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ABSTRACT

In a study of the development of measures that can assess specific learning and reasoning changes affected by a problem-based learning (PBL) curriculum in medical education, evidence is provided of the cognitive benefits of a PBL approach. To determine whether PBL students reach reasoning goals with a novel clinical case, the study evaluated directionality of reasoning, coherence of explanations, and use of basic science information in explanations for 20 medical students in a PBL class and 20 in the same core curriculum without the PBL experience. Both groups evaluated the same clinical case study. The paper-and-pencil measures that were developed revealed a significantly greater use of hypothesis-driven reasoning in the PBL group, as well as greater coherence in their explanations. PBL instruction appears to have distinct cognitive consequences that may influence medical practitioners throughout their careers and may shape the learning strategies they use in lifelong learning. Six figures present study data. (Contains 14 references.) (SLD)

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THE COGNITIVE EFFECTS OF PROBLEM-BASED LEARNING: A PRELIMINARY STUDY

Cindy E. Hmelo, Gerald S. Gotterer, & John D. Bransford

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The Cognitive Effects of Problem-Based Learning: A Preliminary Study [1]

Cindy E. Hmelo, Gerald S. Gotterer, and John D. Bransford[2]

Medical schools are increasingly looking to case-based formats such as problem-based learning (PBL) for their medical students. However, the effects of PBL have not been adequately assessed for an informed decision. It has been argued that PBL improves lifelong learning, clinical reasoning, and basic science learning but the literature on the cognitive benefits of PBL has shown mixed results (e.g., Albanese and Mitchell, 1993). For example, on the National Board of Medical Examiners (NBME) Part I, a test of Basic Science knowledge, PBL students tend to score lower than students in traditional curricula but students in a PBL curriculum tend to perform slightly better on NBME tests of clinical reasoning. However, some of the traditional measures (e.g., board scores) used in earlier studies of PBL may not have been sufficiently sensitive to reveal cognitive effects such as changes in reasoning and self-directed learning (SDL) strategies. The goal of the present study was to develop measures that can assess specific reasoning and learning changes purported to be affected by the PBL curriculum. At the same time, we develop evidence of the cognitive benefits of a PBL approach.

Theoretical Framework for PBL

PBL includes among its goals: 1) developing scientific understanding through clinical cases 2) developing clinical reasoning strategies, and 3) developing self-directed learning strategies. Research and theorizing in cognitive psychology provides evidence that supports some of the general goals of PBL (Norman, 1992). Additionally, laboratory-based research suggests that by anchoring instruction in authentic problem-solving contexts, the knowledge, clinical reasoning processes,

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and SDL strategies learned should be more readily transferred when that knowledge or strategy is needed (e.g., Adams, Kasserman, Yearwood, Perfetto, Bransford, and Franks, 1988; Williams, 1993). Reasons for the effectiveness of PBL include the fact that the relevance of science as a tool for understanding and solving medical problems should be more readily apparent (Bransford, Franks, Vye, & Sherwood, 1989). In addition, the acquisition of prior examples that occurs during PBL may allow later problems to be solved on the basis of similarity (Brooks, Norman, & Allen, 1991). Finally, the active learning promoted in PBL should promote the self-directed learning strategies and attitudes needed for lifelong learning (Bereiter & Scardamalia, 1989; Ng & Bereiter, 1991).

PBL and Clinical Reasoning

In the current study, we examine whether PBL students reach the reasoning goals with a novel clinical case. We assess PBL students reasoning and integration of scientific information using paper-and-pencil instruments. We do this by evaluating: 1) directionality of reasoning, 2) coherence of explanations, and 3) use of basic science information in explanations.

Reasoning can be examined by looking at how the data and hypotheses are related to each other (see Figures 1a and 1b). 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. 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. This may occur for several reasons. First, the problem-solver may not be clear about causality. Second, there may not be, in reality, a clear causal relationship. Subjects may also assert causes without justifying them. These are statements such as "He is diabetic" without any explanations to support the hypothesis.

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Insert Figures 1a and 1b about here

Although data-driven reasoning is more characteristic of experts, it is inappropriate for novices who have an insufficient knowledge base (Patel and Kaufman, 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 prediction (Patel, Groen, & Norman, 1993).

