Understanding Student Decision-making Strategies in Problem-solving in Microbiology using IMMEX Educational Software

Josephine Ebomoyi
St. Xavier University

Richard Jurin
University of Northern Colorado

Abstract

As an aid in helping students develop problem-solving skills the decision-making process was investigated by studying high and low scorers when using a unique computer program (Interactive multimedia exercise (IMMEX) Windows software) that involves problem-solving of real world scenarios. Mid-way through a semester course in college microbiology, all participants in a class were introduced to, and initially became familiar with the IMMEX program through the problem-sets *Puffy Paramecium* and *Who messed with Roger Rabbit*. A month later, all the class did two new problem sets, *Microquest* (Mq) which focuses on cellular processes and mode of action of antibiotics and *Creeping Crud* (CC) which focuses on cause, origin and transmission of diseases. Volunteers (n=18) agreed to participate in a think-aloud protocol (verbalization of thoughts) while solving these new microbiology problems sets. Within case analysis, summaries, IMMEX instructor feedback and transcribed information were data analyzed. Using final scores, 8 (44%) were categorized as low scorers with 5 (28%) as high scorers for Mq, and 5 (31%) categorized low and 6 (35.5%) high for CC. In general, high scorers used fewer steps, spent less time and had a more focused approach than low scorers.

Common attributes and strategies found among most problem-solvers included metacognitive skills, writing to keep track, use of prior knowledge, and elements of frustration in trying to recall and understand microbiology information and lab techniques used when trying to solve the problems. This study is useful for consideration while developing curriculum and criteria for evaluation.

Introduction

One main goal of science education is to improve problem-solving skills in learners (Lavoie, 1993; Palacio-Canyetano, 1997). An important step in meeting this goal would be a focus on the main feature of inquiry and national science education standards (National Research Council, 2000). The main feature of this standard requires students to develop abilities in understanding scientific investigation. According to Watson (1980), the decision-making process should be a major emphasis in any science curriculum and studies to develop strategies helping students' decision-making are required in science education. Many science educators acknowledge the importance of decision-making, but the little work that has been performed in this area are in limited domain and context. Kortland (1992) used a normative decision-making model in addition to short interviews to help in curriculum development in environmental decision-making. Normative focuses on how people should make choices. The current study dealt with dimensional and

procedural cognitive processes. Jung-Lim et al (2004) studied high school students' decision-making processes by "think aloud" and participant observation methods. On the whole, the students' decision-making processes progressed in the following order: recognizing a problem, searching for alternatives, evaluating the alternatives, and decision. Students also had difficulties in analyzing the difference between initial state and desirable state of the problem, organizing biological knowledge-related problems, and clarifying values as selective criteria.

In the theoretical framework of the constructivistic approach (Driver and Oldham, 1986) a strong emphasis is placed on the learner as an active agent in the process of knowledge acquisition. This requires utilization of the cognitive and metacognitive processes in problem-solving. According to Someran, Barnard & Sandberg, 1994, problem-solving that requires decision-making strategies involves constructing solutions and constructing justifications for the solutions. The think aloud method can be used to explore differences between tasks and differences between people's performance while problem- solving (Someran et al. 1994). Learning processes studied by Anzai and Simon (1979) utilized the think- aloud approach to identify changes in knowledge during repeated problem-solving of a simple task.

Models of cognitive processes include dimensional and procedural cognitive processes. The dimensional processes relate to the cognitive processes such as duration (time), number of reasoning steps or extent to which the problem data are used, and sequence of steps. The procedural model describes a sequence of steps and this can mean choosing relevant data that precedes previous data choices (Someran et al. 1994).

Helping students attain their optimum problem-solving skills can be achieved by including problem-solving within the curriculum and working on decision-making strategies (Hattie, Biggs & Purdue, 1996). Decision making strategy is defined here as the cognitive process used by an individual that results in the selection of a course of action among several alternatives (e.g. Harrington, 2008). To further understand the learning process and the goals of students as they solve problems with the use of computers, verbal protocols and think-aloud methods have been found to be useful (Simmons & Lunetta, 1993).   In the think-aloud method of investigation, the subject is asked to talk aloud while solving a problem, thus encouraging the subject to reveal the strategy of decision-making. With this method, a variety of explanations given by students, for choices made during problem-solving, indicate a range of strategies and rationales being employed. A think-aloud protocol can provide direct data on a person's ongoing thinking processes while performing a task. It can be used to investigate differences in problem-solving abilities between people, and between tasks (Someren, Barnard & Sandberg, 1994).

Understanding the usefulness of better decision-making strategies when problem-solving and incorporating them into the curriculum helps improve student achievement (Hattie, Biggs, & Purdue, 1996). Other sources have also found that decision making strategies are crucial in order to allow learners to infer logical next steps of action based on pertinent information available (Boney & Baker, 1997; DeYoung, 2009; Scott, Altenburger & Kean, 2011; Sevdalis & McCulloch, 2006). The innovative role of

computer assisted instruction (CAI) and its attributes cannot be overemphasized, since it can enhance the development of decision-making skills in problem-solving (Huppert, Yakobi, & Lazarowitz, 1998). CAI has the advantage of offering the learner unique options to gain actual experience in a short time frame rather than having to experience through real situations or through passive learning examples as might be found in a lecture. There are numerous advantages for integrating CAI into microbiology programs such as: 1) promoting active learning, (Huppert, Yakobi, & Lazarowitz, 1998), 2) promoting retention through active learning (Carver and Novak 1991), 3) allowing students to control the pace of the lesson (Lazarowitz, and Huppert, 1993), and 4) enabling a step by step procedure explaining how to approach a given problem, immediate feedback from practice problems (Schank and Chip, 1995).

The Interactive multimedia exercise (IMMEX) Windows software (IMMEX, 2007, 2010) was used in this study. The IMMEX program is a problem-solving, authoring, and learning system that has an assessment tool and is able to track students' search path maps (spm). It utilizes Microsoft Windows and has three components; an author section that allows construction of problems, a TEST section that provides hands on problem solving environment that allows students to see complex real world problem and an analysis section which provides the graphical interface (spm) to students' strategies as they work through the problems. This spm tool allows the instructor to access a graphical printout that tracks and shows the specific sequence of each decision that a student makes as they work to solve the problem within the software scenario. Using the IMMEX feedback, the instructor sees how the student accessed the various menus and can discuss with the student the decision-making skills that were employed to verify their validity or skills to improve.   This has been shown in previous studies.

Cox, Jordan, Cooper & Stevens (2006) assessed IMMEX software and found it gave viable feedback for student problem-solving improvement in K-12 and college versions of the software as well as medical schools for which it was first developed. Case, Stevens & Cooper (2007), used IMMEX software with small collaborative group settings and found it enhanced the cooperative learning opportunities for freshman college Chemistry.

