a cognitive approach to understanding the effects of PBL.

In PBL, small groups of 5-7 students and a facilitator meet to discuss a patient case. The students receive an initial scenario and then must question the facilitator to get additional case information. At several points in the case, the students pause to consider the data they have collected so far, to generate questions about the data, and to hypothesize about underlying causal mechanisms for the patient's problems. The students must also identify issues that they do not understand and need to learn more about. After considering the case with their naive knowledge, the students independently research the learning issues they have identified. They then share what they learned, reconsider their hypotheses and/or generate new hypotheses in light of their new learning.

The cases for PBL are carefully chosen to cover particular learning objectives in basic biomedical science. Topics are revisited from several cases. This is intended to allow the students to learn basic sciences in a manner that integrates the science with its clinical applications. By situating science learning in clinical situations, the learners should be better able to recall that information in the future (e.g., Adams, Kasserman, Yearwood, Perfetto, Bransford, & Franks, 1988). Also, by tying the scientific principles to the cases they are working on, the students are generating self-explanations that should result in the construction of more coherent mental models of the underlying science (Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Patel & Kauffman, 1993). In addition, students may be building a library of cases that they can use in subsequent reasoning (Kolodner, 1993). Moreover, by revisiting concepts through multiple cases, cognitive flexibility may be promoted (Spiro, Coulsen, Feltovich, & Anderson, 1988).

To understand the effects of PBL, students were asked to generate causal explanations to clinical cases. Their explanations were evaluated for accuracy, coherence, reasoning strategies, and use of science.

Methods

Students from two medical schools participated in this study. At School A, a midwestern medical school, 35 first-year students participated. Sixteen students were from the school's traditional curriculum and 19 were from the PBL curriculum. The students in the traditional curriculum spent approximately 40 hours a week in lecture and laboratory courses in the basic biomedical sciences whereas the PBL students had two 3-hour sessions for their PBL group meetings and a third optional 1-hour session a week where resource faculty were available to answer questions. At School B, a southern medical school, 39 students participated in the study. Of these, 19 students were in a PBL elective and 20 students were in a different elective. In School B, these electives were in addition to a traditional curriculum. So the PBL students at school B had 1 hours a week of their PBL elective in addition to 40 hours of traditional lecture and laboratory classes. The actual PBL group meetings were very similar at the two schools except that the School A students had a much more intense PBL experience than the School B group. Students were paid $45 for participating in 3 two-hour sessions during their first year of medical school. The sessions took place before the start of classes, after 3 months, and after 7 months of medical school.

The students' task was to generate pathophysiological explanations for the mechanisms underlying a medical case. The cases were presented in 5 segments: presenting information, history, physical examination, laboratory data, and hospital course. Students were asked to generate explanations after each part of the case. At each session, the subject received 2 cases. Six different cases were used that covered a variety of body systems and disease processes. Students were randomly assigned to 6 different cases in orders that were counterbalanced across conditions.

The problem-solving protocols were coded for coherence, science use and accuracy. In addition, the directionality of reasoning was coded. A random sample of 20% of the protocols was scored by a second independent rater blind to condition. Interrater agreement was 91.6%.

Results

Problem-solving

The problem-solving analyses examined the products and processes of the subjects' problem-solving. The data were summed across the sections of the case for the purpose of these analyses. All quantitative analyses were conducted using a 3 x 2 x 2 x 2 (Time of test x Order of problem x Site x Curriculum) ANOVA. For qualitative analyses, the same factors were used in a log-linear analysis.

Because students self-select into PBL, an analysis of preexisting differences was conducted. There was no effect of curriculum on MCAT scores, undergraduate GPA, age, or prior experience in health care. There were differences between the two sites, with the students at School B scoring higher on the MCAT and GPA measures, whereas the School A students had more prior health care experience. However, this suggests that upon entrance into medical school, the PBL and nonPBL students were equivalent on these criteria.

