A COMPARISON OF THE EFFECTIVENESS OF HANDS-ON AND COMPUTER-MEDIATED INSTRUCTION FOR LEARNING SOLUBILITY AND SOLUTIONS AT THE MIDDLE SCHOOL LEVEL

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Submitted to the Graduate Faculty of the

School of Education in partial fulfillment

of the requirements for the degree of

Doctor of Philosophy

University of Pittsburgh

2003

UMI Number: 3119081

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Text of Abstract

Previous research in science education has provided evidence that textbook-oriented instruction falls short of achieving desired educational outcomes. In the 1960s, educational reform movements advocated involving students in laboratory experiments with the belief that such hands-on tasks would necessarily lead to learning. In the mid-1980s, the introduction of computers in education provided an alternative to hands-on instruction, but comparisons between hands-on (HO) and computer-mediation (CM) have been scarce and contradictory. Recently, researchers have speculated about the potential benefits of HO versus CM instruction for individuals of different abilities; but few empirical studies have addressed this issue.

This research compares immediate and delayed achievement (measured as concept understanding, problem solving, and total learning) and conversations of small groups of students (blocked as high, medium, and low achievers) under each condition. Statistical analysis (2X3 randomized block design, Two-Way ANOVA: Instruction method X Prior achievement level) revealed a disordinal interaction between treatment

and achievement level: computer instruction resulted in more learning gains for low achievers and hands-on instruction was more effective for high achievers. Hands-on students struggled with procedural demands and obtained less accurate experimental results, making data more difficult to interpret. In contrast, for high achievers, unreliable experimental results seemed to have engendered more discussion among peers and elicited more explanations, which likely led to greater learning gains. In the computer condition, students were relieved of the manipulative demands of real objects, which helped low achievers concentrate on the conceptual aspects of the lesson. The computer facilitated completion of the "experiments" more quickly and hence allowed low achieving students more time to engage with practice tasks, an activity closely monitored and supported by the classroom teacher.

My findings have important implications in science education. First, there is no method that works best for all students. Second, these findings may assist the design of school support and gifted programs.

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1.0 CHAPTER I: INTRODUCTION AND STATEMENT OF THE PROBLEM

1.1 INTRODUCTION

Although instructional reform has been directed towards all curriculum domains; in particular, science education has been heralded as facing an unprecedented crisis and, more than any other area of the curriculum, has been under continuous reform since the late 1950s (Riechard, 1994). Educational researchers have continually struggled to develop teaching strategies to improve student understanding and perception of science following swings in various educational movements in an attempt to meet the challenge of education. Diverse innovative teaching approaches have been implemented, but because educational research findings are often over-generalized (Eylon, 2000) the conclusions of such innovations are dubious and consequently additional or substitute strategies are needed in an endless cycle of reform (Klopfer & Champagne, 1990). The particular area of Chemistry has been subject to numerous reform efforts nationwide as well but little assessment of learning has been conducted (Bowen, 1998).

Previous research in science education has provided strong evidence that the dominant school practice up until the 1960s, traditional textbook-oriented instruction that views learning as rote memorization and bases instruction on lectures and drill-practice, falls short of achieving desired educational outcomes. During the 1960s, science education reformist advocated for inquiry-oriented approaches, which at the time implied imparting hands-on experiences to school children. Students would be brought to the science lab to perform real life experiments. This teaching practice was based on Piagetian psychology, Dewey's philosophy of education of "learning by doing", and classical constructivism theories. Chapter II addresses these theories in more detail. Later, in the mid 1980s, along with cognitive theories and advances in computer studies, the computer appeared as an alternative to hands-on experiences.

The main difference, at least as it appeared on the surface, would be that virtual experiments would complement or replace the real life event. However, the nature of the learning environment is as important as the learner and may lead to different outcomes (Domin, 1999) and in addition, the method of instruction is a critical variable affecting students' interpretation of phenomena (Mercer, 1992). So the question remains as to the kind and extent of comparability of students' learning that can be achieved from each method. In fact, inconsistencies in scores from computer-simulated and hands-on science performance assessments have led to question the exchangeability of these techniques (Baxter, 1995; Baxter & Shavelson, 1994; Rosenquist, Shavelson, Ruiz-Primo, 2000).

Each of these two science teaching strategies, hands-on and computer-mediated instruction, has been compared to traditional instruction with much encouraging results (see Bredderman, 1983; Buttles, 1992; Hounshell & Hill, 1989; Shymanski, Hedges, & Woodworth, 1990) but comparisons between them, hands-on vs. computer-mediated science education, have been scarce and contradictory (see Baxter, 1995; Baxter & Shavelson, 1994; Bourque & Carlson, 1987; Choi, & Gennaro, 1987; Geban, Askar & Özkan, 1992; Moore & Thomas, 1983). Assessing the exchangeability of hands-on and computer mediated instruction is crucial for informing school practices, redirecting educational efforts, and ultimately improving science learning outcomes. The priority duty of educational research is then to inform school practices about what instructional techniques work better in the context of each class, school level, topic under study, demographics of the class, and other relevant educational variables.

My work is theoretically informed by two main learning theories: classical constructivism and cognitive theories that I briefly describe below and more in detail in Chapter II.

1.1.1 Hands-on: the Emergence of Constructivist Teaching Approaches

The primary learning theory that supports traditional inquiry in science education is classical constructivism. In its early roots, constructivism emerged from Piagetian research in Europe and from Dewey's philosophy of education of "learning by doing" in the late 19^{th} century in America. Constructivist views in science education claim that learners need to be overtly engaged in realistic settings in an active process of experiences which they interpret in a personal manner and negotiate meaning with others to build their own knowledge from those experiences (Merrill, 1992; Tobin 1990). Constructivism and Piagetian psychology strongly emphasize that learners need concrete experiences and manipulation of real life objects in order to build their own new knowledge on the basis of prior knowledge.

These ideas originally gave rise to the hands-on movement in the 1960s, bringing the students to the science labs to actually perform the experiments, discuss their findings with peers and coaches, and conclude about the science phenomena experienced. All these, rather than rote memorization, would promote concept understanding, scientific literacy, and development of problem-solving skills, the goals of the inquiry approach

(Anderson, 1976; Collette & Chiappetta, 1989; Ramsey & Howe, 1969; Schulman & Tamir, 1973; Windrim 1990). To be inquiry-oriented, an educational approach should strive at helping students to be active in discovering science making sense of what they experience and building their own knowledge on the basis of their prior knowledge rather than being passive receivers of teachers' lectures and textbook-driven instruction. Manipulation of equipment better conveys to students the complexities of lab work, which helps students in their development of certain skills (Hofstein & Lunetta, 1982). Middle school children are most often classified as concrete operational thinkers, they tend to solve logical problems through direct experiences (Shaw & Okey, 1985). Middle school age is when children start to acquire the ability to think of all possible combinations to perform a controlled experiment, it is the level at which hands-on experiences may have their most marked and positive impact (Lott, 1983).