A student with good problem-solving skills and an understanding of the concepts would be expected to make focused and rational decisions between the software menus to resolve the problem successfully in a minimum number of steps. A student with poor problem-solving skills, however, would be expected to show an unfocused strategy with many trips to the help and library menus and the use of many steps in trying to resolve the problem. An assumption here is that both good and poor problem-solving students have a similar knowledge base from which to work. Real world topics have been taught in their Microbiology course.   The think-aloud method used in this study compliments the use of spm to explain how individual student thoughts reveal the reasons for each of the choices they make, thus showing their knowledge base and their decision-making strategies. This study shows the validity of using IMMEX feedback and also emphasizes other aspects to be considered when using such programs.

Purpose and Research questions

The primary purpose of this study was to understand the decision-making process that students use when problem-solving. The computer assisted instruction software IMMEX allows numerical and visual instructor feedback to be able to follow this process. The think-aloud verbalization method allowed a deeper insight into the student thinking process. Since a student can solve the problem, but still gain a low score because of unnecessary use of program resources (such as libraries and lab tests), the verbalization can gain valuable insights into program scoring and lack of student confidence in making a decision. This paper argues that a more holistic reviewing of student work using good feedback explains a student's success, or lack thereof, rather than the scores alone. This is not new, but the IMMEX software program allows good feedback to happen more easily. By being able to visualize a student's spm, there is a clearer understanding of the students thinking that is not yielded from a simple numerical score. Fig 3a and b are examples of a search path map. In a typical example, the scores and time spent will be visible on top as well as every menu visited to answer the question will be visible. Students begin with a total score and as they visit various parts of the on-screen resources and pathways, variable amounts of the score are deducted. The final score is determined when the student makes a final correct decision. Instructor program feedback then allows the instructor to evaluate the decision making strategy used by the student. To verify if the test results from IMMEX are a valid measure of a students decision-making process in solving a problem, a group of volunteers was used to check if the final results from the IMMEX instructor feedback matched the thinking process as gauged by a think-aloud vocalization procedure.

Research question: How do high and low IMMEX program scorers make decisions differently while solving problems using an IMMEX software program?

Methods

Participants

This study used undergraduate microbiology students (N=65) from [a mid-sized university in the Western United States who were required to take microbiology as part of their major in Biology (n=38) or Allied Health (n=23) and 2 other science majors. During the mid-point of the semester, in a lab session, all the students were introduced to the IMMEX software and given an introduction and information necessary to complete the IMMEX software problem-sets. The purpose of the study was explained to the students and they were asked to participate in the study. If any students had not consented to the study, they would still have used the IMMEX software as part of the lab experience but no study data would have been collected on their participation. To access the online program, all the students were given a unique identification number and a password provided to the researcher by IMMEX coordinators.

The students were left to familiarize themselves with the software by using two practice problem-sets *Puffy paramecium* and *Who messed with Roger Rabbit*. The instructor roamed within the room answering questions about the program and its menus but not the problem-sets. The problem-sets enable students to see a complex real world problem through the software interface. The analysis section of the program offers various menus that allow the student to access various sets of information to solve the

problem. For instance, there is a menu to understand case studies pertaining to the problem, descriptions of different tests that can be used along with the results of those tests, links to library resources, or 'experts,' with packaged information about the various aspects of the problem that help the student gain more background knowledge, and then a final diagnosis or solution menu where the student makes the final decision of what they consider a solution. The menus are tailored to each problem-set, yet the style of each problem-set is similar. The student has access to a range of packaged information and specified lab-test options in order to make decisions that allow further progress in solving the problem given at the beginning of the problem-set.

A month after the class had been introduced to the IMMEX software, they were introduced to two new problem-sets, *Microquest* (Mq) and *Creeping Crud* (CC). Eighteen students volunteered for the verbalization part of the study (10 Biology majors and 8 allied health majors), but they did the new problem sets on different scheduled dates from the rest of the lab-class. These volunteers were then observed as they followed the CC and Mq, and their think-aloud verbalization was audiotaped as they proceeded through the sets.

Problem-sets
The two main problems-sets used in the verbalization study along with the description of the menus are summarized in figures 1a and 1b.

For each problem-set, there are numerous different scenarios on the same theme to be solved. The prolog, therefore, changes slightly such that students in a class may all be working on slightly different scenarios, yet the main problem (task) is essentially the same in each problem-set.

The prolog provides the problem scenario and is one of the opening screens found on each set that allows the students to use the different menus within the problem-set.

CC Prolog (scenario of the problem to be solved):
   You are working at the Center for Disease Control (CDC) in Atlanta, Georgia. Reports are coming in of people in five cities across the United States with symptoms of fever, stiff neck, headache, nausea, and malaise, not familiar to local health officials. Your task is threefold. You must determine:
   1. The causative organism
   2. How it is transmitted
   3. Where it originated
   Click on "WHAT COULD HAPPEN" to see what could happen!
Menus - Library – provides descriptions of organism and various lab tests; Case Histories – information on travelers and places visited; Test results – Individual lab tests that can be ordered by the student where each costs points; Experts – Specific knowledge e.g. virologist, entomologist, etc.; Maps – schematic/visual representations of the travelers trips; and Hints for the Lazy – specific directions to pay attention to, but are costly in points.

Fig 1a: Description of Creeping Crud (CC) problem-set

Mq Prolog **(scenario of the problem to be solved):**
   You have just returned home from a summer trip to Costa Rica when you discover that your shoes are caked with dirt. As a student studying microbiology, you are interested in microbial growth in soil. After transferring a dilution of the soil sample to a rich medium (yeast triptone agar) and incubating for several days, you find the appearance of zones of growth inhibition around several bacterial colonies. You learn that these zones can be characteristic of antibiotic production.   You decide to determine how this potential antibiotic works. If this is an unknown antibiotic, you may be able to name it after yourself or sell it to a big pharmaceutical company for BIG BUCKS!
Menus: **Library – provides descriptions of cellular processes; Test results – Individual lab tests that can be ordered by the student where each test costs points; and Need Help Menu – specific steps to take, but are costly in points.**

