Effects of Problem-Based and Lecture-Based Instructional Strategies on Problem Solving Performance and Learner Attitudes in a High School Genetics Class

Literature Review

This section of the paper provides a critical overview of the current state of research in the area of problem-based learning. The section begins with a brief review of the current understanding of problem solving as a cognitive process, and the need for research on the teaching and learning of problem solving. This is followed by an overview of the definition and design attributes of problem-based learning as an instructional strategy. The main portion of the section is dedicated to an analysis of the research findings published to date on the impact of problem-based learning on learner performance, attitudes, cognitive development, and metacognitive development. Some of the research on the conditions for the effective design of problem-based environments is also considered.

The Teaching of Problem Solving and Thinking Skills: A Review

Learning specialists generally agree that problem solving, together with several other core competencies (e.g. comprehending and composing, critical and creative thinking, and metacognition) is among the most important dimensions of thinking and learning (Jonassen, 1994). Nickerson (1994) has pointed to several of the reasons why the ability to engage in effective and purposeful problem solving is critical to the development of individuals and their communities. In order of increasing specificity, Nickerson (1994) argues that problem solving is (1) at the core of the survival of individuals and communities interacting with an increasingly complex external environment; (2) essential to developing and sustaining a democratic society, and; (3) an increasingly sought-after high level cognitive ability in the knowledge workplace of today.

Despite the acknowledgement of the importance of developing problem solving skills, relatively little research has been conducted on this theme in the field of instructional design (Jonassen, 1994). Moreover, within the existing research base, even fewer contributions have been made to the development of instructional design approaches for ill-structured or complex problem solving instruction. The majority of the instructional design literature in the area of problem solving instruction points to the use of particular instructional strategies to support the acquisition of problem solving skills (e.g. cognitive apprenticeships and microworlds). However, these strategies have rarely been researched with sufficient rigor to ascertain their effectiveness in achieving the desired outcomes.

Problem-Based Learning: Definition and Design

A number of instructional strategies inspired by constructivist philosophy has been developed and researched over the last years. Such strategies have been applied particularly in instructional contexts where the intended learning outcomes are primarily of a higher order/complex nature (such as problem solving and analytical thinking.) Constructivist instructional strategies include problem-based learning, cognitive apprenticeships, microworlds, and simulations.

Problem-based learning is one constructivist instructional strategy that has shown much promise in its application to disciplines and domains where learners have to tackle complex problems in ambiguous situations. This approach to instruction "structures courses and entire curricula on problems rather than on subject content" (Smith & Ragan, 1999, p. 145.) Problem-based learning is a methodology that situates learning in complex and meaningful problems that are framed in authentic contexts (Hmelo, 1998). Students work in small groups to acquire the conceptual knowledge and procedural skills needed to develop one or more plausible solutions to each of the problems presented to them.

Although problem-based learning was first applied to K-12 classrooms in the 1920's and 1930's, the approach has gained particular attention in recent years due to the success in its application to medical programs at the university level (Smith & Ragan, 1999.)

The specific instructional techniques and procedures used in the design and implementation of a problem-based learning course or curriculum varies from one context to the next. However, the typical learning process followed in a problem-based learning environment is as follows:

1. Students begin the problem "cold" - without any prior experience in dealing with like problems. Each group of students (usually consisting of between five and twelve students) will meet with a facilitator to discuss the problem.
2. The facilitator presents a limited amount of information about the problem, and the group is charged with the task of identifying the different aspects of the problem by asking the facilitator questions to elicit information relevant to the problem.

3. Students work with the facilitator to generate and refine hypotheses related to the problem's potential solution. The facilitator's role is to model hypothesis-driven reasoning skills.
4. Students determine "learning issues" that the group decides are relevant and that they need to learn more about to find an acceptable solution to the problem.
5. The groups are then asked to assign tasks to each member of the group for researching each of the different "learning issues" they have identified.
6. Group members engage in self-directed learning by gathering information related to the assigned learning issues from a variety of different sources.
7. After each of the group members has conducted the necessary research related to the "learning issue" they were assigned, the group members report their findings to each other. They reconvene and re-examine the problem, applying newly acquired knowledge and skills to generating a formal solution to the problem.
8. Once the formal solution has been presented to the class and the facilitator, students reflect on what they have learned from the problem and on the process used to resolve the problem presented.

A Review of the Existing Research on Problem-Based Learning

Recent literature in the field of instructional systems design has dedicated a fair amount of attention to considering the methods for applying problem-based learning as an instructional strategy in the context of primary and secondary school contexts (e.g. Savery & Duffy, 1994; Smith & Ragan, 1999; Reigeluth, 1999; Nelson, 1999). The majority of this work has approached the application of problem-based learning to formal instruction from a conceptual or theoretical standpoint, with little reporting on empirical research studying the effectiveness of this approach. A review of the existing research on problem-based learning suggests that there have generally been very few studies that have been conducted on the effectiveness of problem-based learning outside the context of university-level medical training.