The nature of hypothesis-driven reasoning allows students to learn to filter relevant from irrelevant information. One expected result is a coherent explanation. Coherence of explanation was assessed by looking at the maximum number of relational operators chained together in an explanation. For example, an explanation such as "because he is diabetic, he cannot metabolize carbohydrates so he must use ketone bodies for energy causing a metabolic acidosis" would be scored as containing three relations but "he has an acidosis which causes an increased respiratory rate" would be scored as containing one relation. We expected that the PBL students would generate longer reasoning chains than nonPBL students. In a study of radiologists, a similar measure of coherence revealed an effect of expertise (Lesgold, Rubinson, Feltovich, Glaser, Klopfer, & Wang, 1988). Senior radiologists had longer reasoning chains indicative of more coherent explanations than residents. This suggests that experts are doing more inferential thinking and ending up with a more coherent representation of the patient. Alternatively, novice's explanations, with shorter reasoning chains, suggest a more fragmented representation.

Because PBL students are learning basic science in the context of clinical cases, it

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is reasonable to expect them to use this information in their explanations. We coded explanations for concepts or facts from anatomy, physiology, biochemistry, microbiology, or pathology. These provide evidence that students are integrating basic science information. In a recent study by Patel, Groen, and Norman (1993), PBL and conventional students were asked to construct causal explanations and integrate relevant basic science information into their think-aloud explanations. They found that the PBL students incorporated more of the basic science information into their explanations and generated more hypothesis-driven explanations than the conventional students. The current work attempts to replicate these findings using a paper-and-pencil instruments.

PBL and Self-Directed Learning

In addition to reasoning strategies, the current study examines the impact of PBL on SDL. Self-directed learning has several components. First, learners must assess their own state of knowledge relative to the problems they face. They must formulate these learning needs so they can efficiently meet these needs and make use of appropriate resources. Blumberg and Michael (1991) have provided indirect evidence to show that a PBL curriculum has an impact on self-directed learning; PBL students borrowed more materials from the library than conventional medical students. They did not evaluate the self-assessment of learning needs or the generation of learning plans.

There is little empirical research that clearly defines the nature of good self-directed learning strategies (Hmelo, 1993). Theoretically, when one has a hypothesis, choosing to search in a hypothesis-driven manner may be more efficient than a search that is data-driven. A search that proceeds by investigating the significance of isolated findings may not effectively narrow the search space unless of course one hits on the correct pathognomic finding to look up.[3] In a recent paper by Bassok and Holyoak (1993), a distinction is made between top-down and bottom-

[3] A pathognomic finding is a characteristic that is unique to a particular disease. The presence of such a sign or symptom allows positive diagnosis of the disease.

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up learning. Bottom-up learning refers to inductive learning by examples. Top-down learning depends on prior knowledge of the domain coupled with active learning strategies that allow the learner to make principled judgements about the importance of features to the learner's goals. Bottom-up learning requires that students make generalizations from multiple examples. The learners do not engage in deep analysis of principles and may end up knowing sets of correlated features (including some that are irrelevant). To the extent that top-down learning enables learners to successfully identify relevant but nonobvious features of a problem, more flexible transfer will be promoted. If the domain-knowledge is fragmented however, students may need to have their attention directed to goal-relevant aspects. In problem-based learning the students are encouraged to think about the cases with the underlying scientific principles in mind rather than just collecting sets of features. As cases are connected to domain principles, the learner can begin to understand how knowledge can be applied to solving problems (Chi, Bassok, Reimann, Lewis, & Glaser, 1989). Self-directed learning that proceeds in a hypothesis-driven manner (i.e., top-down) should lead to more flexible knowledge.

In this study, we also examine whether PBL students can assess their learning needs and develop a plan to address those needs. The learning needs (i.e., learning issues) fall into three categories: disease-driven, data-driven, and basic-science issues. An example of a disease-driven learning issue is "complications of diabetes." Disease-driven learning issues map onto hypothesis-driven reasoning in that they indicate the students are researching hypothesized disease mechanisms to try to account for the data. A basic-science driven learning issue might be "acid-base physiology." An example of a data-driven learning issue is "the significance of an elevated respiratory rate." Data-driven learning issues map onto data-driven reasoning because the individual is researching the pattern of data in order to determine the causes. If the students' SDL strategies are consistent with their reasoning strategies, the PBL students should generate more disease-driven and basic science learning issues whereas the nonPBL students should generate more

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data-driven learning issues.