Fig 1b: Description of Microquest (Mq) problem-set

   All students begin with 1000 points. While attempting each problem-set, every selection of an item from the sub-menus causes points to be deducted from the starting score of 1000 points. The number of points deducted for accessing each menu/submenu varies with the degree of information that can be gained from that menu (the more information, the greater the number of points lost). Therefore, a quick solution with minimal menu selections will yield a high final score. The final printout accessed by the instructor after the students have finished shows precisely the sequence of steps that each student used as they accessed each menu and submenu component progressing towards a conclusion (for example of menus, see Fig2). The quality of the students' decision-making strategy to solve each problem was determined from the following: the final score, the spm, the time spent on the problem, and whether or not the student successfully solved the problem. The spm was calculated by counting the number of steps or menu visited before solving the problem. High scorers are those that solved the problem in an efficient manner. Participants visiting irrelevant and redundant menus will be penalized by the program.
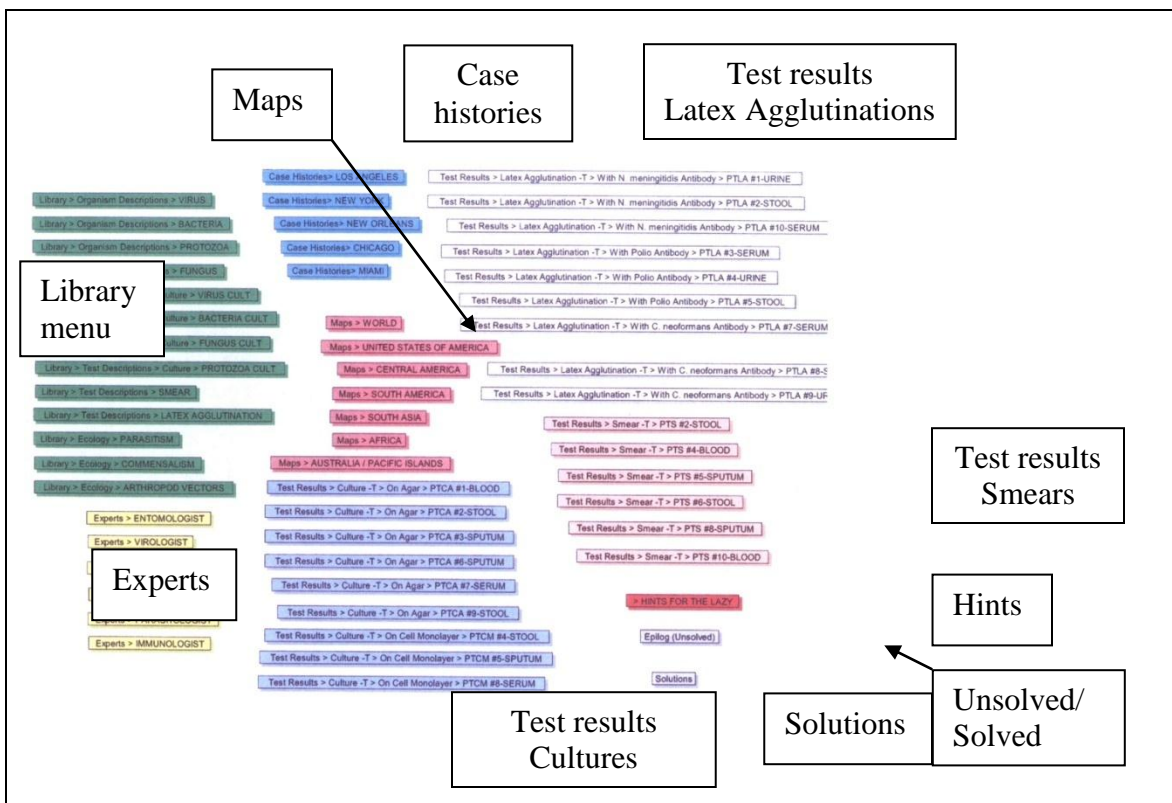
Figure 2: Full screen example of the menu options in CC

Criteria for grouping scorers: After the verbalization volunteer students had finished the problem-sets, their results were accessed from the IMMEX website and analyzed. They were separately grouped into achievement levels based on their ability to solve the problem, or not, and their final score. These criteria are typically ones that may be chosen to score success on participation in such a lab. After reviewing the results for the class, it was decided that for CC, the high achievement group was a score greater than 750 with the problem solved, the moderate group was 500-749 (solved or unsolved), and the low group scores were less than 500 (solved or unsolved) (Table 1). In Mq, the high achievement group was a score greater than 650 with the problem solved, the moderate group was 450-649 (solved or unsolved), and the low group scores were less than 450 (solved or unsolved) (Table 2). For example somebody who did not solve the problem correctly was not simply categorized as High even if they have a high score. Cut offs were done through comparison of overall program feedback. In each problem-set, when a student tries to attempt a solution they can have the right conclusion (solved) or reach a false conclusion (unsolved). If unsolved, the student can begin the problem-set again and attempt the same scenario within that set; this is reported as "tries" (Tables 1 & 2). The program permits only two tries per scenario.

Analysis of data

This involved three methods: 1) within case analysis of spm (this is the number of steps taken to solve the problem as defined by the graphical output from IMMEX), final

score (out of 1000 points), and time taken to reach a solution. The spm were especially important in elucidating between "low" scorers (low scorers because of numerous extra menu visits) who were logical from those who seemed to have difficulty focusing and whose thinking strategies were apparently haphazard. The spm can show a clear path of thinking where accessing a menu makes logical sense, while unclear, haphazard thinking shows menu visits that make no sense based on the information that should be known. A typical example in CC would be a participant hunting for information and tests about bacteria when the answer should be about a virus. Another example would be a participant who does not understand why a comparison with the control is essential in choosing an appropriate test and whether it is accurate or not in providing evidence on the problem. These latter cases could also include students who simply have not studied and do not know the information, yet the path of the menus visited can help in understanding whether a student was simply hunting blindly, merely seemed confused, or obviously understands the whole problem clearly with a set of clear decision choices with the menus; 2) Summaries of the transcribed verbalizations compared with the problem-set and spm; and 3) Qualitative analysis: For example, in Phenomenology it is assumed there is an essence to the experience, which implies giving meaning to the experience of solving problems (Husserl, 1962; Patton, 1990). The qualitative methods identified by Moustakas (1988, 1990) and Merriam (1998) and Creswell (1994) were employed in analysis to understand the student strategies being used. For example, after the verbalizations were transcribed, they were initially coded (Merriam, 1998). Upon coding, a thematic analysis was conducted to determine which common themes arose from the interviews (Creswell, 1994).

Results & Discussion

Summaries of the IMMEX data for the talk-aloud participants using the two problem-sets (CC and Mq) are shown in Tables 1 and 2.