In this literature review, the findings reported in the studies on the application of problem-based learning to medical school programs will be reviewed. The literature review will specifically focus on the research findings related to the effect of problem-based learning on the attitudes, performance, cognitive strategies and metacognitive techniques of students receiving this form of instruction. In addition, some attention will be given to research findings on the role of facilitator subject-matter expertise, learner characteristics, and student reliance on instructional support tools, in determining the effectiveness of problem-based instructional strategies. In the analysis of these findings consideration will be given to the potential generalizability of the research conducted to date. In addition, the limitations of the current research basis will be considered, and a case will be made for the need for additional research on the effectiveness of problem-based learning as an instructional strategy for primary and secondary school application.

Research findings on learner performance

The existing research on learner performance in problem-based learning environments is characterized in a number of ways: (1) most of the research conducted to date compares the impact of problem-based learning on learner performance to the instructional strategies that characterize traditional, classroom-based teaching (e.g.; Hmelo, 1998; Blake, Hosokawa, & Riley, 2000). (2) the research studies tend to focus primarily on learner performance on standardized tests, rather than performance in complex and authentic transfer contexts, and (3) the studies generally measure performance in terms of outcome measures rather than process-measures of performance.

In this context, the research on the impact of problem-based learning on student performance has generally shown that there are no statistically significant differences in learner performance when compared to performance of learners receiving lecture-based instruction (Chang, et al.,1995; Albanese & Mitchell, 1993; Kaufman & Mann, 1998; Login et al., 1996). A meta-analysis of English-language research on the impact of problem-based learning in medical education found that PBL students generally performed at the same levels as traditional students on basic science examinations, while in a few instances scoring lower than their conventionally trained counterparts (Albanese & Mitchell, 1993). Similarly, Vernon & Blake (1993), in their meta-analysis of problem-based learning research in medical schools, found no significant differences in student achievement on tests of factual and clinical knowledge.

The findings from the two meta-analyses cited above are generally consistent with a number of other research studies where it was found that there was no statistically-significant difference in performance on the U.S. Medical Licensing Examination (e.g. Blake, Hosokawa & Riley, 2000) or the National Board of Medical Examiners examination (Farquhar, Haf & Kotabe, 1986) between students participating in problem-based learning and those receiving lecture-based instruction. Colliver (2000) concludes his review of the literature with a similar conclusion, i.e. that the impact of problem-based learning on student performance revealed no convincing evidence that problem-based learning improved declarative knowledge or clinical performance beyond traditional lecture based instructional methods. Albano, et al. (1996) conducted research on the differences in the final levels of knowledge acquisition in medical schools using a variety of instructional strategies, including problem-based learning and lecture-based learning, and they concluded that the differing strategies seem to have only limited influence on the final level of knowledge of the graduates.

Student perceptions of the effectiveness of problem-based learning on their performance appears to be consistent with the general research findings. Although only one research study was identified regarding student perceptions of the effectiveness of problem-based learning, it is worthwhile noting that in this study, students pointed to problem-based learning as a more effective method of instruction than traditional, lecture-based methods, while qualifying their observations by noting that traditional teaching methods are more effective for knowledge acquisition (Bernstein, Tipping, Bercovitz & Skinner, 1995).

Research findings on student attitudes

While the research conducted to date does not show a statistically significant difference in learner performance on standard assessments used in medical schools, the research studies in this area do suggest that the problem-based learning strategy positively impacts learner attitudes in a statistically significant manner. Vernon & Blake's (1993) meta analysis reports on learners' superior evaluation of problem-based learning as an instructional strategy over other instructional strategies. This is consistent with a number of other research studies, in which students in problem-based learning environments reported significantly higher levels of motivation and satisfaction (Alabi, Gerritsma, Maude & Parry, 1996; Bell & Hendricson, 1993; Chang et al, 1993; Bligh, Lloyd-Jones & Smith, 2000), and where it is reported that problem-based learning enhances intrinsic interest in the subject matter to a greater extent than traditional instructional methods (Norman & Schmidt,1992).

Given the general finding that learners in problem-based learning environments report more positive attitudes and higher levels of motivation, it is important to consider the factors learners attribute to their favorable disposition toward problem-based learning. Research conducted by Bercovitz, & Skinner (1995) provides some insight into this, reporting that students in problem-based learning curricula perceived their curriculum to be more stimulating and enjoyable than traditional instructional methods. In addition, research conducted by Kaufman & Mann (1996) reports that students in problem-based learning environments rated their curriculum more favorably for democratic decision making, and for supporting effective interaction among peers.