We would predict that given their experience, the PBL students would be more facile with choosing the learning resources for this task. However, the nonPBL students also have considerable experience in writing papers and using the library. We make no predictions about which group would use more resources but we do expect them to use different resources. The learning resources that the students used are categorized into basic science textbooks, clinical textbooks (which include both medical texts and diagnostic manuals), and use of expert consultants. We expected more basic science textbooks to be used by the PBL students because that maps onto the hypothesis-driven reasoning, integration of science information and the associated learning issues. We expected more clinical textbooks to be used by the nonPBL students because that maps onto data-driven reasoning.

Methods

Forty medical students participated in this study. Twenty students had participated in an elective class in PBL; twenty students (the nonPBL group) had taken a different elective. Within each condition, half the students were in their second year of medical school and half the students were three months into their first year of medical school. Each cohort of students was also taking the same traditional core curriculum.

Instruction for the PBL students consisted of a group of eight medical students and a facilitator meeting for two hours. once each week. The facilitator gave the students a small amount of information about the patient case. The group's task was to evaluate and define different aspects of the problem and to gain insight into the underlying causes of the disease process. This was done by questioning the facilitator, generating and evaluating hypotheses, and generating learning issues. Learning issues are topics that the group has decided are relevant and which they needed to learn more about. The group members would divide the learning issues and research them, using both material resources (e.g., the library) and expert consultants. During the next session, they then shared the information in an

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attempt to explain the patient's disease process.

To study the cognitive effects of instruction, students were presented with the case of a child with diabetic ketoacidosis. The case was presented in four segments: presenting complaint, history, physical examination, and laboratory data. After each segment, the students were asked to explain, in writing, the underlying causal mechanisms that would account for the patient's problem. At the end of the case, the students were asked what they would want to learn more about to better understand the case and how they would go about meeting their learning needs.

Results

The subjects' reasoning strategies, coherence, learning self-assessments (referred to as learning issues) and learning plans were coded from the subjects written responses. These problem solving protocols were coded by a rater blind to conditions. A second blind rater independently scored a randomly selected subset of 20% of the protocols. The two raters agreed on 92% of the responses.

Problem-solving

With respect to the reasoning strategies, the results indicated that PBL students were more likely to use hypothesis-driven reasoning in their explanations than nonPBL students, $F(1,36)=15.59$, $p<.001$, $MS_e=0.12$ (Figure 2). In contrast, nonPBL students were more likely to use data-driven reasoning strategies ($F(1,36)=5.23$, $p<.05$, $MS_e=0.06$). Second-year nonPBL students were more likely than the second year PBL students to use other relations in their reasoning ($F(1,36)=6.17$, $p<.05$, $MS_e=0.05$). This suggests that, in general, the PBL students transferred the hypothesis-driven reasoning strategies that they were taught. The second-year nonPBL students appear to realize that there are relationships between data and hypotheses but they do not make clear what these relationships are. The groups did not differ on the number of unjustified assertions they made (Overall mean=.60, $F(1,36)=1.78$, $p>.60$).

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Insert Figure 2 about here

By measuring the length of the students' reasoning chains, differences in the coherence of the explanations can be detected. With this measure, we detected greater coherence in the PBL students' explanations. The PBL students generated longer reasoning chains than the nonPBL group as shown in Figure 3 ($F(1,36)=7.22$, $p<.01$, $MS_e=0.97$). Finally, PBL students showed a marginal trend toward using more basic science in their explanations however, this was a low frequency event ($F(1,36)=3.09$, $p<.10$, $MS_e=0.20$; see Figure 4).

Insert Figures 3 and 4 about here

Self-directed learning

With respect to the SDL strategies, our measures revealed qualitative differences in the learning issues that PBL and nonPBL students generated. The students learning issues were categorized into patterns that included disease-driven or basic-science issues (combined to form hypothesis-driven patterns) and those that included data-driven or mixed (a combination of data-driven and hypothesis-driven) learning issues. The use of experts did not differ reliably across groups so this resource was not used in comparing the patterns of learning plans. As shown in Figure 5, the second-year PBL students generated exclusively hypothesis-driven patterns of learning issues whereas only 60% of second-year nonPBL students generated hypothesis-driven patterns of learning issues (c2(1)=5.0, p<.05). Of the second-year nonPBLstudents, 40% included data-driven learning issues. For the first year students, the distribution of learning issues did not differ significantly between the two groups but the first year PBL students did show a trend toward more hypothesis-driven learning issues than their nonPBL counterparts

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flexible knowledge and problem-solving.