Table 1: Summary performance of participants - Creeping Crud

Id	Score (1000 start)	Achievement	Solved	Tries	spm	Time (mins)	Major
57	300	Low	No	2	40	59*	AH
27	395	Low	Yes	2	37	21	BS
53	425	Low	Yes	2	35	29	BS
45	450	Low	No	2	15	30	AH
2	455	Low	Yes	1	24	18	BS
11	505	Mid	Yes	2	42	23	BS
58	515	Mid	Yes	2	38	56*	AH
3	565	Mid	Yes	2	21	8	BS
50	595	Mid	Yes	2	16	14	AH
55	645	Mid	Yes	2	23	25	AH
51	655	Mid	Yes	2	21	52*	AH
61	730	Mid	Yes	1	18	25	BS
39	820	High	Yes	1	31	60*	AH
31	820	High	Yes	1	9	10	BS

35	840	High	Yes	1	13	11	BS
10	885	High	Yes	1	8	6	BS
23	890	High	Yes	1	10	20	AH
9	920	High	Yes	1	9	10	BS

* Delayed time due to fire alarm lasting approximately 40 mins

Table 2: Summary Performance of participants - Microquest

Id	Score (1000 start)	Achievement	Solved	Tries	spm	Time (mins)	Major
50	210	Low	No	2	36	18	AH
55	215	Low	No	2	31	13	AH
23	230	Low	No	2	37	17	AH
51	250	Low	No	2	32	8	AH
39	400	Low	Yes	1	33	9	AH
57	435	Low	Yes	1	22	8	AH
2	470	Mid	No	2	18	10	BS
3	505	Mid	No	2	30	9	BS
10	570	Mid	Yes	2	19	6	BS
27	580	Mid	Yes	1	22	9	BS
53	595	Mid	Yes	1	22	10	BS
9	600	Mid	No	2	11	5	BS
45	625	Mid	No	2	10	10	AH
58	700	High	Yes	1	14	6	AH
61	700	High	Yes	1	14	7	BS
35	715	High	Yes	1	16	7	BS
31	725	High	Yes	1	13	8	BS
11	875	High	Yes	1	7	3	BS

Performance Based on Scores

It is the holistic nature of the program feedback that makes it useful. A high score with few spm shows logical choices (the student understands the problem clearly and has the knowledge to make good decisions) made in a relatively short period of time and is a clear indication that the student is applying good information with clear thinking and good decision-making. A low score with multiple spm that visit all over the program indicates a student who is clearly hunting and confused. They are usually found to have low scores since they access multiple unnecessary parts of the menu. It is possible that a student might stab for a conclusion in a short period of time, thus gaining a higher score, but the spm would clearly show the path of logic and decision-making that is most likely haphazard. Students who were middling would clearly fit this categorization for similar reasons. Knowledge comfort in one area of a discipline does not necessarily mean comfort in another. Thus a high scorer in one problem set does not automatically mean a high scorer in another problem set.

In Table 1, the separation between the achievement categories is relatively clear with the exception of Id2 where the student solved the problem on the first try in a reasonable amount of time, yet had a large spm and scored low because of many tests performed (large point loss each time). A high scorer, Student Id39, scored high, solved the first time in a reasonable amount of time, yet also had a large spm, but didn't lose as many points because this student selected sub-menus in CC that did not lose as many points when accessed. For instance Id39 did not use the library menus. The four students who were in think-aloud during the fire-alarm (lasted about 40 minutes and they were supervised outside the building to restrict conversation) did not express any adverse effects to their continuation of the problem when they returned to it.

In Table 2, the performance of five students stand out as anomalies because of their scores. Three scored mid-way (Id3, Id9 and Id45), but could not solve the problem even on a second try. They all have few spm steps and a short duration on task. It was apparent from the think-aloud that they had problems with consolidating their knowledge base and making rational choices before they attempted to solve the problem. Analysis of the verbalization scripts showed that these students gave up early and guessed a solution when they could not solve the problem.

Two low scorers in Mq, however, Id39 and Id57, both solved the problem first time with short duration on task, but with high spm. These students showed uncertainty in their knowledge and accessed high point deducting sub-menus (such as library and tests) quickly to confirm or check their ideas.

If a student was unsuccessful in solving the problem-set the first time, the program allows a second trial of the same problem. While the scenario remains the same, the specific circumstances may vary with any attempt of the scenario, thus eliminating memorization as a source of improvement. Students who repeated the problem-set (failed to solve first time) tended to have similar test parameters each time, the main difference being simply that they solved, or failed to solve, the second time. This demonstrates the importance of determination because many who tried a second time succeeded. Ziegler and Terry (1992) emphasize that determination, especially when accompanied by success, enhances learning.

The strategies of the high scorers on both problem-sets were consistent. The spm for these students showed that they moved through the problem in a logical sequence, meaning that decisions made as based on reasoning, where one piece of information builds on another piece of known information, gradually leading to a logical and correct conclusion. In the cause of infection in Diagnostic Microbiology, for example, accessing only the menus that addressed the problem at hand with few, if any, "side-trips' to help sub-menus would indicate a logical sequence of thinking. The think-aloud investigation revealed that these students were confident in their knowledge and had planned strategies showing clear deductive thinking. The advantage of this program feedback is also useful is helping teach low scorers how to develop better decision-making strategies besides just encouraging that they study the course materials more thoroughly. Zajchowski & Martin (1992), emphasize that using examples of the strategic approach of expert problem-

solvers can help other students in learning effective strategies to help them solve problems effectively by learning logical reasoning.

Performance based on number of steps (spm)

        For CC all the low scorers had more steps in the spm that ranged from 15 to 40. For the high scorers, most of them (except Id39 who had 31 spm) had less (9-13) spm steps than the low scorers. This agrees with Barba and Rubba (1992) who reported that expert problem-solvers use fewer steps to arrive at an answer. Participant Id57, who could not solve CC and used the highest number of steps, appeared confused and went through most of the menu in a non-sequential manner (Figure 3a). This student also went to "experts" (yellow boxes on Figure 3) in eleven different instances, and used the hint menu twice (deep red menu on Figure 3). The think aloud investigation of this participant revealed that after going through many non-sequential steps the participant remarked *"Okay, I am a little bit confused on what the causative organism* is." This kind of comment was more common in the low scorers and not evident in the high scorers.

        Rowe (1983) identified confusion as one of the cognitive deficits that appear to be common among novice problem-solvers. However, since confusion is the inability to think as clearly or quickly as you would normally, it can be inferred that in this study we may also be seeing more of a lack of understanding or worse, a simple lack of studying being more evident. In considering how to help individuals like this, a careful look at the search path maps (spm) often indicates where the cognitive problem of solving the problem-set started (Fig. 3a). This allows the instructor to gauge the point at which a specific student's problem solving errs – is it a misconception or simply that they now seem to be guessing? There was not a common point at which this happened with the students. From using the think-aloud verbalization it was evident when later looking over the spm that the logical strategizing would often start fine but then become more haphazard as key decisions needed to be made.