Directionality of reasoning

The reasoning strategies were of four types: data-driven (forward) reasoning, hypothesis-driven (backward) reasoning, other relational reasoning, and unjustified assertions. In the PBL sessions, the students are taught to use hypothesis-driven reasoning but early in the year when the students do not know very much, they may either unsuccessfully use data-driven reasoning or they may not justify their assertions at all. Preliminary research suggested that these measures help distinguish PBL from nonPBL students (Hmelo, Gotterer, & Bransford, 1994). Data-driven reasoning involves reasoning from the data to a hypothesis whereas hypothesis-driven reasoning involves using a hypothesis to explain the data. An example of a data-driven reasoning statement is "If he has an elevated blood sugar, then he must have diabetes." "Because he has diabetes, he has an elevated blood sugar" is an example of a hypothesis-driven reasoning statement. This is the type of reasoning that is modeled in a problem-based curriculum. Other relations may also be expressed, for example, "He has an infection in association with diabetes." In this case, the directionality of reasoning is unclear. Subjects may also assert causes without justifying them. These are statements such as "He is diabetic" without any explanations to support the hypothesis.

Although data-driven reasoning is more characteristic of experts, it is inappropriate for novices who have an insufficient knowledge base (Patel & Kauffman, 1993). In PBL, students are taught to use hypothesis-driven reasoning to construct explanations that account for all of the data. Thus we predicted that the PBL students would be more likely to use hypothesis-driven reasoning than conventional (nonPBL) students because that is the strategy they were taught. Prior research has demonstrated that traditional medical students were more likely to use data-driven reasoning although there is not a clear theoretical basis for this result (Patel et al., 1993).

Log-linear analyses were conducted to analyze these data. The PBL students increased their use of hypothesis-driven reasoning relative to the nonPBL students over the course of the year ($\chi^2(4)=42.10$, $p<.001$) but simple effects tests indicated that both the PBL and nonPBL groups increased their use of hypothesis-driven reasoning over the course of the year ($\chi^2(4)=20.34$, $p<.001$ and $\chi^2(4)=54.86$, $p<.001$, respectively). Figure 1a illustrates this effect by showing the percentage of students using hypothesis-driven reasoning as their dominant form of reasoning. There was no consistent effect across conditions and time for data-driven or other-relational reasoning. The change in dominant use of unjustified assertions is shown in Figure 1b. Overall, the number of unjustified assertions decreased over time as the students generated more elaborate explanations ($\chi^2(4)=25.02$, $p<.001$).

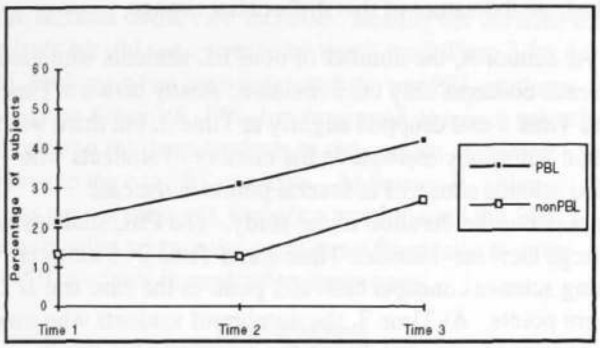

Figure 1a: Dominant use of Hypothesis-Driven Reasoning

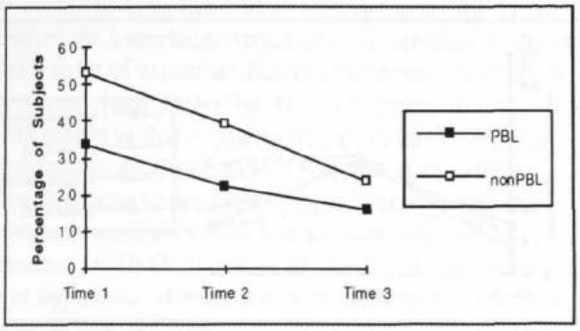

Figure 1b: Dominant use of unjustified assertions

Coherence

To measure the coherence of an explanation, the number of findings that the subjects used in their longest reasoning chain was measured. A fragmented explanation that only deals with a single finding is less coherent than longer statements that include multiple findings. A finding was counted if it was a repetition of data given in the case or a low level interpretation of that data (e.g., an elevated heart rate). For example, "A decreased *bicarbonate level* would cause a metabolic acidosis resulting in an increased *respiratory rate*" contains 2 findings.The results, shown in Figure 2 indicate that, there is an interaction of Curriculum x Site x both linear and quadratic trends for Time ($F(1,68)=5.16$, $p<.05$, $MS_e = 0.37$ and $F(1,68)=5.96$, $p=.05$, $MS_e = 0.36$, respectively). Further evaluation was therefore conducted separately for each site.