Theoretical considerations and extensive empirical research comparing hands-on with traditional instruction support the idea that hands-on strategies are more conducive to meaningful learning of science, including content knowledge, process skills, problem solving, and students' attitudes (Ausubel, 1968; Dreher, Davis, Waynant, & Clewell, 1998; Gennaro & Lawrenz, 1989; Glasson, 1989; Lindberg, 1990; Scott, 1973; Scruggs, Mastropieri, Bakken, & Brigham, 1993; Tamir, 1983; Tyler-Wood, Cass & Potter, 1997). The hands-on teaching method was warmly welcomed by most of the educational community as a promising reform to improve science education. It rendered valuable outcomes but also arose criticism. Indeed, many studies also presented some drawbacks of hands-on or found no significant differences between the hands-on condition and science demonstrations (Bates, 1978; Berry, 1989; Gallagher, 1987; Gerlovich & Gerard, 1989; Hofstein & Lunetta, 1982; Tamir, 1989). As a consequence, some science educators (e.g., Lehman, 1990; Tobin, 1990; Welch, 1981) began to question the worth of hands-on experiences and to look for alternative teaching strategies.

1.1.2 Computer-mediated instruction: Later Constructivist Teaching Approaches

In the 1980's, computers became very popular in general and at schools. By 1996, more than 80% of school students in the US reported using computers for learning purposes either at school or at home (National Assessment of Educational Progress, 1996). The introduction of computers in education was supported by financial consideration, time efficiency concerns, and the fashionable "computer revolution" movement of the second half of the XX century. Many saw the movement as a renewed opportunity to improve science learning. Particularly at the K-12 level, computers were seen as a promising instructional tool (Duit, 1991), the idea was to replace the science lab with the computer lab, the students no longer would handle real objects but rather would select variables, problems, demonstrations, and so forth at the click of the mouse and watch virtual science.

It was hypothesized that students' exposure to virtual experiments could parallel the real experience and even potentially improve it. Cognitive theories, like the Dual Coding Model (Pavio & Csapo, 1983) focus on visual and verbal stimuli and how to present these in order to optimize human coding and linking to other information nodes. Cognitive theories contend that humans learn by constructing three different types of internal representational connections: (a) visual connections that represent information provided in pictorial form, (b) verbal connections that represent information provided in verbal form, and (c) joint connections between corresponding elements of the learner's internal visual and verbal connections or referential connections (Mayer & Sims, 1994). All three of these types of connections are hypothesized to be superior when words and pictures are presented contiguously instead of successively, because the visual and verbal systems can process information at the same time (contiguity principle). Accordingly, it has been hypothesized (Mayer & Sims, 1994) that computer-mediated instruction promotes learning by simultaneously contributing to the formation of all three connections and hence this line of research strongly supports the introduction of computers for school instruction. The students would be brought to the computer "dry" lab to interact with programs that instead of performing a science experiment in the science "wet" lab. In this manner, it is hypothesized that learner's cognitive system may code more easily the information presented. The real life presentation of science takes a second place after the virtual representation of it.

Other arguments favoring computer instruction in science education include claims that computers: 1) eliminate irrelevant, potentially distracting elements (Boblick, 1972); 2) help students focus on the essential aspects of the lesson (White & Frederiksen, 1998); and 3) render more efficient and reliable data than hands-on experiments (Geban, Askar, & Özkan, 1992). Numerous studies gave support to computer-mediated instruction as opposed to traditional instruction (e.g. Buttles, 1992; Coleman, 1997; Rogers, 1987; Trumper & Gelbman, 1997).

However, there is also extensive research on science instruction using computers (Jong & Van Joolingen, 1998) that concludes that there is no clear and univocal outcome regarding students' learning in favor of computer-mediated instruction and many researchers call for more studies on this matter (see Choi & Gennaro, 1987; Geban, Askar, & Özkan, 1992; Tinker, 1983). As Shay (1980) expresses "*It is clear that simulations are designed to meet many worthy goals, but the questions remains: How effective are simulations as compared to other teaching methods?*" (p. 27).

In sum, the two instructional approaches differ in a great number of features, some of which are detail in figure 1.

	HO	CM
Stimuli	All senses	Visual, audio
Time	More time-cons. Real time	Less time-consuming Self-paced
Procedural demands	Manipulation of objects	Operating the computer
Path of instruction	Sequential	Contiguous
Cognitive demands	Reading and writing	Listening and typing
Experimental results	Uncontrolled variables and measurement error	More reliable

Figure 1: Comparison between hands-on and computer-mediation

1.1.3 Operational definition of learning

It is generally agreed among science educators that meaningful learning involves understanding of major scientific concepts and application of those concepts to solve problems (Bybee, 1987; Collette & Chiappetta, 1989; Costenson & Lawson, 1986; Helgeson, 1987; Shulman & Tamir, 1973; Shymansky, Kyle & Alport, 1983, 1982).

Particularly in Chemistry, concept understanding and problem solving skills are valued learning outcomes (Bowen & Bunce, 1997). In the 1997 National Survey on College Chemistry Faculty Beliefs and Attitudes of Assessment-of-Student-Learning Practices (Slavings, Cochran, & Bowen, 1997) it was found that the two most valued learning outcomes held by faculty for college chemistry students are the understanding of chemical concepts and the ability to use those concepts to solve various chemical problems. Gabel and Bunce (1994) in their comprehensive review on problem-solving research in chemistry suggest that one of the main reasons students have difficulties solving some chemical problems is that they lack understanding of the concepts needed to solve the problems. Therefore, concept understanding and problem solving are necessary elements of Chemistry learning. Hofstein and Lunetta (1982) found that very few studies attempted to assess problem solving as an outcome of laboratory work. In my research, I address this issue by measuring mastery of concept understanding as separate form problem solving. To assess acquisition of problem solving skills, students will be requested to solve problems related to design simple experiments; for example, experiments to distinguish solutions from pure substances or to the identification of substances on the basis of their differential solubility.

I found that a suitable Chemistry topic to compare students' learning under the two different instructional methods, hands-on and computer-mediated instruction, is solubility and solutions at the middle school level. At that level, solubility and solutions is a new topic to students, which is an essential feature to assess problem-solving skills

(Mayer, 1992; VanLehn, 1989). Middle school students are in the transitioning phase from concrete reasoning to formal thought; which means they are developing hypothetical reasoning based on the logic of all possible combinations, necessary to design experiments, and the ability to perform controlled experiments (Inhelder & Piaget, 1958). Solubility and solutions nicely lends itself to assess simple experimental design. Figure 2 below gives an overall view of the study.