Research findings on metacognitive skills acquisition and application

One of the critical features in the design of problem-based learning environments is an emphasis on the learner's reflective engagement during the learning and problem solving process. With this type of instructional strategy, learners maintain a "problem log," throughout the course of the problem solving process, in which they keep a record of their tasks for resolving the learning issues identified by their group members and for monitoring their inquiry process and findings (Hmelo, 1998). The problem log is intended to assist learners in developing their key self-regulative skills, such as planning, knowledge evaluation and self-evaluation (Ellis & Siegler, 1994). In addition, students in problem-based learning engage in a fair amount of self-directed searching and knowledge acquisition activities, as each of the members of the group is given responsibility for identifying the needed information for resolving the learning issues related to the problem.

Intuitively it appears that the incorporation of problem logs and self-directed search activities in the instructional process should positively impact the development of the metacognitive skills of learners. Research validating this assumption, however, is scarce. The research conducted to date on the role of problem-based learning in supporting the metacognitive and self-regulatory skills of learners appears limited to a review of research evidence conducted by Norman & Schmidt (1992), in which a number of studies are cited as having found that problem-based learning appears to enhance self-directed learning skills of students, and that, overall, learners in problem-based learning environments show sustained and positive changes in their self-directedness. However, Norman & Schmidt's (1992) review of the literature does not give significant insight into the operational definitions used for the concept of self-directedness, nor does it elucidate the nature and validity of the research methods used to measure the presence of this variable.

<u>Research findings on factors affecting the effectiveness of problem-based learning</u>

The current research on problem-based learning in the medical schools has brought to light a number of issues that seem to impact the effectiveness of the application of problem-based learning as an instructional strategy. Some of these are findings related to the implementation of the problem-based learning design (Kalaian & Mullan; 1996; Dolmans et al.,1993; Schmidt et al., 1992), while others address the issue of the impact of learner characteristics on performance in problem-based learning environments (e.g. Cariaga-Lo et al, 1996). The research findings from this handful of studies will be briefly considered below.

One of the key concerns raised with the application of the problem-based learning curriculum in the classroom context is that the role of the learner in determining the learning issues to be addressed may cause one or more critical learning objectives not to be met, since there is no systematic design to ensure alignment between the instructional objectives and the specific content covered in the practice activities. However, careful construction of the problem activities used in a problem-based learning strategy can ensure that learners must cover a number of key content areas in order to succeed in solving the presented problem. Dolmans et al. (1993) conducted an analysis of alignment between instructional objectives and instructional content addressed in problem-based learning environments, and found that students' learning activities covered an average of 64% of the intended course content. While this is somewhat lower than might be the case in a rigorously-designed direct instruction course, the authors argue that course content covered in problem-based learning is likely not significantly lower than in standard traditional lecture-based classes. In addition, Dolman et al’s (1993) study found that the students in problem-based learning courses also generated learning issues that had not been expected by the faculty, and it was determined through retroactive analysis that approximately 50% of these issues were judged relevant to the course content. This research thus concludes that, while there may be some inefficiency in the instructional process (with learning issues being identified that have little relevance to the course content), these inefficiencies are compensated for with a fairly high degree of alignment between the instructional objectives and the instructional content, coupled with a high degree of learner ability to adapt learning activities to their own needs and interests in problem-based environments.

While the instructors take on a largely facilitative role in the problem-based learning environment, they remain a central determinant of the success of the problem-based strategy due to the important roles that they play in modeling hypothetical reasoning processes for learners, and providing subject matter insight needed for the resolution of the problems. Schmidt et al. (1992) conducted research on the impact of varying levels of instructor subject-matter expertise on the performance of students in problem-based learning. They found that students guided by subject-matter experts spend more time on self-directed study, and that they achieved somewhat better than did the students guided by non-expert facilitators. Furthermore, they found that the effect of subject-matter expertise on achievement was strongest in the first curriculum year, suggesting that novice students are more dependent on their facilitators' expertise than are more advanced students. In addition, Schmidt et al.'s research found that the facilitators' process-facilitation skills also affected student achievement in a significant way, thereby leading to the conclusion that subject-matter expertise and facilitation skills are both necessary conditions for effectiveness of problem-based learning environments.

Another issue of relevance to effective design of problem-based learning environments is the extent to which various instructional support tools and mechanisms are provided to learners through this strategy. Research conducted by Kalaian & Mullan (1996) found that students tend to rely on different instructional support tools at different stages in their learning process. In their study, Kalaian & Mullan (1996) found that the four most meaningful elements impacting the students' learning processes were (1) learning materials, (2) small-group process, (3) facilitator effectiveness, and (4) academic support. Furthermore, the study found that these four factors shifted in relative importance as the students progressed through the curriculum, with facilitator effectiveness being of greatest importance at the outset, while learning materials were the most important factor in determining learning success toward the end of the instruction. This finding appears to be generally consistent with the theory underscoring problem-based learning, which argues that, as students develop greater independent ability to engage in effective hypothetico-deductive reasoning, their reliance on the facilitator for this kind of support will be reduced (Hmelo, 1998).