At School A, there was differential change over time (Curriculum x linear trend for Time $F(1,31)=9.20$, $p<.005$, $MS_e = 0.49$, Curriculum x quadratic trend for Time $F(1,68)=5.16$, $p<.05$, $MS_e = 0.37$). This effect occurred because of the linear increase in the number of findings used over time for the PBL students ($F(1,31)=29.47$, $p<.001$) whereas there was no significant change over time for the nonPBL students. The results of this measure indicate that the PBL students have a big improvement in coherence from Time 1 to Time 2 which they sustain until Time 3. The nonPBL students do not show any change.

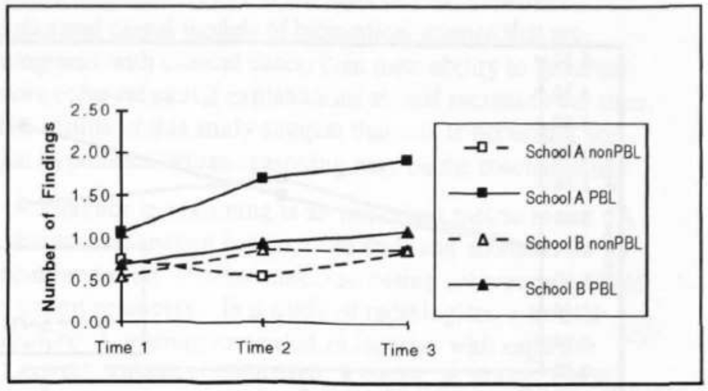

Figure 2: Coherence: Number of findings per reasoning chain

There was no evidence of a PBL effect for change over time in the School B students. The School B students as a showed an overall improvement in the number of findings that they accounted for over the course of the year. This improvement was seen as a linear increase over time ($F(1,37)=20.64$, $p<.001$, $MS_e = 0.28$).

Accuracy

Accuracy was measured at each point in the case. If the PBL students are constructing causal models and acquiring a library of cases from which to reason, they should become more accurate over the course of the year. The nonPBL students should also become more accurate over the year if they are able to apply their increased knowledge to patient cases. One point was given for a partially accurate score (i.e., a superordinate hypothesis, such as *Tuberculosis* in a case of *Disseminated Tuberculosis*) and 2 points were given for a fully accurate hypothesis. A subject who considered a fully accurate hypothesis from the start of the case could score 10 points for accuracy. A subject who first considered the correct hypothesis in the lab portion of the case and carried that hypothesis through the hospital course could score 4 points. A contrast that tested a Curriculum x Linear trend across time effect was significant, indicating that the PBL students showed a different rate of improvement in accuracy than the nonPBL students ($F(1,68) =4.69$, $p<.05$, $MS_e=6.12$), as illustrated in Figure 3.

This interaction occurred because there was an increase in accuracy over time for the PBL students (F(1,68)=22.68. p <.001) but the nonPBL students did not show significant improvement. This indicates that the PBL students were correctly applying their knowledge to clinical cases whereas the nonPBL students did not show improvement.

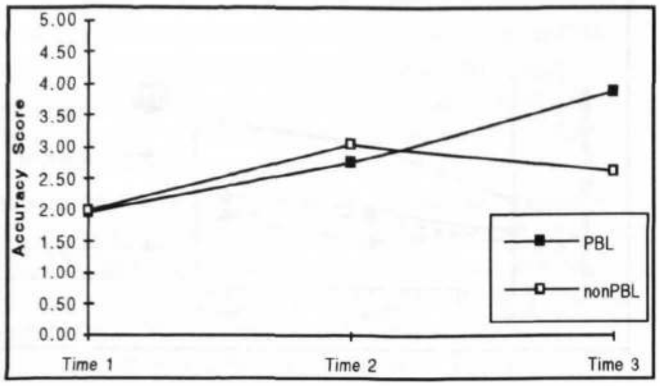

Figure 3: Accuracy

One explanation for these results might be that the PBL students had experiences with the types of cases that were used in this study. A follow-up analysis on the Time 3 results which used case-specific experience (as reported by the students) as a factor still showed a difference favoring the PBL students (F(1,64)=11.53; p<.001, MS_e=9.35). This suggests that there is a beneficial effect of PBL, beyond the experience it provides with specific cases. Moreover, case experience was also a significant factor in determining accuracy (F(1,64)=20.32, p<.001).