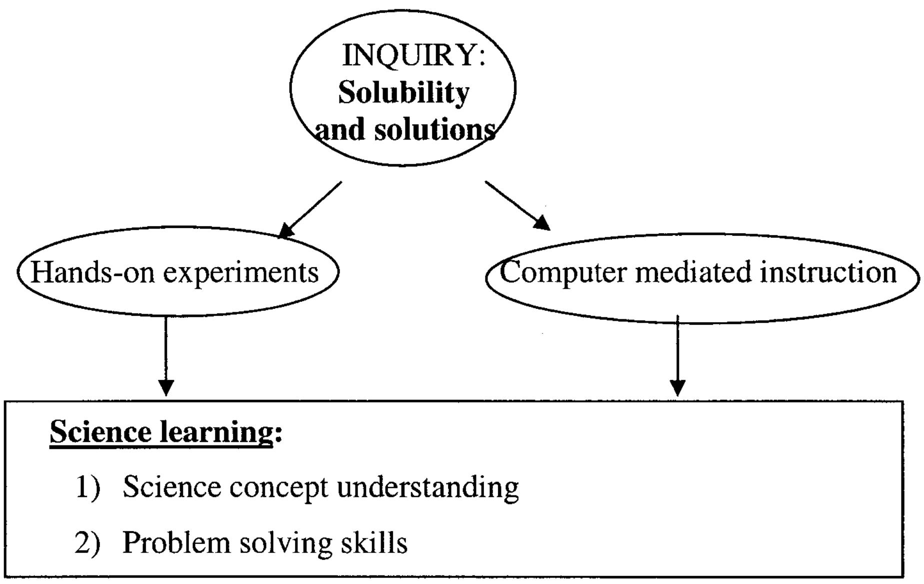


Figure 2: Schema of the study

However, just knowing which instructional technique further promotes learning may not be enough to hypothesize about the causes of such improved learning. To better understand the learning processes involved under each condition, in this study, I am also investigating the kind of cognitive engagement elicited by each method by audio-taping students' conversations while working in pairs in their tasks, either performing the experiments in the science lab of experiencing computer-mediated instruction.

In addition to discussion of their overall comparative effectiveness, debates regarding the relative merit of hands-on vs. computer-mediated science instruction have also speculated about their respective benefits for individuals of different ability levels (see Abraham, Williamson, & Westbrook, 1994; Carin, 1997; Ronen and Elihau, 2000; Shay, 1980; Tamir, 1989). Shay (1980) points out that *"[T]here is no evidence which indicates that simulations are more effective, or less so, with different types of students, such as those who are already active and articulate or those who are decidedly withdrawn" (p. 28).* Research results in education are often over-generalized (Eylon, 2000) and individual differences of students tend to be overlooked. Indeed, the overwhelming majority of the comparisons between hands-on and computer-mediated instruction reported in the literature, reach their conclusions from the average attainment of whole classes exposed to one or the other instructional technique (see for example Ayres & Melear, 1998; Bourque & Carlson, 1987; Choi and Gennaro, 1987; Geban, Askar, & Özkan, 1992; Moore & Thomas, 1983; Rosen & Petty, 1992; Shaw & Okey, 1985). To avoid over-generalizations, a uniqueness of my study is a control of results for students' ability levels. Many research studies such as Chandran, Treagust, and Tobin (1987), Johnson and Walberg (1989), Kuyper, van der Werf, and Lubbers (2000) to mention a few, give strong evidence about the predominance of prior achievement over other educational variables in predicting posterior attainment in all disciplines and at all levels of education.

At the core of my dissertation research is the question of how hands-on and computer-mediated instruction facilitate Chemistry learning of students of diverse ability levels collaboratively working in small groups. It might be that prior achievement by itself is the best predictor of students' accomplishments regardless of the instructional method. Or it might be that the two teaching techniques have differential effects on low or high achievers in terms of achievement and cognitive engagement. This thesis attempts to answer these research questions by comparing the effectiveness of both teaching methods in learning Chemistry for groups of students of different achievement levels.

1.2 RESEARCH QUESTIONS

The main problem that I present in this dissertation is to find out which instructional method, hands-on science or computer-mediated instruction, is better at both: (a) developing middle school students' understanding of the concepts of solubility and solutions; and (b) developing problem-solving skills for students of diverse science achievement levels. In addition, in order to better understand the learning processes involved under each condition, I am also investigating the cognitive engagement elicited by each method by recording students' conversations while working in pairs, either performing the experiments in the science lab of experiencing computer-mediated instruction.

Accordingly, this study will address itself to the following research questions:

When middle school students are exposed either to hands-on science or computer-mediated instruction,

1) For each of the three dependent variables (understanding of the concepts of solubility, problem-solving skills, and total learning), are there any significant interactions between instructional method (hands-on and computer mediated instruction) and prior science achievement (high, middle, and low)?

2) a) If no interaction exists for understanding the concept of solubility, which instructional method better promotes learning?

   b) If no interaction exists for problem-solving skills, which instructional method better promotes learning?

   c) If no interaction exists, which instructional method better promotes overall learning?

3) What are the kinds of pair students' conversations elicited by each instructional technique: hands-on and computer-mediated instruction during performance of the tasks? Do these conversations revolve around the content, the process, manipulative demands of the task, features of the computer package, or other issues? How long these conversations last? Is there collaborative learning, tutoring, or dominance of the more capable student of the pair?

My working hypotheses are that on the one hand, the noisy environment and manipulative demands of the hands-on science lab with the additional reading demand of the lab manual may prevent students from receiving simultaneous visual and verbal stimuli which may be detrimental for low achievers. For these students then, the computer approach may work better. However, if the hands-on technique, which per se involves more physical activity than the computer approach, also invites more verbal engagement and peer negotiation of meaning, that may compensate for the great demands of hands-on on low achievers. These students would then receive more peer scaffolding in the hands-on condition and similar visual and verbal stimuli. Therefore, if indeed hand-on contributes to more meaningful verbal engagement, then that would be the preferable strategy for low achievers. For high achievers, because of the increased ability, I hypothesize that the differences between conditions will tend to become smaller but yet, the benefits of interacting with real objects in the hands-on approach would still render higher learning outcomes.

1.3 SOLUBILITY AND SOLUTIONS

The place of solubility and solutions in science is prominent as one of the major topics in Chemistry (Ebenezer & Erickson, 1996). The fact that solubility and solutions constitute at least one chapter in almost every school science textbook (see Aldridge, et al., 1993; Heimler, Lamb, Cuevas & Lehrman, 1989; Price, 1987; Wilbraham, Staley, Simpson & Matta, 1990) gives further evidence of its importance at the school level.

Most chemical reactions occur in solution, most medicines or liquids we drink or use for cleaning purposes are solutions, natural environmental phenomena such as sea water are solutions -- solubility is the process that produces solutions. Still, solubility has not yet received much attention from science education researchers and there is need for more research on this topic (Ebenezer & Erickson, 1996; Gennaro, 1981).

I argue that solubility and solutions is a suitable science topic to test learning as concept understanding and development of problem-solving through hands-on and computer-mediated instruction. Following, I present several arguments in support of this claim.

First, solubility and solutions is not formally taught until the end of middle school or high school and hence it constitutes a new topic (not yet learned) for middle school students. If prior to treatment, students have already learned the topic, they may respond to assessment on the basis of prior instruction instead of showing their learning due to treatment. Novelty is critical not only to study concept understanding but also particularly important in studying problem solving (Mayer, 1992; Mayer & Anderson, 1992; VanLehn, 1989).