The Limitations in the Scope and Generalizability of the Findings

From Research to Date on Problem-Based Learning

While the research on the effectiveness of problem-based learning in medical school programs is quite voluminous, the research conducted to date presents a number of concerns in terms of its scope and its potential generalizability to the context of secondary school environments. A number of limitations of the research are raised, and each of these will be briefly considered in this section.

One of the primary concerns with the potential generalizability of the findings on problem-based learning in medical schools is the difference in the learner characteristics and learning conditions between medical schools and public secondary schools. Medical students are in many ways quite different in their general attributes from students in secondary schools. Due to the age differences between medical students and secondary school students, these two groups of students are at varying levels of cognitive and metacognitive development. Adolescents in secondary school, falling within the formal operations stage of Piagetian development theory, are relative novices in the use of hypothetico-deductive reasoning skills (Fabes & Martin, 2000). These skills, however, are critical to novice problem solvers or problem solvers with little content knowledge in the context of the problem presented (Hmelo, 1998). Thus, while there appears to be little difference in the impact of problem-based learning on performance of medical students when compared with more traditional instructional methods, it is possible that this strategy may have a more pronounced effect on the cognitive development and problem solving process of adolescent learners, since they are still in the process of acquiring and refining their hypothetico-deductive reasoning skills.

Another factor in considering the generalizability of the research findings from the application of problem-based learning to medical school contexts is that the students in medical schools in many ways are an elite group of students, since most medical schools have rigorous admission requirements and students admitted to those programs will likely have significantly higher levels of education, and verbal and quantitative skills than the general school-going population (Mergendoller et al., 2000). This may play a significant role in determining the impact of any instructional strategy on the cognitive and metacognitive development of students, as well as their attitudes. This is further compounded by the findings from research conducted by Cariaga-Lo et al (1996), in which it was determined that students who entered the problem-based learning curriculum at one medical school had higher total Medical College Admission Test scores and undergraduate grade point averages than students who entered the lecture-based curriculum. Cariaga-Lo et al (1996), also found that students who entered the problem-based learning curriculum were more self-sufficient and were more likely to do well in individualistic and less structured settings. Since many of the medical schools offer two parallel curricula – one that is problem-based and one that is lecture-based – it is possible that the research conducted on the effectiveness of problem-based learning as an instructional strategy is biased toward learners of particularly high levels of academic achievement, and thus that these findings cannot be generalized to a broader population.

A further limitation of the research conducted to date on the effectiveness of problem-based learning as an instructional strategy is that the research has tended to compare this strategy to the default instructional strategy of lecture-based traditional teaching. Few of the studies provide effective operational definitions for the latter instructional strategy, with little attention being given to individual variations in teaching styles in lecture-based traditional teaching. There is thus a concern with determining what the measure of comparison is, since there is likely to be high variation in teaching effectiveness and teaching style in the traditional instructional framework.

Finally, research conducted to date does not appear to have adequately addressed the varying impact that the problem-based learning strategy may have on students of differing levels of ability and motivation. According to Mergendoller et al. (2000), there is considerable evidence that aptitude-treatment interactions exist, and that problem-based learning favors students with high levels of motivation and achievement. This is of particular importance when considering the potential application of this strategy to secondary school situations, where the goal is to use instructional methods that address the needs of students with varied learning styles, levels of achievement and motivational characteristics.

The case for conducting research on the application of problem-based learning as an instructional strategy in the secondary school setting

The purpose of the proposed study for the dissertation research is to determine the impact of two types of instructional strategies on performance and attitudes in problem solving in a high school statistics course. Specifically, the study will compare performance (on both simple problem and complex problem assessments), and attitudes of learners receiving instruction presented through either a problem-based instructional strategy or a direct instructional strategy. The problem-based instructional strategy situates learning in complex and meaningful problems (Hmelo, 1998) that simulate the complexities of the real world settings in which the learner might expect to apply the skills and knowledge acquired through the instruction. The second instructional strategy is direct in nature, with instructional content presented through carefully sequenced instruction with systematic relationships among behavioral objectives, instructional strategies, and assessment techniques (Dunn, 1994) and with problem solving practice activities of gradually greater levels of complexity, in accordance with Reigeluth's (1992) Elaboration Model.

The proposed research study seeks to overcome some of the limitations of the research conducted to date on the effectiveness of problem-based learning as an instructional strategy for supporting the acquisition of problem solving skills. In so doing, the researcher seeks to contribute to the empirical basis for determining the potential effectiveness of this instructional approach in several ways: (1) by considering the effectiveness of this strategy when applied to secondary school classrooms, (2) by studying the impact of problem-based learning on measures of performance, and (3) by considering the impact of self-regulatory attributes on learners' success in problem-based learning settings. The proposed research study will, in this manner, shed light on a number of the important factors related to the instructional effectiveness of problem-based learning that have hitherto not been addressed, or that have been insufficiently addressed, as evidenced in the above review and analysis of the current research on problem-based learning.