Science use

Because one of the goals of PBL was to learn science, it is important to measure whether students used science information in their explanations. Use of science concepts was scored 0-1 for each section of the case and then totaled across the case so the maximum score was a 5 for this measure. An example of an explanation coded as a 1 for science use is :

> " she seems to have something in her left atrium. Whatever it is seems to be blocking the movement of blood from the left atrium into the left ventricle. This would explain the enlarged LA. It would continue to fill with blood coming from the lungs, but would not be able to relieve the tension by giving all of the blood to the LV. In other words, the LA would have to accommodate more and more blood resulting in hypertrophy. "

In this example the subject used her knowledge of anatomy to explain why the heart was enlarged in this specific case.

A log-linear analysis revealed a three-way Curriculum x Time x Site interaction suggesting that the Curriculum x Time effect was different at each site ($\chi^2(4)=21.13$, p <.001). To clarify the nature of these effects, simple effects tests were conducted within each site. At both School A and B, there were significant Curriculum x Time interactions ($\chi^2(4)=338.20$, p <.001 and $\chi^2(4)=141.37$, p <.001, respectively) indicating that at both sites the PBL students became more likely to use science concepts in their responses, but the nature of the Curriculum x Time interaction was different at the two sites. Figures 4a and 4b illustrate the nature of this differential change.

At School A, the number of nonPBL students who used science concepts only once remained steady between Time 1 and Time 2 and dropped slightly at Time 3, but there was a small but steady increase in the number of students who used science concepts at several points in the case throughout the duration of the study. The PBL students had a large increase between Time 1 and Time 2 in subjects using science concepts both at 1 point in the case and at 2 or more points. At Time 3, the number of students who used science concepts once during the case drops but this is probably because those students who used science once during the case at Time 2 used science concepts more frequently at Time 3.

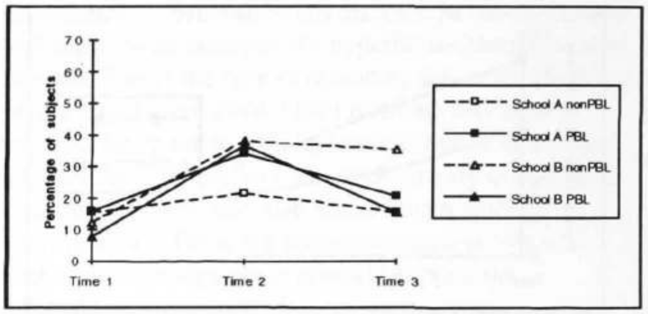

Figure 4a: Use of science concepts in a single section of the case

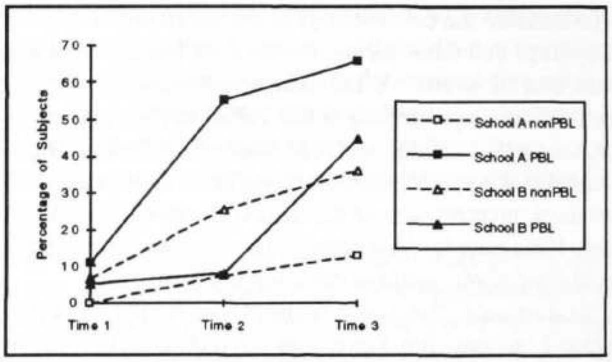

Figure 4b: Use of science in two or more sections of the case

At School B, between Time 1 and Time 2, both the nonPBL students and the PBL students showed a large increase in the number of students using science concepts at least once, but the nonPBL students maintained the same numbers at time 3 whereas the PBL students show a decrease in the number of students using science concepts at this level. Figure 4b helps clarify this because it can be seen that the number of students using science concepts in two or more sections of the case increased steadily for the nonPBL students but did not increase by much until Time 3 for the PBL students when they surpassed the nonPBL students. Clearly, at School A, PBL has improved access to scientific information for these students in the context of clinical cases relative to the nonPBL students. At School B, although the results are not clear cut, there is a trend toward the PBL students using science concepts more frequently than the nonPBL students in explaining these cases.