        High scorers usually had lower spm, although, as mentioned under the discussion on "scores", one participant in CC (Id 39) that had a high spm of 31 (Fig.3b). On analysis of the strategy and verbalization, it was observed that this participant went through all the low costing library information (it does not cost a lot of points to use the library menu) first to understand everything about each microorganism. The use of many steps in this case did not prevent attaining a high score. This shows a unique strategy of a high performer where prior background knowledge was not a crucial factor in success. It is also notable that this person also scored low on Mq because of the same strategy where more points were deducted for accessing information menus, even though this person finished fast and solved the first time. This shows the multiple strategies available to the user. According to Stevens, McCoy and Kwark (1991) students use different strategies to solve any particular problem. For Mq, low scorers all had a much higher number of spm steps than high scorers.
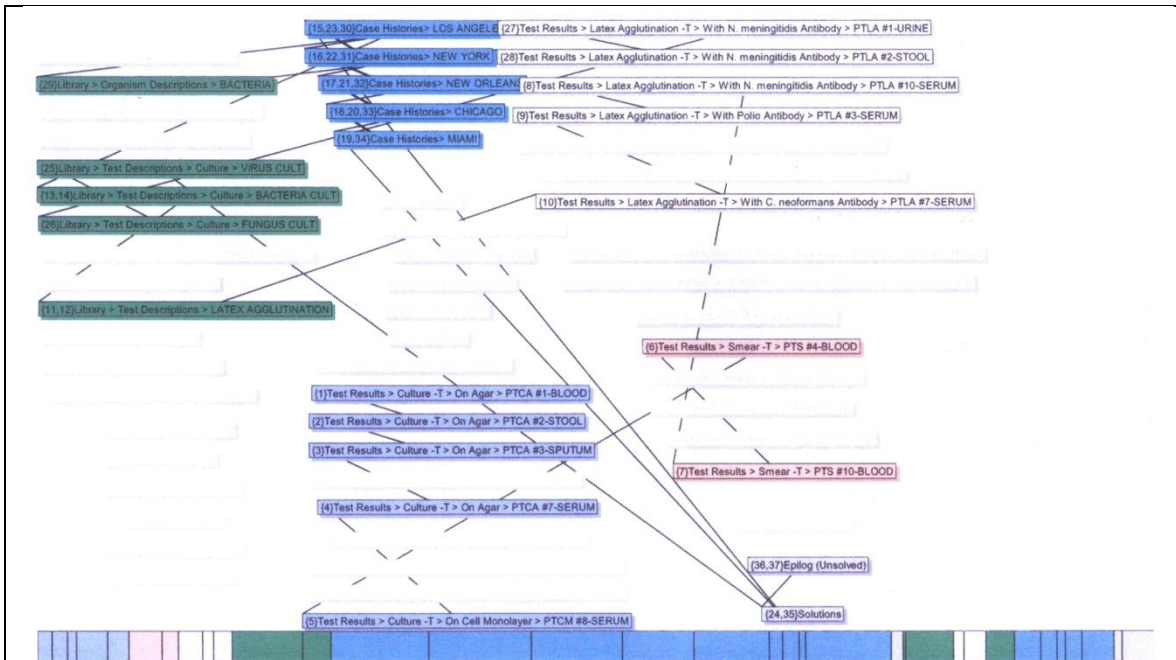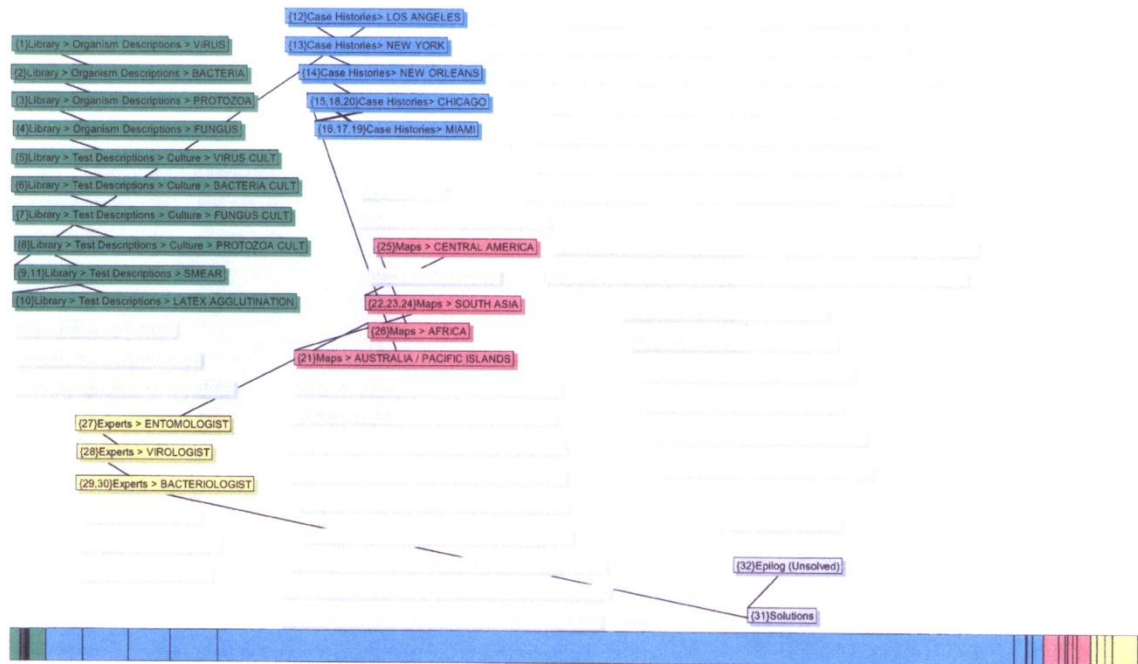
Fig 3a: CC spm map for ID 57.

Fig 3b: CC spm map for ID 39.

The bar at the bottom of each map represents the percentage of time total spent on each of the steps taken sequentially (for ID39, the long blue space is the fire-alarm time).

Performance based on Time

In general high scorers spent less time solving the problems. However, there was one high scorer (Id23) in CC who spent up to 20 minutes reaching a solution first time, yet had a spm of only 10 steps. During verbalization analysis, it was seen that all through the process this participant was conscious of losing points, which suggests that this individual was more interested in taking the time to be successful. This variation of achievement time emphasizes that not everybody works at the same pace and that depending on instructor objectives, students should be given enough time to solve the problems. This suggests that sometimes sufficient time can play a positive role for a better outcome and that individual differences in use of time should be acknowledged in the teaching and learning process.

Emergent strategies from analysis

Writing strategy: Observation and analysis of verbalization showed that most students wrote on a sheet of paper while solving the IMMEX problems. In CC, Id23 wrote down information while reading the problem, and spoke aloud: "*Just at the prologue and I have copied the tasks down. ...Ok, I'm reading the Los Angeles case history and as I'm reading I am writing down the places that they have gone to and the dates....*" According to Martinez (1998), keeping track of what to do, and when, is a common feature of metacognition. In Mq problem, Id31 sketched down information that was considered important: "*I'm looking at two electrophoresis plates, one of which the control has bars in the upper section and with compound X those bars are non-existent and they are now moved down to the lower section. I'm going to sketch this on my paper now. All right, having sketched the drawing on my paper, I've labeled it accordingly as protein synthesis termination.*" These observations clearly suggest that writing serves a purpose in strategic thinking and is a strategy to ensure success in problem-solving performance and is well described in the literature (Howe, 1974; Stefanou, Hoffman & Vielee, 2008; Kibum, Turner & Pérez-Quiñones, 2009; Makany, Kemp & Dror, 2009; Gee, 2011). As an example, Id53 in CC merely took a mental note of the case histories when reading and did not write any information on paper. This probably accounted for this person's repeated visits to the case histories, which resulted in poor performance. Analysis of other low scorers showed they went to "expert" help much more compared to high scorers. Id57, the worst performer in CC went to the expert sub-menu eleven times, and expressed a lot of self doubt about knowledge of science. Using the IMMEX results could be used as a 'wake-up call for low achieving student's to reflect on their poor performance and to understand what they need to achieve to perform better. Tutoring and enrolling in student support learning programs can help such students. Working with the instructor who is using such programs would also help them understand better decision-making strategies, and encourage them to develop better study habits to learn the material before engaging such problem-solving programs. What makes using a program like IMMEX so important is both the instructor and the student can understand individualized strategies that can be used to help a student improve on individual problem solving thinking and techniques. While techniques such as keeping track using notes may be one avenue, going into the problem sets with a better understanding of the background knowledge needed would seem to underscore the student's need to improve skills for problem solving (Genyea, 1983; Reif, 1983) and to recognize the need for better study habits.