Since there is a growing interest in the application of problem-based learning strategies to secondary school classrooms, there is a need for specific research on the impact of this strategy in the secondary school classroom setting. The generalizability concerns expressed regarding the research data on the application of problem-based learning in medical schools provide a strong foundation for conducting research specifically on the transfer of the problem-based learning strategy to the secondary school classroom. Finally, the proposed research study will consider the impact of problem-based learning on learners of differing levels of self-regulatory abilities, with the goal of ascertaining the factors affecting the successful application of this strategy in classroom contexts where there is a high degree of heterogeneity in the self-regulatory attributes of the learners.

Rationale for the Research Study

Research Question

The research reported in this paper was conducted as part of a large-scale impact study of the effects of problem-based, problem-centered, and lecture-based instructional strategies on learner performance, cognitive processes, and attitudes in high school courses. The specific research questions pertinent to the research reported on in this paper is:

1. What are the effects of problem-based and lecture-based instructional strategies on the post-test performance of students enrolled in an 11th grade Genetics class?

2. What are the effects of problem-based and lecture-based instructional strategies on the attitudes of students enrolled in an 11th grade Genetics class?

3. What is the correlation between self-regulatory attributes of learners in the 11th grade Genetics class and their performance in either a problem based or lecture based instructional setting?

Independent variable

The independent variable for the research study was the instructional strategy. The first level of the independent variable is the problem-based instructional strategy. The second level of the independent variable is the lecture-based instructional strategy.

The lecture-based instructional treatment will be centered on a combination of instructor-led lecturing and student-oriented practical activities. The general nature of the course design follows Gagne's nine events of instruction. The instruction is initiated with a presentation of the instructional objectives for the class, and a "prior recall" activity (either an advance organizer or some other activity integrating the instructional content to prior knowledge and skills of the students) and an event to secure the motivation of the students. Next, the instructor will conduct a lecture in which the critical instructional content will be presented to the students. During the lecture, the instructor provides descriptions of key instructional knowledge and skills, and examples of the application of the concepts in practical contexts. The students are then given the opportunity to apply their understanding of the instructional content in the context of practice activities. The practice activities are generally focused around constrained problem sets (directly related to instructional content that has been presented), where students work in groups to apply their understanding to solving instructional problems requiring students to draw on acquired knowledge or skills. During the practice activities, the instructor provides guidance and feedback to the students in small groups and to the class as a whole. The instructor continues to provide instructional content in the lecture-based format throughout the class session on an as-needed basis (either during or after the practice activities). The class session is concluded with a summary activity, in which the key instructional content is summarized for the class, and a transfer assignment (usually in the form of a homework assignment) in which students apply their understanding of the instructional content to a more in-depth individual task in which students extend themselves to a transfer context. This instructional strategy is in place at the institution in question, and will be reviewed and analyzed by the researcher prior to the gathering of data.

The problem-based instruction treatment will be centered on a series of authentic problems that situate learning in the context of complex and meaningful challenges. Each of the problems will be characterized by having a direct relevance to the subject of instruction (i.e. genetics at the 11^{th} grade level or world studies at the 10^{th} grade level.) While the problems are designed to emerge logically from the instructional content, they are also ambiguous and complex in nature, requiring students to search for relevant information and skills that have not been previously covered in the information presentation. Students will work in small groups to acquire the conceptual knowledge and procedural skills needed to develop one or more plausible solutions to each of the problems presented to them. Each group of students (consisting of between five and seven students) will meet with a facilitator to discuss the problem. The facilitator will present a limited amount of information about the problem, and the group will then be charged with the task of identifying the different aspects of the problem by asking the facilitator questions to elicit information relevant to the problem, generate and refine hypotheses related to the problem's potential solution, and determine "learning issues" that the group decides are relevant and that they need to learn more about to find an acceptable solution to the problem. The groups are then asked to assign tasks to each member of the group for researching each of the different "learning issues" they have identified. After each of the group members has conducted the necessary research related to the “learning issue” they were assigned, the group members report their findings to each other and use it to generate a formal solution to the problem. The role of the facilitator in this context is to model hypothesis-based reasoning for the students. Upon developing a solution to the problem, students are asked to reflect on what they have learned from the problem.

Dependent measures

Performance:

Solution (product) performance was measured through the administration of a pre-test and a post-test to determine the number of correct solutions to problems presented by all participants in the treatment group. The pre-test and post-test reported on in this research study were focused on solving of near-transfer problems. The pre-test was administered to determine baseline equivalency in prior knowledge of students in the problem-based and lecture-based treatment groups. The post-test consisted of 15 problems that required students to respond to near-transfer information recall and problem solving skills, and was administered to determine the differences – if any – in mean performance on near transfer problems as a result of the instructional intervention (problem-based or lecture-based) administered.