Second, if research results are to make an important impact on science education, then the topic of research should be educationally worthy. Solubility and solutions are one of the major ideas in chemistry (Ebenezer & Erickson, 1996). Solutions and solubility are very important concepts in all science fields from environmental science and physics to biology and medicine. Extensive literature shows that when students perceive the topic at hand as relevant to their daily life, they demonstrate better learning (Johnson-Laird, Legrenzi & Legrenzi, 1972). Middle school students have already encounter plenty of solutions in their life (juices, colored water, medicines, etc.) and have seen many instances that involve the solubility process, as for example dissolving sugar in hot tea, salt in water, or even washing off spots (for example from blood or salsa) from clothes (Abraham, Williamson & Westbrook, 1994; Longden, Black & Solomon, 1991). Evidence of the importance of the topic is further given by the fact that solutions and the solution process are part of many school science curricula (e.g., I. P. S[1]; Science Content Standards for California Public Schools) at various levels of science instruction (Abraham, Williamson & Westbrook, 1994), and hence constitute at least one chapter in almost every school science textbook (see Aldridge, et al., 1993; Heimler, Lamb, Cuevas & Lehrman, 1989; Price, 1987; Wilbraham, Staley, Simpson & Matta, 1990). Basic concepts of solubility and solutions can be presented in a simple way for middle school students to grasp but it is important that they understand this basic concepts well because at a more advanced level, the topics become much more abstract and difficult (Burke, Greenbowe, & Windschitl, 1998).

Third, solubility and solutions, in basic form allow for safe and simple experimentation without the need of sophisticated equipment. Therefore, solubility and solutions are most appropriate topics to assess concept understanding and development of problem-solving and experimental design skills at the middle school level.

Fourth, although students' performance on solubility and solutions is far from satisfactory, the topic has not yet received much attention from science education researchers and they call for more research in the area (Ebenezer & Erickson, 1996; Gennaro, 1981). Johnston and Scott (1991) investigated students' understanding of

[1] Introductory Physical Science (I. P. S.) is a well-known course for junior high school science (Gennaro, 1981).

conservation of mass after dissolving but the emphasis has been on the conservation of mass rather than on the dissolution process. In any case, findings are mostly discouraging. This is probably indicating that students do not understand what happen when a solute is dissolved.

1.4 SIGNIFICANCE OF THE STUDY

Today's unprecedented crisis and continuous reform in science education (Riechard, 1994) call for exhaustive revision of classroom practices. The area of chemistry has also been subject to numerous reform efforts nationwide but there has been little assessment of learning (Bowen, 1998). One distinctive feature of Chemistry is the possibility of being taught in various learning environments: the classroom, the computer lab, or the science lab. According to currents constructivist views, the nature of the learning environment is as important as the learner and may lead to different outcomes (Domin, 1999). Concurrent with the learning environment, the method of instruction is a critical variable affecting students' interpretation of phenomena (Mercer, 1992).

Comparative studies between available teaching methods are critically important to better inform school practices. The National Research Council (1996) made a strong call for scientific literacy for all students. This means that educational researchers should assist teachers and administrators in choosing the instructional method that better serve all students. The implications of this study are straightforward; a detailed look at the effectiveness of instructional methods for various levels of students' academic success could redirect educational efforts (curricula, material, teaching strategies, money, professional development, equipment, etc.) and improve educational outcomes.

Whereas in the 1960s there was a strong push to turn all school science into hands-on, now there seems to be a press for turning all science instruction into computer-mediated classes. Lunetta and Hoftein (1981) cogently argue that both hands-on experiences as well as computer instruction should have a place in school science. The question is *what method for what students*. This study may contribute to clarify this aspect. No study has yet examined the relationship between students' prior performance at school and science teaching methods in the topic of solubility and solutions at the middle school level.

This study specifically focuses on the effectiveness of instruction under two conditions: hands-on and computer-mediated instruction. *"Several attempts have been made to carefully assess the impact of simulations as a teaching technique, but such studies are plagued with the methodological problems of validity and comparability since most deal with single exercises or subjective comments over time"* (Shay, 1980, p. 27). In addition, given that one of the major goals of science education is to promote science achievement, there is continued interest in improving student learning and providing individual differences (Geban, Askar, & Özkan, 1992). Consequently, this study goes even further to avoid over-generalization and controls for the most important predictor of school achievement, different ability levels. Moreover, this research may also illuminate the mechanism of differential learning under each condition by examining the cognitive engagement of students elicited by each instructional strategy.

2.0 CHAPTER II: LITERATURE REVIEW

Chapter II reviews the literature related to this study. To this end, the chapter will be divided into five sections. Section 1 addresses the issue of hands-on in school science instruction and section 2 concerns itself with a review of literature related to computer-mediated instruction in science. Both, section 1 and 2 are in turn divided into the following four sub-sections: brief historical account, theory, empirical research, and conclusion from the literature review. Section 3 relates to studies that compare the effectiveness of hands-on and computer-mediated instruction. Section 4 reviews research that account for the primary importance of prior achievement in science and mathematics over other educational variables to predict students' posterior achievement. Finally, section 5 reviews research on the teaching and learning of solubility and solutions at schools as related to students' achievement in the subject.

2.1 HANDS-ON

2.1.1 Brief historical account of the hands-on movement

The hands-on approach has its roots in Dewey's philosophy of education of "learning by doing" in America in the late 19^{th} century, later reinforced by Piagetian research in Europe in the first half of the 20^{th} century, and finally supported by constructivism, the current dominant paradigm in education. In contrast to the traditional textbook-based curricula, which emphasize rote memorization of facts, laws, and theories, the inquiry approach stresses problem solving, process skills, creativity, and positive attitudes toward science. However, it was not until the 1960s that the first major reform movement in education promoted hands-on activity-based science programs. Science labs were installed at schools where students could perform scientific experiments and get a vivid experience of science. It was hypothesized that such approach would make science more relevant to students and would conduce to better learning. Curriculum developers designed numerous science programs that revolved around lab experiments such as Biological Sciences Study Committee (BSCS), Earth Science Curriculum Project (ESCP), Physical Science Curriculum Project (PSCP), Chemical Education Materials Study Program (CHEM), Chemical Bond Approach, Science Curriculum Improvement Study (SCIS), Science A Process Approach (SAPA), and Elementary Science Study (ESS) (Collette & Chiappetta, 1989; Hudes & Moriber, 1969). These new science programs were initially accepted with zeal, but within a few years the enthusiasm waned. Studies conducted in the 70's showed that achievement test scores did not reflect significant gains in learning compared to the traditional curriculum (Occhuizzo, 1993). Later, in the 1980s, the hands-on approach received a renewed push when a new educational reform movement re-ignited the flurry of interest in science education that emphasize connection to real world applications, hands-on, and inquiry based learning (Yager, 1991).

However, the fact that students are brought to the science lab does not necessarily imply that they are experiencing an inquiry-oriented education. Domin (1999) presents a taxonomy of laboratory instruction styles and highlights their distinctive features.

According to his classification, laboratory work falls mainly into one of four categories: expository (traditional or verification labs), open-inquiry, guided-inquiry (discovery), and problem-based.

Expository labs hold a close resemblance with traditional textbook-center approaches; this lab instruction style only furnishes the traditional lecture with an experiment component that mostly involves verification of scientific laws. Students do not build their new knowledge, they experiment with materials to reinforce the validity of a general science law that has already been told to them, students do not discover science in these deductive laboratories, they just observe science as it happens, whether performed by themselves or by the teacher. These labs have been the most heavily criticized style of lab instruction because of their "cookbook" nature.