An alternate explanation for these results is that they were due to self-selection and preexisting differences. To deal with these limitations, additional research is needed that uses a longitudinal design. In addition, to generalize these results, further studies must use multiple cases and multiple sites, as well as to control for self-selection effects. A study in progress focuses on using the this methodology in a longitudinal study designed to to compare the impact of full-time PBL, elective PBL, and conventional curricula.

The current study, using an authentic diagnostic task, found that PBL instruction has distinct cognitive consequences that may influence medical practitioners throughout their careers. This is important as the medical education community decides whether to adopt a PBL approach. Prior studies have used traditional measures to assess PBL and have found few robust effects. Given that no strong differences between PBL and conventional students have been found on traditional measures such as board scores, the question becomes what are the subtler and more long-lasting effects that may not captured by traditional measures. In this study, we developed measures pertaining to the cognitive changes that affect lifelong learning. Our preliminary findings are important because they suggest that PBL may endow physicians with the learning strategies necessary to stay informed in the face of rapid medical advances.

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($\chi^2(1)$=.83).

Insert Figure 5 about here

The PBL and nonPBL students generated different learning plans in a manner that was consistent with their learning issues and reasoning strategies (Figure 6). PBL students were more likely to use a combination of basic science and clinical texts whereas nonPBL students were more likely to use exclusively clinical texts especially at the first year level ($\chi^2(1)=7.27$, $p<.05$ for the first year students; $\chi^2(1)=1.50$, $p>.40$ for the second year students). In fact, none of the first-year nonPBL students planned to use mixed resources. Recall that clinical texts include not only general medicine textbooks but diagnostic manuals as well. When the specific resources that students with data-driven learning plans were examined, it was found that for the first year nonPBL students, 40% of the resources in their plans were diagnostic texts compared with 22% of the first year PBL students' resources. So again, this pattern is consistent with the reasoning strategies the students were using.

Insert Figure 6 about here

Discussion

The measures used in this study revealed a significantly greater use of hypothesis-driven reasoning in the PBL group. Moreover, by measuring the length of the reasoning chains, we detected a greater coherence in the PBL students' explanations. Our measures also revealed qualitative differences in the learning issues and plans that PBL and nonPBL students generated. These strategies were consistent with the reasoning strategies that the students used. The hypothesis-driven learning strategies that the PBL students use should lead to more