Attitudes:

Learner attitude will be measured through the used of Keller’s (1995) Course Interest Survey (CIS). This instrument will be administered at the conclusion of the instruction. Attitude will measured in terms of the confidence (in the ability of the learner to successfully meet the course objectives) and satisfaction with the instructional treatment (as an effective means of attaining the course objectives levels), of participants as a result of receiving the instructional treatment, and in terms of the students’ attitudes toward the strategy’s effectiveness in attaining and sustaining their attention, and in providing them with a sense of the relevance of the instructional content being offered to the students. The Course Interest Survey provides a situational measure of learner motivation in a specific classroom setting (Keller, 1995). The

CIS instrument has been developed on the basis of Keller's ARCS model (1987a; 1987b) and requires students to report their degree of agreement with a variety of different statements concerning their attention, relevance, confidence and satisfaction.

Self-Regulatory Attributes:

Student self-regulatory attributes will be determined through the administration of the Weinstein and Palmer (1990) Learning and Study Strategies Inventory (LASSI) survey. This survey is comprised of 77 questions about the following; attitude toward school, motivation to perform certain tasks, time management skills, anxiety toward academic tasks, ability to concentrate, elaboration and organization to foster understanding and recall, ability to select the main ideas, skill in using study aids, self testing strategies and strategies for studying for tests. The survey will be administered at the beginning of the research study, to determine the overall self-regulatory attributes of the research sample. Students will be placed in one of three categories in terms of their self-regulatory attributes as measured by the LASSI survey. The categories are 1) highly developed self-regulatory skills 2) moderately developed self-regulatory skills, and 3) minimally developed self-regulatory skills. Students will be randomly assigned to instructional treatments, regardless of their self-regulatory attributes.

Research Hypotheses

Performance:

Hypothesis 1.a.: Learners receiving the lecture-based instruction treatment will demonstrate significantly higher performance in solving near-transfer problems.

Attitudes:

Hypothesis 2.a.: The overall attitude of students (as reflected in scores on the attention, relevance, and satisfaction components of the course interest survey) will be better among students receiving the lecture-based treatment than those receiving the lecture-based treatment at the mid-term point in the semester.

Hypothesis 2.b.: There will be statistically significantly higher learner confidence scores (in regard to instructional content), reported in the course interest survey by students receiving the lecture-based instructional treatment as compared to the confidence scores reported by the students receiving the problem-based instructional treatment.

Self-Regulation

Hypothesis 3.a.: There is a strong positive correlation between self-regulation and performance in the problem-based instructional treatment, while the correlation between self-regulation and performance will be weaker in the lecture-based instructional group.

Research Method

Participants

The participants in the study will be 60 students who are attending the Illinois Math and Science Academy (IMSA), a public residential school for high school age students with demonstrated potential for mathematics and science. Within the course about half of the participants were assigned to the problem-based learning treatment, while the other half were assigned to a lecture-based instructional treatment. The study took place during the regularly-scheduled class periods for the genetics class and the world studies class.

Most participants are between the ages of 15 and 17, with 52% of the participants being male and 48% being female. Participants are of diverse ethnic backgrounds, and the overall ethnic composition of the participant pool is representative of the ethnic composition of applicant pool (see chart overleaf); 12% are African American, 31% are Asian American, 5% are Hispanic, 46% are White, 5% are Bi-Racial. The ethnic origin of less than 1% of the class is unreported.

The majority of the children are from middle-income families. The mathematics and natural science achievement levels of the participants are typical of their level in the school. However, since admission to the academy is highly selective, mathematical and natural science achievement scores of the participants are not typical of the 11th grade level achievement scores in the school district. Mean scores of participants in the Standard Achievement Test are as follows: Mathematics section – 645, and Verbal - 591. The mean cumulative grade point average for the participants is 3.85.

The participants were drawn from two sections of the Genetics class (n= 30 in each section) at the institution in question.

Instructional Materials:

The instruction was centered on the instructional objectives for a one-semester course on University Genetics. The Genetics course goal is; "To develop within each student an understanding of the fundamental concepts and principles of transmission genetics, molecular genetics and population genetics." The course fulfills the following IMSA Standards of Significant Learning (SSLs):

- To encourage scientific thought and to promote curiosity for learning genetics and related sciences.
- To foster an interest in genetics that could lead to further studies at a higher level.
- To illustrate the role and importance of the science of genetics in society.

- To enhance critical inquiry and problem-solving skills.

Procedures:

Participants in the study were randomly assigned within sections to one of two treatment groups; the problem-based instruction group (receiving the problem-based learning strategy), or the lecture-based instruction group (receiving the instructor-led direct instruction). Admissions test scores, grade point averages, and performance in related subject areas were used to assess treatment group equivalence at baseline.