The second type of lab work, open inquiry labs are more at tone with the current constructivist paradigm in education; students experiment, analyze, discuss, and conclude from experience; they derive a general law that has not been stated for them previously and in this way they build their new knowledge from what they have observed, reasoned, and discussed with peers in the particular laboratory activity. Open inquiry requires students to generate their own research question and procedure, and the outcome of the activities is therefore undetermined. This method is highly time-consuming and assumed learners' ability to utilize formal operational thought. These characteristics may indicate that open-inquiry may not be the best teaching method at the middle school level.

In guided-inquiry instruction, the third lab style, teachers give students more directions for what they are expected to do to reach a desire outcome; it is then probably more adequate for middle school students and is then the laboratory instruction style adopted in this study.

Problem-based instruction involves that the laboratory manual would be discarded and that teachers would pose a problem often lacking crucial information for students to redefine in their own words and solve, which includes developing the procedure to solution. Learners are strongly encouraged to develop testable hypothesis rather than obtaining correct results. This type of instruction is also highly time consuming and demanding from both teachers and students.

2.1.2 Theory supporting hands-on

Learning may indeed take place when students watch or listen to a lecture, but deeper learning requires a more overt involvement of the learner (Tobin, 1990). From the theoretical point of view, by performing the experiment students get more involved in the task, actually handling equipment, and they are hence more likely to discover new knowledge. Abraham, Williamson and Westbrook (1994) found that 61% of their sample of nine graders still reason at the concrete ability level and another 13% were at the transitional stage. From this, they conclude that instruction should provide concrete experiences in order to compensate for low levels of reasoning ability. Saunders (1992, p.138) stresses that "learners need abundant sensory experience with their external world" which is only reflected through hands-on science. Middle school age is when children begin to develop formal thought, they start to acquiring the ability of hypothetical reasoning and to think of all possible combinations to perform a controlled experiment. According to Piagetian psychology, learners at middle school age are in the operational stage of their intellectual growth, that means that they are capable of mentally transforming data, reorganize it and use it selectively to solve problems. The essentials of Piaget's theory includes that knowledge is a biological function that arises out of action and that it is basically "operative"--it is about change and transformation. Development proceeds by the assimilation of the environment to cognitive structures, and the accommodation of these structures to the environment; movement to higher levels of development depends on "reflecting abstraction," which means coming to know properties of one's own actions, or coming to know the ways in which they are coordinated. Cognitive structures are active things; they are means of interacting with your environment. Piaget's view was that cognitive structures naturally change in the course of being used, and both the organism and the environment are involved in this process of change (Inhelder & Piaget, 1958).

As derived from the above paragraphs, actions upon real objects, concrete operations, are at the very core of what is considered learning in Piagetian terms. The basic operations needed to understand solubility and solve related problems are class multiplication (to think of all the possible combinations of given variables), serial-ordering (to consider all possibilities in a logical order), and conservation of physical quantities. These are the means through which children at the concrete reasoning ability level structure their immediately present reality, the experiment they just performed.

A tenet of constructivist philosophy is that the acquisition of knowledge requires the use of general procedural knowledge. Lawson (1991) showed that when students were presented with concepts acquisition tasks, skills in reasoning were highly correlated with performance. According to constructivism, knowledge is internally constructed by the learner based on past experiences, the meaning of which is negotiated through multiple perspectives with other learners. Learning is then conformed of personal discovery based on insight and is revealed when the learner is capable of solving problems. The memory structure of individuals is seen as highly personalized constructions of no specific structure. Constructivism favors instruction in realistic settings and responsive environments that propitiate active, self-guided reflective learning where students could be intrinsically motivated (autotelic principle). Accordingly, the preferred kind of classroom practices is discovery learning, where activities are the basis for learning, testing is based on problem solving, and group work is largely encouraged.

The manipulation of objects necessary in a hands-on experiment better conveys to students the complexities of lab work which helps students in their development of certain skills and reveals to students the physical relationships between equipment and scientists (Hofstein & Lunetta, 1982; Olson, 1973). Laboratory experiments closely resembles the ultimate work of scientists both in term of the activities performed and the group dynamic of team work -- in this sense, wet lab experiments portray a much realistic view of science more conducive to scientific literacy. Lucas (1971) contents that through hands-on experiences students get a deeper understanding of how scientists work and think and also how to acquire new knowledge. Students engaged in hands-on labs may begin to reflect on their misconception and reformulate their ideas on the basis of what they observe. This is the process of equilibration in Piagetian terms (Glasson, 1989).

The main empirical support for hands-on science is based on the extensive literature that accounts for students' higher achievements and acquisition of manipulative skills. Bredderman (1983) analyzed research results from studies published since 1965 and concluded that "a 14 percentile improvement for the average student as a result of being in the activity-based program group ....the use of activity-based programs promote student achievement in all analyzed areas" (p. 504). Comparing standardized achievement test results from students under traditional textbook-oriented instruction and students from hands-on instruction, he concluded that the fear that hands-on places too much emphasis on science process at the expense of science content is unwarranted. Another analysis of over 81 published research on hands-on effects on science achievement was conducted by Shymanski, Hedges, and Woodworth (1990). They conclude that science programs developed in the 1960s and 1970s (which emphasized hands-on in opposition to didactic models) improved students scores and attitudes toward science and did not compromise content and process skills as often argued by opponents to the new curricula. Hands-on experiences provide the students with unique opportunities to engage in the processes of scientific inquiry (Hurd, 1969; Lunetta & Tamir, 1973; Schwab, 1962) and help students construct scientific concepts that are long-lasting (Carin, 1997). Most science educators agree that hands-on activities help the students develop laboratory skills such as careful observations, manual ability, gathering of data, etc. (e.g. Bourque & Carlson, 1987; Hofstein & Lunetta, 1982).

Hands-on science education has also received criticism mainly based on four arguments: a) few teachers are competent to use laboratory work effectively, b) too much emphasis on lab work leads to narrow conceptions of science, c) too many experiments are trivial, and finally d) lab work at schools is often remote from, and unrelated to the capacities and interests of the students (Hofstein & Lunetta, 1982). Moreover, in relation to scientific understanding of concepts, Bates (1978) argues that what is supposedly accomplished by doing lab-work, may also be accomplished by other less expensive and less time-consuming instructional methods. Glynn, Yeany, and Britton (1991) argue that a trendy emphasis on hands-on will not, per se, further advance students' scientific literacy if not accompanied by a minds-on approach. Some would contend that lab work places a great emphasis on the mastery of essential skills but students lack interest in text learning. Welch (1981) conducted a survey of teachers' perceptions of the hands-on curricula; the results are not encouraging. Teachers found hands-on curricula difficult to teach, time-consuming, and do not feel that they are prepared or have received appropriate support. Overall, they believe that hands-on is not effective for learning science.

Manipulation of equipment and chemicals is another difficulty of wet labs. There are great safety concerns in the misuse and administration of drugs. Equipment and material are expensive to acquire and to maintain in good conditions. In addition, hands-on activities can be very demanding of students who have to incorporate knowledge at the same time they manipulate variables and use equipment (Tamir, 1989). The careful attention that this aspect requires could be overwhelming for some students, particularly low achievers, and teachers. Teachers need to constantly supervise students' work and behavior in order to prevent accidents, and because of this, they often have to leave aside their teaching duties. Already at the onset of the hands-on movement in the 1960s, many authors called for instructional opportunities that would not require such continuous teacher supervision (Bruner, 1964; Glaser, 1976; Maier, 1971).