Prior knowledge: Using prior knowledge was also an attribute observed in the findings of this study. For example, in CC, Ids 9, 10, 31 (high scorers) and 53 (low scorer) did not go to maps to confirm the location of Rio de Janeiro before making their choice of where that city was located. However, in CC, Ids 23, 35 and 39 (high scorers) needed the map menu to confirm where the city was located. One of the CC case history's stated, "Maria has been suffering with strep throat and just recovered a few days before the trip." Using prior knowledge, Id 23 commented, *"Therefore, she may be susceptible to possible infections."* This participant understood that a sick individual is susceptible to more infection than a healthy person. Prior knowledge can be an attribute that differentiates expert and novice problem-solvers (Gabel, 1994); however, in this study it can be seen that high scorers using microbiological knowledge were not necessarily equivalent in their geographical knowledge. This is a place where interdisciplinary knowledge (in this case Geography) could be emphasized as necessary to solve complex situations.

Recognizing patterns/Metacognitive skills: In this current study, high scorers could recognize patterns (as shown from their choices while using the software and from comments in their verbalized thoughts) more easily than low scorers. In CC, most low scorers utilized the 'hints for the lazy' menu, and in Mq, the 'need help' menu, which was not the case for the high scorers. For example, in CC, Id53 had difficulty making the proper connections while problem-solving. After confirming diplococci bacteria from a smear, this participant went to check if it had polio or neoformans antibody. This shows a problem with knowledge acquired since with diplococci bacterium already was confirmed the participant did not need to check polio and neoformans because these are viral and fungi respectively – this is a good point of feedback for the instructor to review some knowledge basics with the students. This may also indicate a lack of student confidence with knowledge. Id53 in CC also spent unnecessary effort and points going to check the bacteria cultures menu.

Poor problem-solvers tend to categorize problems illogically (Barba & Rubba, 1992). The low scorers also used more non-logical steps as well as non-productive steps than high scorers. Vermunt (1996) found that undirected learning is a negative predictor of academic success. According to Sankaran and Bui (2001), students using undirected learning strategies generally have problems discriminating what is, and is not, important. They have problems processing and coping with the amount of material to study. It seems crucial that instructors make the connections clear when lecturing the concepts by providing learning objectives in every lecture. This would help students stay focused on the most important concepts. Also by providing practice questions towards the end of each lecture period, the students could better prepare themselves.

Other evidence of pattern recognition was also found. In CC, high scorer Id23, while reading the New York case history said, *"Right now I'm thinking it may be the sneeze from the elevator in Rio de Janeiro, but [I'm] not so sure. First I thought it was the mosquitoes, but the New York couple had not been to Belize City, so that is negative."* While looking at the Test results menu, high scorer, Id 31 in CC states: *"The virus plates show nothing, they are the same as controls so virus is knocked out of the*

competition...I'm still thinking bacteria." According to Lambert and McCombs (1997), successful learners show strategic thinking in their approach to learning, reasoning, problem-solving and concept learning. All these observed characteristics of recognizing patterns are typical of metacognitive skills. It requires self-monitoring of the learning process and involves planning a strategy to solve and carry out the process, which referred to as metacognition (Martinez, 1998). This study is part of a bigger study that included how declared major affect performance. Allied Health students and Biology Major students typically take the General Microbiology class. Students in an allied discipline may not perform very well in all areas of biology and microbiology because of the different complexities of the discipline and varying interest levels of students for different subjects. The knowledge level of a student can greatly affect their program score regardless of their decision making abilities.

In Mq, Participant Id39, a low scorer because of time on task and high number of spm steps, tried to make connections with information available: *"Like last time[in CC], I just checked to see which one looked different. Um, and that helped me solve it. Okay, this one looks different. The termination test. So I need to gather some information about termination testing and ... yeah, it looks different than the control, so I think that has something to do with it. "* This quotation is important for many reasons: 1) this person looked for what was different; 2) the person is using the same strategy by looking for the difference between the control and the compound; 3) this person found the difference under the termination of the protein synthesis (so subject remembered termination codons without which the microorganism cannot function); 4) this individual noticed this and decided to find more information about termination testing; 5) the person noticed the difference between the control (which is a normal reaction) from the compound and concludes that the mode of action of the unknown compound X is termination of protein synthesis. This is further explained by Lambert and McCombs (1997), that successful learners are able to use a variety of strategies to aid their learning and performance goals. Id39 used a metacognitive strategy by monitoring and comparing the compound X (isolated from the soil) with the control. This student also is using prior experience of content (as evidenced by knowledge of the termination step in protein synthesis) to remember how to be successful in answering questions correctly. Even though this participant was categorized as a low scorer, it was mainly because of an inefficient problem-solving strategy and continual need to check information rather than poor reasoning skills. Thus helping this person in class would be for more effective decision strategizing.

Elements of Frustration/Confusion: An element of frustration was a common feature observed among both High and Low scorers in this study. For the low scorers this was revealed because of the inability to make connections while problem-solving. For example, in Mq, low scorer Id23 exclaimed: I'm *not really sure what this means. I assume the abbreviations on the right are amino acids, obviously, its says. Ummm ... the control and the compound only are the same for the PHE but not for the other two. There is no data for the control. So I will write down fidelity test, because it is not the same as the control therefore, could be a possible answer looking at the picture down below, it's a little small and not really sure but I'm reading the side caption... Umm, seems like it's*

supporting the graph, which is good, I guess." This participant (Id23) was a confident High scorer in solving CC yet exhibited feeling of frustration and anxiety from unfamiliar things while solving Mq.   While effective problem-solving strategies are obviously needed to be a High scorer, the role of knowledge and metacognition are also obvious factors that are needed. Id23 was not as confident with biochemical mechanisms that focus on cellular processes and mode of action of antibiotics, as with microbiology concept that focuses on the origin and transmission of diseases. It is important to recognize that different interest levels and background in science disciplines can interfere with what is focused on by students as opposed to what is emphasized by instructors.