The treatments are being administered over the course of one academic semester, and students dedicate three hours of instructional time to participating in the study each week. During this time, participants receive the instructional treatment that they have been assigned to, at the regularly scheduled class times. In addition, they complete the homework assignment and tests associated with the instructional content. However, while the treatment is administered over the course of one academic semester, active data collection is conducted during two, two-week periods, with approximately six weeks between each period of data gathering. The reason why the instructional treatments are administered over the course of an entire semester (while formal data collection is limited to only four weeks of that semester), is so that the researcher can ensure that the data gathered regarding problem solving performance and attitudes of learners is a true measure of the instructional treatment. By administering the treatments over an extended (14 week) semester, it can be ensured that students are saturated by the experience, and that data is reflective of the specific instructional treatments, and not outside variables that form the general schooling experience.

During the periods of active data gathering, students were expected to contribute about 5 hours of instructional time per week to participation in the research study. Three of those hours were dedicated to receiving the instructional treatment they have been assigned to. The additional time commitment (two hours per week) was dedicated to gathering data outside of the scheduled class periods (this time was used to administer the CIS and LASSI surveys, and to conduct instructor and student interviews).

Throughout the Spring 2002 academic semester, the students in each treatment group attended three hours of instruction per week delivered through the instructional strategy that is part of the treatment that they were assigned to (please see Appendix F for a review of the overall course syllabus). The students assigned to the problem-based learning treatment received three hours per week of instruction on genetics delivered through the problem-based instructional strategy. The students assigned to the lecture-based treatment received three hours of instruction on genetics via the lecture-based instructional strategy. Students in the problem-based learning treatment received their instruction on Mondays and Thursdays from 7:30 a.m. to 9:05 a.m. Students in the lecture-based instructional treatment received their instruction on Mondays and Thursdays, from 2:15 p.m. to 3:25 p.m. Both treatment groups received their instruction in the A207 classroom, which is a class assigned for teaching science courses at IMSA.

Data

There were two classes of dependent measures in this study: (1) performance and (2) attitude. As a dependent variable, performance was measured in terms of scores on a post-test containing near transfer problems. The dependent variable of attitude was measured in terms of learner confidence and learner satisfaction. Means and standard deviations of the test scores for performance on the problem-based and lecture-based post-tests are presented in Table 1. Distribution of attitudinal data is reported in Table 2.

As shown in Table 1, the total mean score for the mid-term near-transfer assessment was 84.1%. By instructional strategy, the mean score for the lecture-based instruction (86) was somewhat higher than the mean score for the problem-based instruction (82). Standard deviation (5.1) on the lecture-based instruction group's scores was almost the same as standard deviation of the problem based instruction groups' scores (5.0).

A t-test was used to determine the effects of each of the types of instructional strategies on learner performance in a post-test containing near-transfer problems related to the course objectives for the Genetics course. With alpha set at 0.05, and with 30 participants per group, the probability of detecting a moderate effect size was 0.45.

For the scores on the post-test, a review of the distribution of the scores did not indicate any serious violation of the normality assumption. Furthermore, the F-Max value for the total scores F= (31, 29) = 0.98, a = 0.05 did not demonstrate a violation of the assumption of the homogeneity of variance. Therefore, it was decided to use the t-test for equality of means.

The t-test revealed one-tailed statistically significant differences between performance of the lecture-based instruction students and the problem-based instruction students on the post-tests t (60) = 0.03, p< 0.05. This result supported the hypothesis that students in the lecture based instruction group would out perform problem-based instruction students on near-transfer post-tests.

The dependent variable of attitude was measured in terms of learner confidence and overall learner motivation as reported on Keller's (1995) Course Interest Survey. Means and standard deviations of the confidence measures, and motivation measures of both treatment groups are presented in Table 2.

As shown in Table 2, the total mean motivation score for the lecture-based instruction group was 132.6 (SD = 36). The total mean motivation score for the problem-based instruction group was 122.4 (SD = 38). By treatment group, the mean confidence score for the lecture-based instruction treatment group (29) was somewhat lower than the mean confidence score for the problem-based instruction treatment group (33). Standard deviation (2.24) on lecture-based instruction group's confidence scores was low, whereas on the problem-based instruction group's confidence scores (SD = 8) it was somewhat higher.

A t-test was used to determine the effects of the two types of instructional strategies (the lecture-based strategy and the problem-based strategy) on both learner confidence and learner motivation, as reported on Keller's (1995) Course Interest Survey. An analysis of the distribution of the scores for learner confidence did not indicate any serious violation of the normality assumption or the homogeneity of variance assumption.

The t-test for equality of means on the confidence scores, $t\ (49) = 0.00008$, $p<0.05$, revealed a statistically significant difference between the confidence levels of the lecture based instruction group and the confidence levels of the problem-based instruction group, such that confidence was higher among problem-based instruction students. This result failed to support the hypothesis that learner confidence would be significantly higher among learners receiving the lecture-based instruction than among those receiving problem-based instruction.