Potential dangers of wet labs also arose some concern among parents, principals and educational-administrators; they fear of teachers' lack of control over students in the informal setting of the lab. This concern is so strong that some researchers proposed safety guidelines to follow in chemistry demonstrations (Berry, 1989) and even court rulings have established three basic responsibilities that school labs must meet: (1) inform students about the hazards they might encounter; (2) provide a safe learning environment and properly maintained equipment; and (3) ensure adequate supervision (Gerlovich & Gerard, 1989). Still, these rulings are insufficient to assure that accidents will not happen. Yet additional aversions regarding wet lab activities expressed by many members of the educational community refer to ethics and moral believes against certain experiments such as those involving animal use.

2.1.3 Empirical research on hands-on

Numerous studies compared students' achievement in science after they experience hands-on instruction versus traditional textbook-oriented instruction. These studies provide strong evidence of the effectiveness of hands-on. For example, higher levels of thinking were reported by Wheatley (1975), Raghubir (1979), and Reif and St. John (1979); growth of students' creativity was found by Hill (1976) and Penick (1976); improvements in science scores as well as increase in enrollment were reported by Fix and Renner (1979).

Lott (1983) conducted a meta-analysis involving 39 studies mainly from 1969 to 1973, 33 of which were non-published doctoral dissertations and 6 published articles. He concluded that the hands-on strategy had a positive effect at the intermediate level and is more useful for developing higher thinking. More recently, Shymansky, Hedges, and Woodworth (1990) conducted another meta-analysis and synthesized research studies on the new science curricula form the 60's and 70's and they found that the new approach was indeed more effective than the textbook approach particularly for science achievements and problem solving.

Other types of comparisons involve hands-on science versus teacher's demonstrations. Scott (1973) found that students who were taught under inquiry approaches (students performed the experiments) followed by "yes" or "no" answers given by the teacher to students' questions were more analytical than were the comparison group who experienced teacher's demonstration instruction. Glasson (1989) reported that both instructional techniques (hands-on and teacher's demonstrations) in ninth-grade physical science resulted in equal declarative knowledge achieved; however, students in the hands-on condition gained significantly more procedural knowledge.

Other researchers conducted surveys of students and teachers to investigate their perceptions as protagonists of hands-on. Stohr-Hunt's (1996) survey of almost 25,000 eight graders from over 1,000 public and private schools describes the relationship between how frequent students experience hands-on science and their level of achievement. Findings suggest that experiencing hands-on science at least once a week leads to higher scores on standardize tests than experiencing it once a month or less frequently.

In opposition to the previous body of research, some studies do not inspire such excitement over wet labs. Bates (1978) reviewed 13 published studies on science teaching at the secondary and college non-major levels from 1962 to 1976. He did not find differential effects on learning science content nor on reasoning ability as a result of laboratory activities as measured by conventional paper-and pencil achievement tests. Gallagher (1987) reviewed 10 pieces of research on K-12 hands-on conducted in 1985. He found that most studies did not use non-hands-on control groups and from those that did have control group, one reports no positive effects of lab instruction. Tobin (1990) argues that there is evidence that indicates that hands-on fall short on achieving the potential for promoting student learning. Lehman (1990) states that much research shows that hands-on does neither assist nor hinder students' learning of science. He analyzed students' conversations during lab sessions and found that much of verbal interaction concerned figuring out the procedure rather than understanding the concepts.

2.1.4 Conclusion from the literature review on hands on

From all the empirical evidence presented above, it is plausible to conclude that science education research has not yet produced unequivocal results applicable to all cases of hands-on. Weak research designs apart, it may be that such general conclusion does not exist but rather, the effectiveness of hands-on depends upon numerous variables, among them the topic at hand, the quality of the lab, and the expertise of the teacher. Furthermore, it may even be the case that within the same class, where the mentioned variables are set, students' individual differences, such as prior achievement in science, affect the effectiveness of the hands-on activity for each learner.

The empirical research presented above, only compared hands-on teaching versus traditional instruction. Up until the 1980s, these comparisons were in perfect accordance to school practices. However, the introduction of computers into education opened new possibilities that needed to be explored. Computer-mediated instruction is now well in vogue but there are not yet many pieces of literature comparing it to hands-on.

2.2 COMPUTER-MEDIATED INSTRUCTION

2.2.1 Brief historical account of computers in education

In the mid-1980s, the role of science in society was changing; the importance of technology-related issues was escalating and hence, the goals of science education needed to be re-oriented to include computers as learning aids in order to prepare a science literate population for the technology society. Computers assist learning in many ways, as a source of information, as a sophisticated tool for graphing and calculations, as a neat storage of files, as a device that provides immediate feedback to drill and practice, as a device to watch short edited videotapes, etc. and as such, computers are seen as a promising tool to improve students' learning (Duit, 1991). It is assumed that the knowledge and skills gained by the student in his/her interaction with the computer would later be transferred to the real world; however, this assumption seems to be challenged by Baxter's (1995) study who found significant discrepancies when the same student is assessed with equivalent tests through hands-on or in the computer.

The first experimental studies of the effect of computer on students' learning began in the 1970s but the computer didn't become popular at schools until the 1980s and during the 1990s educational multimedia technology has advanced very rapidly (Burke, Greenbowe & Windschitl, 1998). By 1992, well over one million computers were in use in U.S. classrooms (Buttles, 1992) and the Office of Technology Assessment estimated that by 1994 more than 4 million microcomputers were in use at schools (Simmons, 1991). In 1996, more than 80% of school students in the US reported using computers for learning purposes either at school or at home (NAEP, 1996). Nowadays, computers are very popular in classrooms (Harrison & Treagust, 2000) and there are countless programs, websites, and CD-ROMs for school use (Schwartz & Beichner, 1998).

The computer is also thought of sometimes as a potential alternative to traditional hands-on experiences by means of designing a computer package that would include either a demonstrated science experiment or a virtual lab (Ronen & Eliahu, 2000). However, theoretical considerations cast some doubts about the "exchangeability" of hands-on and computer-mediated techniques (Rosenqist, Shavelson, & Ruiz-Primo, 2000)

2.2.2 Theory supporting computer-mediated instruction

Two theories, both derivation form information processing research, provide support for the effectiveness of learning through computer software: the Dual Coding Theory of Multimedia Learning, proposed by Mayer and Sims (1994) and Mental Models theory proposed by several authors (Greca & Moreira, 2000; Jonhson-Laird, 1983; Reed, Ayersman & Liu, 1996).