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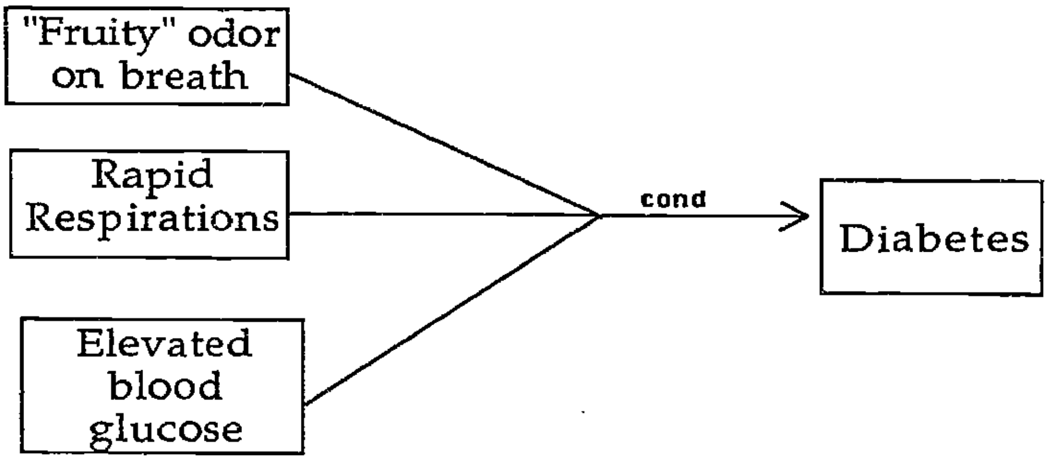
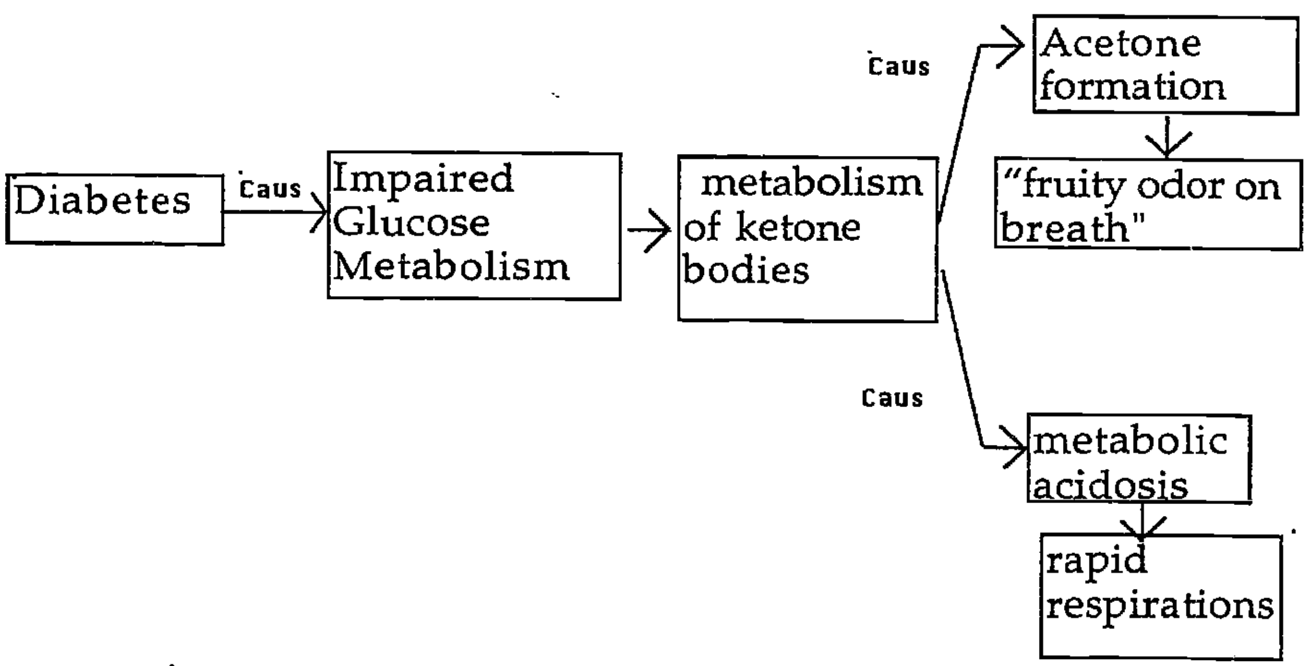
Figure 1a. Data-driven Reasoning



All links in the diagram are from effects to hypothesized cause

Figure 1b. Hypothesis-driven Reasoning



All links in the diagram are from hypothesized cause to effects

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Figure 2. Directionality of Reasoning