A t-test was once more used to determine the effects of the two instructional strategies on learner overall, as reported on Keller's (1995) Course Interest Survey. An analysis of the distribution of the satisfaction scores did not indicate any serious violation of the normality assumption. The t-test for motivation scores, $t\ (49) = 0.0001$, $p<0.05$ revealed a statistically significant difference between the motivation levels of the lecture based instruction group and the motivation levels of the problem-based instruction group. This result supported the hypothesis that learner motivation would be higher in the lecture-based instruction group than in the problem-based instruction group.

A Pearson Product Moment Correlation was conducted to determine the strength of correlation between self-regulatory scores (as measured through the Learning and Study Strategies Inventory) and learner performance on near-transfer problems. The results of this analysis found that there is a positive correlation of 0.6 between self-regulation levels and post-test performance in the lecture-based instructional treatment, and a positive correlation of 0.75 between self-regulation levels and post-test performance in the problem-based instructional treatment. This finding, while preliminary, supports the hypothesis, which stated that learner performance and self-regulation would be more strongly correlated in the problem-based instructional treatment than in the lecture-based instructional treatment.

Discussion

A brief overview of the main findings from the research, in relation to the stated hypotheses for the research study, are presented below.

Performance*:*

Hypothesis 1.a.: Learners receiving the lecture-based instruction treatment will demonstrate significantly higher performance in solving near-transfer problems.

Statistical analysis of performance data from both treatment groups supported this hypothesis. Since instruction in the lecture-based treatment group is more consistent with a focus on near-transfer application of knowledge and skills for stated instructional objectives, it appears sensible that the data should reflect this hypothesis. The performance of learners in the problem-based treatment group was anticipated to be more oriented toward solving complex, unfamiliar problems through application of hypothesis driven reasoning skills, and it is therefore reasonable to conclude that students in this treatment group are less well-equipped to perform efficiently on recall of information and skills in near transfer problems. At the end of the semester, students from both treatment groups will participate in far-transfer problem solving tests, and it is anticipated that the performance scores on those far-transfer tests will be the inverse of performance on near transfer tests.

Attitudes*:*

Hypothesis 2.a.: The overall attitude of students (as reflected in scores on the attention, relevance, and satisfaction components of the course interest survey) will be better among students receiving the lecture-based treatment than those receiving the lecture-based treatment at the mid-term point in the semester.

The statistical analysis of learner motivation levels supported the hypothesis that lecture-based students would have overall higher motivation scores than their problem-based counterparts. This appears a reasonable assumption, since learners in the problem-based instructional treatment are confronted with a fairly high level of newness factors in their learning experience as a result of participation in the instructional treatment. Classroom observations in both treatment groups confirmed the idea that students in the problem-based treatment group had a higher level of frustration with the instructional experience as a result of the unfamiliarity of the conditions, and the high level of self-regulation required in order to succeed in the instructional setting. Students in the lecture-based treatment were placed in a situation that modeled the traditional classroom learning experiences, where responsibility for learner performance and learning is more equally shared between the instructor and the learners.

Hypothesis 2.b.: There will be statistically significantly higher learner confidence scores (in regard to instructional content), reported in the course interest survey by students receiving the lecture-based instructional treatment as compared to the confidence scores reported by the students receiving the problem-based instructional treatment.

Statistical analysis of the data on learner confidence scores did not support this hypothesis. Interestingly, the data gathered actually contradicted the a priori hypothesis, indicating a statistically significant higher confidence score for students in the problem-based instructional treatment than for students in the lecture-based instructional treatment. A cross-analysis between data from the CIS survey and the LASSI survey will be conducted to attempt to further elucidate on this finding. In addition, further research will be conducted to determine whether the unique nature of the sample population (with higher than average performance, motivation, and self-regulation scores) impacted this finding.

Self-Regulation

Hypothesis 3.a.: There is a strong positive correlation between self-regulation and performance in the problem-based instructional treatment, while the correlation between self-regulation and performance will be weaker in the lecture-based instructional group.

The correlational analyses of the relationships between self-regulation and performance in both treatment groups supported this hypothesis, finding that there is a stronger positive relationship between self-regulation and performance among problem-based learners than among lecture-based learners. Again, the nature of each of the instructional treatments, and the research on instructional strategies appears to explain this finding. Since lecture based instructional treatments appear to provide more support for learners in managing their learning processes, and since they tend to be more guided in their learning approach, learners of varying levels of self-regulation may expect to perform at comparable levels in the class. In the problem-based instructional treatment, where there is a high level of individual responsibility for managing the learning process, learners with less developed self-regulatory skills may be expected to perform less well. Thus, the correlation between performance and self-regulation would be higher in the problem-based instructional strategy than in the lecture-based instructional strategy.

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