For others, frustration was due to the loss of points. Participant Id39 in CC did not like to lose points, exclaiming, "*Ouch, 100 points"* for going to hints menu. Also another High scorer, Id31, in Mq was frustrated with the animated nature of the test results viewed on the computer, "*This one also has flashing bar graphs. Not cool."* This shows that elements of distraction could be irritating while solving problems. Also areas that were unclear to participants created some anxiety and frustration, as stated by Id31 while referring to Mq, "*Oh, Dangit there is two more traces. Peptide bond formation or fidelity test. We'll try peptide bond. Dang bar graphs."* When this participant did realize a mistake she became more frustrated and said: "*Same kind of chemical, so obviously this one's negative too. I should have known better. Dangit* (frustration expletive)*."*

Conclusion
This study focused on many areas of decision-making in solving microbiology problems. Understanding the strategy used by students during the decision-making process provides insights into how students arrive at an answer. The utilization of the unique IMMEX program coupled with the think-aloud method of investigation utilized in this study has provided a better understanding of the decision-making experience. Decision making or problem solving, often thought of as synonymous skills in the work place, can be taught and enhanced. Whatever the discipline involved, the need for these skills is highly rated and should almost be as an important a factor for the student as the content itself. Indeed, it could be said that knowledge without the ability to apply it well to a problem is of little benefit (Maul &Gillard, 1996; Memmert, 2006; Lee, 2007; Snyder & Snyder, 2008; Parsonage, 2010; Griffin, 2011; Mettas, 2011; Parker, Claire, Bissell & Macphail, 2011).

According to Someren et al. (1994), duration and number of reasoning steps are important properties in models of the cognitive process. In utilizing the IMMEX program for educational purposes it is possible to observe individuals who were successful high scoring problem solvers and the strategies they employed by being able to analyze the specific steps they utilized as observed using the spm program feedback. Coupled with the feedback knowledge of time spent on each sub-task in the problem and the sequence of that sub-task in the broader process of the problem set gives an instructor insight in areas that may need more instruction or explanation. The IMMEX program uses the number and sequence of reasoning steps (spm) in determining performance in solving a problem. People who used more steps naturally spent more time on task, although some Low scorers rushed through the process as well but inevitably showed

more haphazard strategizing and rarely got the correct solution early. In this current study, the topics included in the IMMEX program problem-sets used had also been taught earlier in the general microbiology course. It was not possible to ascertain whether prior knowledge from other coursework helped the students, but the primary aim here was to understand the decision-making process used by students to solve problems, and how High and Low scorers varied in that process.

Some students used self-monitoring metacognition while solving these problems. This was evident in both quantitative and qualitative findings (Ebomoyi, 2009). More students solved CC than Mq. This may be due to the straight forward nature of the CC task when compared to Mq. As one participant (Id23) remarked "*Creeping Crud was clear on the task required, unlike Microquest.*" In general, the frustration of Low scorers seems to be related to their inability to solve the problem or make sense of the information available to them. Useful attributes that enhanced performance evident from this study include clarity of task and the prior knowledge before taking the program test. Time taken to solve the problem was also a measure of performance in this study. It was observed that High scorers spent less time than Low scorers and showed more logical flow of thinking. Student thinking as gauged by verbalization showed how logical thinking and prior knowledge was clearly connected to success in solving the IMMEX problem sets successfully.

In science education we are always trying to improve ways to help learners comprehend the relevance of the content we teach. Having them apply it logically to situations outside of the context in which it was taught requires that we further teach students the skills to think critically and rationally so that they are able to solve problems for efficient and effective decision-making. Having the ability to see how students are actually applying their knowledge, or not as the case may be, is a major step in preparing them to become effective decision makers in future careers. This program gives us an insight into how the students are acquiring knowledge, which also helps the instructor in knowing if it is merely confusion that promotes the problem-solving frustration or simply poor study skills. This latter case can be resolved as simply as helping students develop better study habits, thus helping engage them more and with more successes on problem solving, creating a more motivated student (Franklin, 2006, Foster & Gibbons, 2007).

Further research is needed to understand how an intervention program using decision-making takes into account individual differences in domain knowledge, problem-solving methods, and characteristics of the problem-solver (Gabel, 1994). Another aspect worth mentioning is the design of computer-assisted instruction. Some attributes that might be improved with IMMEX software should include an ability by the instructor to pause the timer when the computer has been idle e.g. fire alarm since this affects one of the measurements of success (time taken), and possibly a numerical measure of the time spent on each step of the program.

References

Anzai, Y., & Simon, H.A. (1979). A theory of learning by doing. *Psychological review*, 86, 124-120.

Barba, R. H. and Rubba, P. A. (1992). Procedural task analysis: A tool for science education problem-solving research. *School Science and Mathematics*, 92 (4), 188-192.

Boney, J. & Baker, J.D. (1997). Strategies for teaching clinical decision-making. *Nurse Education Today*, 17 (1), 16-21.

Case, E., Stevens R. & Cooper M. M. (2007). Is Collaborative grouping an effective instructional strategy. *Journal of College Science Teaching,* 36 (6), 42-48.

Carver, P.L. Novak, J.C (1991) use of computer Assisted instruction to review Microbiology and Antimicrobial agents. American journal of Journal of Pharmaceutical Education, 55, 248-252

Cox, Jr. C. T., Jordan, J., Cooper M. M. & Stevens R. (2006). *The Science Teacher*, 73 (4), 56-61.

Creswell, J. W. (1994). Research Design: Qualitative and Quantitative Approaches. Sage Publications.

DeYoung, S. (2009). *Teaching strategies for nurse educators*, 2nd ed. Upper Saddle River, N.J.: Prentice Hall.

Driver, R. & Oldham, V. (1986). A constructivist approach to curriculum development in Science, *Studies in Science Education* 13, 105-122.

Ebomoyi, J. I. (2009) Problem solving skills and Learning strategies of Students, Theories, Research, Technological applications and attributes for success as a learner. Lambert Academic Publishing (LAP).

Foster, N.F. & Gibbons, S.L. (2007). Studying Students: The Undergraduate Research Project at the University of Rochester. Chicago, IL: Assoc of College & Research Libraries.

Franklin, F.A. (2006). Study habits of undergraduate education students. Published Dissertation: University of Houston.

Gabel, D. (1994). *Handbook of research on science teaching and learning.* New York: Macmillan Publishing Company.

Gee, K.L. (2011). *The Impact of Instructor-Provided Lecture Notes and Learning Interventions on Student Note Taking and Generative Processing.* (2011). Master's Theses. Paper 3927. Http://scholarworks.sjsu.edu/etd_theses/3927 (Retrieved July 24, 2012)

Genyea, J. (1983). Improving students' problem-solving skills. *Journal of Chemical Education*, 60 (5), 478-482.