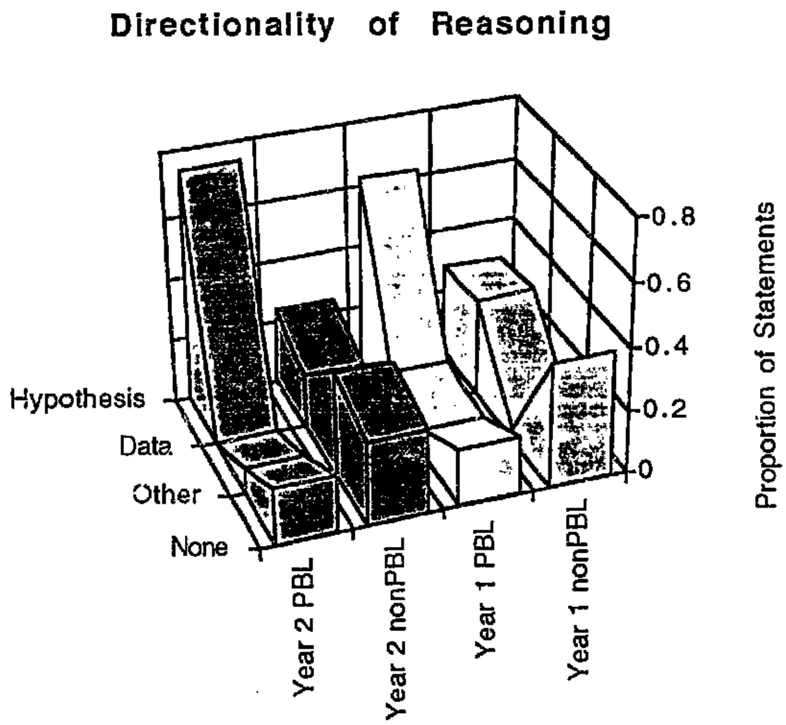

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Figure 3. Maximum Reasoning Chain Length

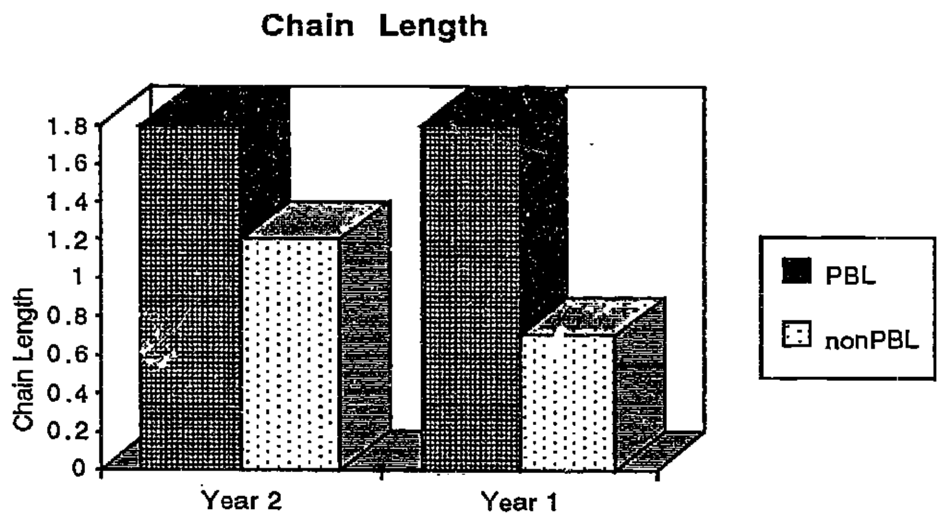

Figure 4. Use of Basic Science Concepts

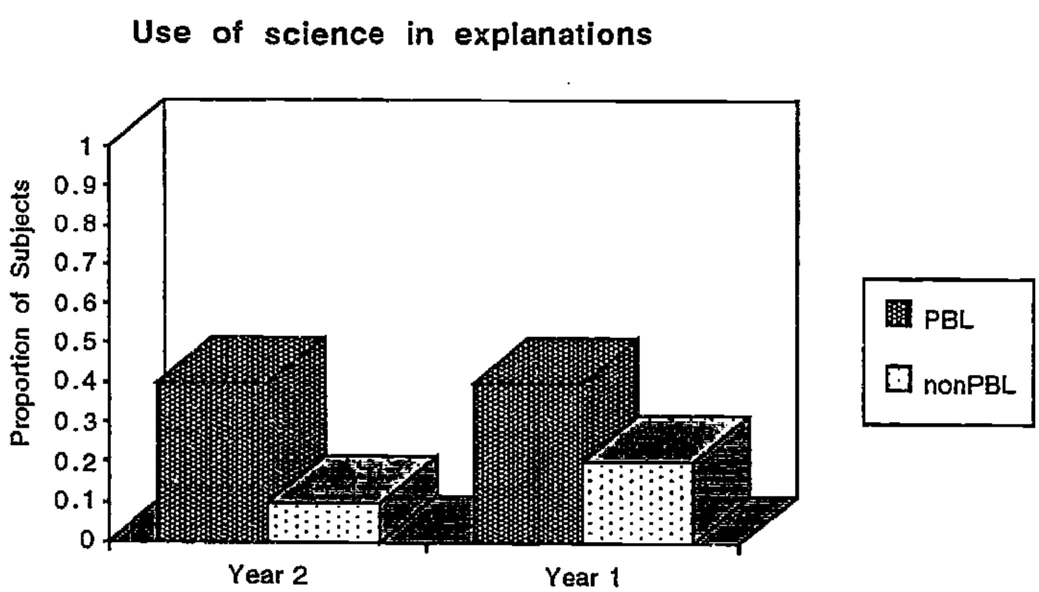

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Figure 5. Self -directed Learning: Learning Issues