Already in the early 1970s, Murray and Newman (1973) studied the coding of information in the human short-term memory system. They proposed that at least 2 types of coding occurred for the retention of material: a visual code and a verbal code. Later, Pavio (Pavio & Csapo, 1983) produced the Dual Coding Theory, which was in turn extended by Mayer and Sims (1994) to produce the Dual Coding Theory of Multimedia Learning. This theory contends that humans use two information-processing systems to represent information: the visual and verbal systems and these detect and process environmental stimuli. With these two systems, the learner constructs three internal representational connections at the individuals' working memory: (a) visual connections that represent information provided in pictorial form, (b) verbal connections that represent information provided in verbal form, and (c) join connections between corresponding elements of the learner's internal visual and verbal connections (referential connections). Because individuals' working memory capacity is limited, these last referential connections are better constructed when words and pictures are presented contiguously instead of successively -- the visual and verbal systems would be processing information at the same time (contiguity principle). Mayer and Anderson (1992) argue that the mayor cognitive demand for successful performance on retention tests is the construction of at least one kind of connection but developing problem-solving skills necessarily requires the construction of the third referential connections. However, Mayer and Sims (1994) go even further and contend that a teaching strategy would promote the development of learners' problem solving skills when it contributes to the formation of all three connections, such the case of computer-mediated instruction. Almost all computer packages use a multimodal representation of information and hence promote the formation of these three connections in the working memory, multimedia instruction results more effective when words and pictures are presented contiguously (Mayer & Anderson, 1992). Accordingly, the computer instructional unit of this research was developed on the basis of the contiguity principle, videotaped laboratory experiments will be shown in a "video window" on the computer screen along with audio (sound and explanation) and text. The videotaped experiments will be the same as those performed by the hands-on group in the science lab. According to Smith, Jones, and Waugh (1986), the combination of video with computer-mediated instruction could be a useful teaching tool.

The second theory that supports learning through computers also focuses on mental representations of information. Johnson-Laird (1983) argues that there are at least three types of mental representations: prepositional representation (formal logic), mental models (analogues to the world), and images (views of the model). Mental models refer to the mental knowledge representation people construct to make sense of their world. They are personal, incomplete, inconsistent, unscientific and unstable, the only requirement mental models fulfill is that they are useful for the person to explain and predict related events. This is in accordance with authors who argue that children do not operate with coherent frameworks. Mental models are continually enlarged and improved as new information is added to them and it is doubtful that we could establish a "closed catalogue" of mental models (Greca & Moreira, 2000). Further, Greca and Moreira state that analogical representations (mental models and images) have a great pedagogical potential in the creation and comprehension of scientific theories. It would be then, reasonable to hypothesize that an instructional strategy that addresses both analogical representations and prepositional representations, such as computer package, would greatly contribute to learning.

Reed, Ayersman, and Liu (1996) proposed a very similar approach but they put it into different terms. They suggest that computer packages include semantic network features, concept maps features, frames and scripts features, and schemata features. All these features parallel those of the learner's mental structures and therefore learners are more likely to incorporate, process, and retain information delivered through computers. On this basis, the text portion of the computer program to be designed will be rich in frames and scripts that students could open as they click on the frame.

Burke, Greenbowe, and Windschitl (1998) developed and tested their computer animation package for Chemistry instruction following the contiguity principle. They found that in order to prevent distractions, text and narration should be kept to a minimum, just assisting the learner to grasp the central points of the science event. The authors also report that computer animations sequences that play for 20-60 seconds seem to work best because those are both short and focused. In sum, the main characteristics of the computer package that highlight as important and that will be incorporated in the computer program designed for this study are:

- 20-60 seconds animations
- Accurate Chemistry concept
- Option for accompanying text or audio narration explanations (kept to a minimum)

- Panel with pause, forward, reverse, and exit controls
- Nonlinear navigation
- Interactivity and decision-making
- Feedback

Venezky and Osin (1991) state six reasons for using computer technology in education: 1) because they can model the physical world without dangerous chemicals, vivisections, or expensive experimental apparatus; 2) because they provide access to vast amounts of information from databases; 3) because they can be an integral part of the thinking and problem-solving process; 4) because they can adapt to student learning pace acting as an individualized tutor; 5) because they can deliver instruction to remote places or bring remote information to the classroom; and 6) because they improve visualization of physical processes through a three dimensional effect.

Kulik and Bangert-Drowns (1983) performed an analysis of more than 50 computer-based instructional studies and reported that students increased their cognitive skills as demonstrated through achievement scores and learned in less time than in traditional forms of instruction. One of the advantages of computer use at school is that the program can help the student focus on the essential aspects of the lesson while eliminating irrelevant elements that could distract him or her (Boblick, 1972). The manipulative demands of a science lab in traditional hands-on experiments could disperse students from the central issue under study and could cause intellectual overload, in these cases the computer appears as the best choice to replace the real life experience. Wet labs and the consequent performance of a real experiment may constitute a threatening setting for some students, in which case discovery learning could be stressful. The possibility of a "clean" interaction with a computer could constitute a more amiable environment and hence the computer may indeed contribute to discovery learning much more than the hands-on experience for these students. Computer use saves the students from the awkwardness of wet labs and hence the virtual environments may contribute to increased discovery learning for all students (White & Frederiksen, 1998). Geban, Askar, and Özkan (1992) argue that computer-mediated instruction is a valuable learning alternative that provides reliable data and is less time consuming than demonstrating experiments in the wet lab because there is no need to setting up materials, equipment, and space, waiting for the real-time event, gathering the data, and cleaning up after the experiment. Tamir (1985/86) lists the numerous benefits of computer use that include: calculations, data accumulation and processing, graphing, examination of models of the real world in controlled conditions. To this list, O'Brien and Pizzini (1986) add the advantages of computer for writing research reports using word processing programs. They found that writing science reports using a word processing program was not only less time consuming but also generated better-written reports in terms of spelling, punctuation, organization and design, sentence structure, clarity, and overall quality.

Computer instruction may be more sensitive to individual learning differences because students can progress at their own pace instead of struggling to proceed together with the rest of the class (Carin, 1997; Thorndyke & Summach, 1982). Treagust (1980) argues that computers can be use to eliminate the sex-differences in level of response to basic science concepts and ensure equal opportunities in higher education and employment. Jonassen (1985) claims that computers can support a variety of learning strategies because they store and manipulate lots of information. In addition, computers can better guide learners through the learning process by not allowing him or her to go to the next step until a previous one is resolved. Realistic laboratory experiments on the computer can provide each student with the freedom to choose his/her own learning path and expose the student to a greater variety of material that could better help him/her learn more than in normal school science labs (Smith, Jones & Waugh, 1986).

Data tainted with uncontrolled variables and measurement error are additional problems in laboratory settings that interfere with the attainment of educational goals (Lunetta & Hofstein, 1981; Rivers & Vockell, 1987). Advocates of virtual instruction suggest that computer can bridge the gap between theoretical idealized models and reality (Ronen & Elihau, 2000) and that the sense of immediacy to the learning task offered by the computer is a significant advantage of it over the natural event (Bushnell & Allen, 1967). Moreover, many educationally worth science experiments cannot be carried out at school labs because of costly equipment, dangerous drugs, time involved, fragility or excessive work in setting up equipment (Schwartz & Beichner, 1998) but can certainly be observed and experienced with on a computer. Computers also allow the study of phenomena that cannot be observed directly in real time because they are too slow, too fast, or too hazardous (Smith, Jones & Waugh, 1986) or that cannot be at all experienced at school such as absence of friction or absence of gravity (Carin, 1997; White & Frederiksen, 1998). The power of computer packages is that they allow students to analyze "what if …" scenarios (Schwartz & Beichner, 1998) and that they can observe extreme cases performed in sophisticated science labs and conclude about the behavioral implications of science laws.