Discussion

In this study, many changes were found that resulted from the type of curriculum that the students participated in. The reasoning strategies that the students learn and transfer to new problems (i.e., hypothesis-driven reasoning) helps them construct the knowledge structures that are used in the early development of expertise. Early development of medical expertise is characterized by the development of elaborated causal networks that explain diseases in terms of general pathophysiological processes (Schmidt et al., 1990). Through extensive application of this knowledge, the networks become compiled and are subsumed under diagnostic labels (Schmidt et al., 1990). By promoting the use of hypothesis-driven reasoning strategies, PBL may accelerate this development. The same argument may be extended to the knowledge compilation stage as the PBL students have a greater opportunity to apply their knowledge to clinical cases. In addition, learning to use causal knowledge appropriately will be important as the students become experts and face difficult problems that require them to use their causal knowledge (e.g., Norman et al., 1994).

Although the data reported in this study show some of the outcomes associated with PBL, they do not explain how learning occurs. Research in cognitive science offers some explanations that are consistent with the results obtained. In PBL, learning occurs through collaborative discussion. The development of causal models is facilitated in PBL as students activate their prior knowledge in PBL groups, enhancing the processing of new information (Schmidt, 1993). Group discussion encourages students to articulate their knowledge and theories. These discussions use hypothesis-driven reasoning which serves the function of self-explanations which itself is a learning mechanism as students connect abstract knowledge to clinical applications (Chi et al., 1989).The nature of hypothesis-driven reasoning allows students to learn to filter relevant from irrelevant information. One result of this is a coherent understanding. Mental models are constructed and restructured in response to the problem posed and students' explanations of the phenomena to be understood. In later discussions, as the group seeks to further understand the causal mechanisms underlying the case, further tuning of the mental models occurs (Schmidt, 1993). If students in PBL construct elaborated causal models of biomedical science that are integrated with clinical cases, then their ability to generate more coherent causal explanations should increase over time. The results of this study suggest that this is occurring and that hypothesis-driven reasoning may be the mechanism.

Coherence in reasoning is an important metric to use. A coherent explanation has no loose ends and accounts for all the information. Furthermore, increasing coherence is found in expert reasoning. In a study of radiologists, a similar measure of coherence revealed an increase with expertise (Lesgold, Rubinson, Feltovich, Klopfer, & Wang, 1988). Senior radiologists chunked more findings together than residents. This suggests that experts do more inferential thinking and end up with a more coherent representation of the patient. Novice's explanations, with less data accounted for, suggest a more fragmented representation.

Transfer-appropriate processing is another mechanism that has been proposed to explain the effectiveness of PBL. Because students learn science in the context of clinical problems, they should be more likely to recall that information in clinical practice (Adams et al.,1988, Needham & Begg, 1991). In this study, explanations were examined for concepts or facts from the biomedical sciences as an indication that students were integrating science information. The results showed that PBL students became increasingly likely to use science in their explanations, particularly in the full-time PBL program. This is consistent with other work as well (Hmelo et al, 1994, Patel et al, 1993). For example, in Patel et al. (1993), PBL and conventional students were asked to construct causal explanations and integrate relevant basic science information into their think-aloud explanations. The PBL students incorporated more of the science information into their explanations and generated more hypothesis-driven explanations than the conventional students. It is tempting to conclude that the PBL students learned to use science as a tool for understanding, but further research is needed to investigate this issue.

Another possible mechanism for the effects of PBL is that the students acquire a library of cases from which to reason (Kolodner, 1993). The post-hoc analysis of the accuracy data suggest that specific experience accounts for part of the accuracy effect but that there is an influence of PBL beyond this. Further investigation is needed to better understand the effect of PBL on case-based reasoning.

Conclusions

PBL has clear-cut cognitive effects that are related to the intensity of the PBL experience. For School A, the fully problem-based curriculum, the students constructed coherent models of science that were integrated with the cases they are studying. At School B, the results were not as clear. There were PBL effects for science use, use of hypothesis-driven reasoning, and accuracy. Further research needs to be done to examine the role of the specific cases used and the development of misconceptions that may occur in these student-directed groups. Nonetheless, PBL holds the promise of powerful cognitive benefits for learners.

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