Griffin, D. (2011). Nudging Students' Creative Problem-Solving Skills. *Political Science and Politics*, 44 (2), 425-427.

Harrington, J. E. (2008). Games, Strategies and Decision Making. Worth Publishers.

Hattie, J., Biggs, J. and Purdue, N. (1996). Effects of learning skills interventions on student learning: A meta–analysis. *Review of Educational Research,* 66, 99-136.

Howe, M. J. A . (1974). The utility of taking notes as an aid to learning. *Educational Research*, 16 (3), 222-227

Huppert, J., Yakobi, J. and Lazarowitz, R. (1998). Learning microbiology with computer simulations: Students' academic achievement by method and gender. *Research in Science & Technological Education*, 16 (2), 231-245

Husserl, E. (1962). *Ideas*. London: George Allen and Unwin. (republished, New York: Colliers)

IMMEX [Windows software] (2010). Culver City, CA: IMMEX. URL: www.immex.ucla.edu (retrieved December 21st, 2010)

Jung-Lim, H. Nam-Kee C. (2004) Analysis of Korean High School Student's decision making processes in Solving a Problem Involving Biological Knowledge. *Research in Science Education* 36, 97-111.

Kibum, K., Turner, S.A. & Pérez-Quiñones, M.A. (2009). Requirements for electronic note taking systems: A field study of note taking in university classrooms. *Education and Information Technologies*, 14 (3), 255-283.

Kortland, J. (1992). Environmental education: sustainable development and decision-making. In R. Yager (Ed.), *The status of STS reform around the world ICASE year book* (pp 32-39). Petersfield, UK: ICASE.

Lambert, N. M. and McCombs, B. L. (1997). *How students learn*: *Reforming school through Learners centered education*. Washington, DC: American Psychology Association.

Lavoie, D. R. (1993). The development, theory, and application of cognitive network model of prediction problem-solving in biology. *Journal of Research in Science Teaching,* 30(7), 767-785.

Lazarowitz, R. Huppert, J. (1993) Science process skills of 10th Grade Biology students in a computer assisted learning setting. *Journal of Research on Computing in Education,* 25, (3), 366-382.

Lee, Y.C. (2007). Developing decision-making skills for socio-scientific issues. Journal of Biological Education, 41 (4), 170-177.

Makany, T., Kemp, J. & Dror, I. E. (2009). Optimising the use of note-taking as an external cognitive aid for increasing learning. *British Journal of Educational Technology*, 40 (4), 619-635.

Martinez, E. M. (1998). What is problem-solving? *Phi Delta Kappan* April, 605-609.
Maul, G.P & Gillard, J.S. (1996). Teaching problem solving skills. *Computers & Industrial Engineering*, 31 (1), 17-19.

Memmert, D. (2006). Self-controlled practice of decision-making skills. *Perceptual and motor skills*, 103 (3), 879-882.

Merriam, S. (1998). Qualitative Research and Case Study Applications in Education. San Francisco, CA: Jossey-Bass.

Mettas, A. (2011). The Development of Decision-Making Skills. *EURASIA Journal of Mathematics, Science & Technology Education*, 7 (1), 63-73.

Moustakas, C. (1988). *Phenomenology, Science and Psychotherapy*. Sydney, Nova Scotia: Family Life Institute, University College of Cape Breton.

Moustakas, C. (1990). *Heuristic research: design methodology, and applications*. Newbury Park, CA: Sage.

National Research Council. (2000). Inquiry and the National Education Science Standards: A guide For teaching and Learning Washington, DC: National Academy Press.

Palacio-Canyetano, J. (1997). *Problem-solving skills in high school biology: The effectiveness of the IMMEX problem-solving assessment software*. Doctoral Dissertation, University of Southern California, Los Angeles.

Parker, S., Claire J., Bissell, A.N. & Macphail, R.A. (2011). Developing Metacognitive and Problem-Solving Skills through Problem Manipulation. *Journal of Chemical Education*, 88 (11), 1489-1495.

Parsonage, I. (2010). Making clinical decisions in emergency situations. *Emergency Nurse*, 18 (4), 18-22.

Patton, M. Q. (1990). Qua*litative evaluation and research methods* (2nd ed.). Newbury Park, CA: Sage Publications, Inc.

Reif, F. (1983). How can chemists teach problem solving? *Journal of Chemical Education*, 60 (11), 948-953.

Rowe, M. B. (1983). What Can Science Educators Teach Chemists about Teaching Chemistry? A Symposium: Getting Chemistry Off the Killer Course List. | | . *Journal of Chemical Education*, 60 (11), 954-956.

Sankaran, S. R. and Bui, T. (2001). Impact of learning strategies and motivation on performance: a study in web based instruction. *Journal of instructional psychology*, 28 (3), 191-198.

Schank, R.C. Chip C. (1995) *Engines for Education* Lawrence Erlbaum Associates Publishers, 1-221.

Scott, P J., Altenburger, P.A. & Kean, J.A. (2011). Collaborative Teaching Strategy for Enhancing Learning of Evidence-based Clinical Decision-making. Journal of Allied Health, 40 (3), 120-127.

Sevdalis, N. & McCulloch, P. (2006). Teaching Evidence-Based Decision-Making. *Surgical Clinics of North America*, 86 (1), 59-70.

Simmons, P.E. and Lunetta, V. N (1993). Problem-solving behaviors during genetic computer simulation: Beyond the expert/novice dichotomy. *Journal of Research in Science Teaching,* 30 (2), 153-173.

Someren, M. W. Barnard, Y. F. and Sandberg, J. A. C. (1994). The think-aloud method: A practical guide to modeling cognitive processes. Academic press.

Stefanou, C., Hoffman, L. & Vielee, N. (2008). Note-taking in the college classroom as evidence of generative learning. Learning Environments Research, 11 (11), 1-17.

Stevens, R. H. McCoy, J. M. and Kwark, A. R. (1991). Solving the problem of how medical students solve problems. *Educational Softwar,* M.D. computing : computers in medical practice , 8 (10), 13-20.

Snyder, L & Snyder, M.J. (2008). Teaching Critical Thinking and Problem Solving Skills. *Delta Pi Epsilon Journal*, 50 (2), 90-99.

Vermunt, J. D. (1996). Metacognitive, cognitive and affective aspects of learning styles and strategies: A phenominographic analysis. *Higher education,* 31, 25-50.

Watson, F. (1980). Science education for survival. In C.P. Mcfadden (Ed.), *World trends in science education.* Halifax, Canada: Atlantic institute of Education.

Zajchowski, R., and Martin, J. (1992). Differences in problem-solving of stronger and weaker novices in physics knowledge, strategies or knowledge structure? *Journal of Research in Science Teaching*, 30 (5), 459-470.

Ziegler, E. W. and Terry, M. S. (1992). Instructional methodology, computer literacy, and problem-solving among gifted and talented students. *International journal of Instructional media*. 19 (1), 45-51.