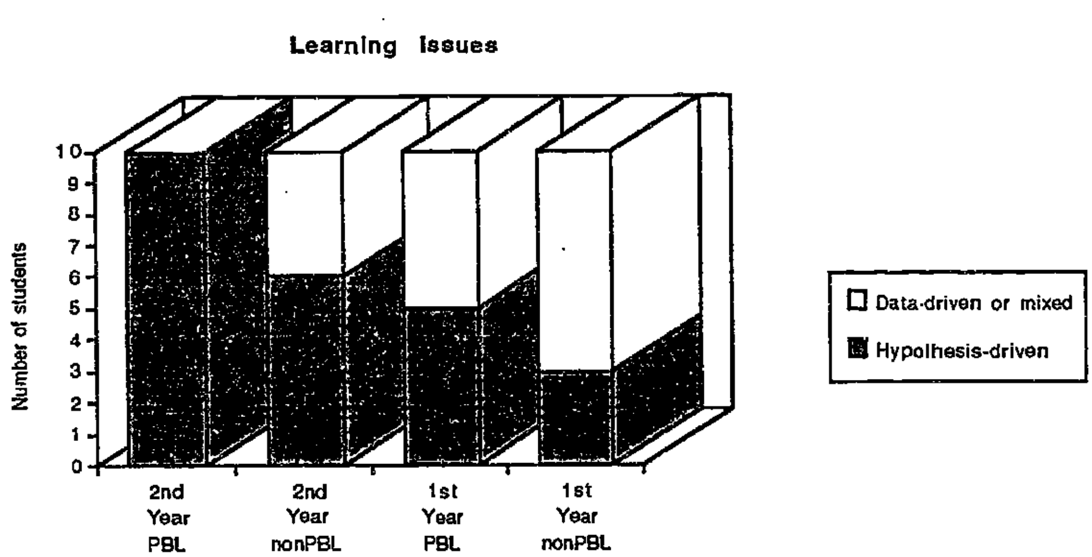
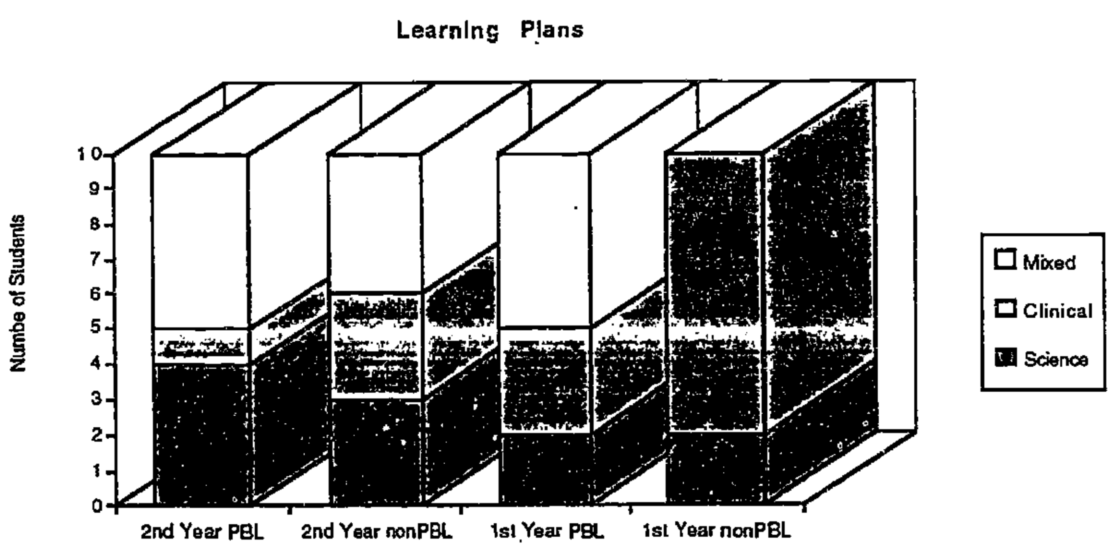


Figure 6. Self -directed Learning: Learning Plans



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