Furthermore, Burke, Greenbowe, and Windschitl (1998) pointed that science textbooks and lab manuals present static pictures and diagrams. These representations of science phenomena fail to capture the dynamic nature of the events, a very much distinctive characteristic of Chemistry. Hence, students often have difficulties visualizing and understanding how the Chemistry process occurs. A correct representation of the event is the first step toward conceptual understanding and successful problem solving. The use of computers to display motion offers a mean to help students understand complex Chemistry phenomena mostly because the computer can present the event at the microscopic level which contributes to increased students' concept understanding and performance on exams. Computer graphics also add to the appeal of the instructional material and appear to motivate the learner (Baker, 1983; Baxter, 1995; Merrill & Bunderson, 1982). Use of toxic drugs, manipulation of fragile equipment, and ethical dilemmas related to animal use constitutes no problem in computer demonstrated or simulated labs; the virtual reality presented by the computer avoids these inconveniences.

Aligned with the educational goal of turning students into life long learners, many researchers (Bruner, 1964; Glaser, 1976; Maier, 1971) have early pointed out that instructional opportunities should be made available for students without the need of constant teacher supervision because ultimately, in real life, the student has to function independently from the teacher. In today's technological world, individual learning in out-of-school settings is more likely to occur through computers because computer are more available than science labs in daily life and because science labs involve the risk of handling potentially harmful drugs and equipments. Instruction mediated by computers has the advantage of extending learning opportunities to home or out of school settings when a computer is available as it was done in Ronen and Elihau's (2000) study. In addition, experiments experienced at the science lab require later discussion of observations and conclusions with peers and instructors to achieve full understanding of the event, that is, sound lab work necessarily involves feedback from others and that feedback comes after the experiment is concluded (sometimes even days later). The computer on the other hand, can provide immediate feedback, no third persons involved, which has been reported as one of its major advantages over traditional and hands-on instruction; computer instant feedback could result in more effective learning and less instructor intervention (McDermontt, 1990). According to Ronen and Eliahu (2000), if the instructional program provides constructive feedback, it indeed helps students identify and correct misconceptions at the very moment those appear. In addition, computers can maintain a full record of performance, a sort of formative feedback, to inform teachers of students' progress (Baxter, 1995).

But not all science educators are so enthusiastic about computers in education. Surveys regularly contend that the end result of traditional teaching methods do not significantly differ from technology based instruction (Bangert-Downs, Kulic, & Kulic, 1985). Furthermore, Rivers & Vockell (1987) found that studies examining the effect of computer simulations in science on either scientific or general problem solving ability have provided divergent results. Thomas (1989) has compiled a series of articles with both pro and con views of computers and microcomputers in the school; this compilations shows that contributors are split on their opinions on whether the computer technology is a blessing or a bane as a classroom tool. D'Amico (1990) argues that researchers have had a difficult time establishing whether computer mediated instruction changes the way teachers teach or what impact they have on student learning and achievement. From a more recent and extensive literature review on science instruction using computers conducted by de Jong and Van Joolingen (1998) the authors conclude that there is no clear and univocal outcome regarding students' learning in favor of computer-mediated instruction.

Moreover, some science educators argue, however, that computerized labs should be used only when performing the real experiment would be dangerous, too expensive, would require unavailable equipment, would demand too much time, would involve particular difficulties, or would be too complex causing conceptual overload (Zohar & Tamir, 1986); computer experiments are the second best choice after hands-on experiments (Carin, 1997). Interpreters of Piaget, like Ginsburg and Opper (1969) argue that the introduction of a science concept through a representational media, such as a computer, is not an appropriate substitute for the hands-on experience because the development of logical thinking requires manipulation of real objects.

2.2.3 Empirical research on computer-mediated instruction

Shay (1980) argues that many of the studies that attempt to assess the impact of computer use as a teaching strategy are plagued with methodological faults of validity and comparability.

Boblick (1972) reported that computer labs provided more effective discovery learning than the traditional method of teaching high school physics students. Computer labs have been sown effective also in improving students' understanding of science events (Reed & Saavedra, 1986) and correcting misconceptions (Grosky & Finegold, 1992). Moreover, computer-mediated instruction has been reported as valuable supplement to teachers' instruction in helping students learn problem-solving strategies (Woodward, Carnie & Gersten, 1988).

Buttles (1992) reports a significant improvement on students' immediate and delayed scores after a computer-based lab was implemented instead of previous traditional instruction. He also found that students who learned from the computer used a more sophisticated approach to the subject matter and developed more positive attitudes about learning science. The computer package kindled students' interest in learning other topics through the same media. He also reports that students particularly liked virtual experiments and that progression at their own pace and the possibility of reviewing already learned sections were among the mayor benefits of computer use. Hughes (1974), Cavin and Lagoski (1978), and Hounshell and Hill (1989) also reported improvements on achievement after computer-mediated instruction.

Shay (1980) assessed the advantages and disadvantages of using computer simulations in the classroom and presents criteria for selection of computer material. Snyder (2001) presents a list of student's perceptions about the advantages and disadvantages of using the computer in class.

2.2.4 Conclusion from the literature review on computer-mediated instruction

From all the empirical evidence presented above, as in the case of hands-on instruction, we can deduce that there is no conclusive evidence about the benefits of computer-mediated instruction and certainly a general case for computer use in education applicable to all science topics or to all students cannot be made. It may be, as in the case of hands-on, that the effectiveness of computers for science instruction is affected by a variety of educational and non-educational factors such as previous science achievement, the main predictor of further science achievement (Brookhart, 1997; Gamoran & Hannigan, 2000; Kuyper, van der Werf, & Lubbers, 2000 among others) and a factor that will be used as a blocking variable in this study, prior experience and attitudes of students towards computers (Ronen & Elihau, 2000), gender (Choi & Gennaro, 1987), other individual differences, the topic under study (Rivers & Vockell, 1987), the software used (Rivers & Vockell, 1987), etc. Moreover, computer programs are continually being developed, many of them are improved versions of previous ones in light of advances in educational technology (White & Frederiksen, 1998); hence, old studies' results may not apply to new programs and new research is needed.

As mentioned earlier, the effectiveness of an instructional technique such as computer mediation, needs to be compared to other available methods for the teaching of the same content area (Shay, 1980). The research presented above, compared computer-mediated instruction to traditional teaching but computer science demonstrations may better be assessed against hands-on, and there are not many reports in the literature with such comparisons.

2.3 COMPARISONS BETWEEN HANDS-ON AND COMPUTER-MEDIATED INSTRUCTION

As stated earlier in Chapter I, in the whole area of Chemistry little assessment of learning has been conducted (Bowen, 1998). It is not surprising that that the number of empirical studies comparing learning under different conditions in a Chemistry content topic is very limited. Furthermore, some studies (for example DeClercq & Gennaro, 1987; Ronen & Elihau, 2000) do not compare one method vs. the other, rather they study the added value of supplementing hands-on instruction with computer instruction.

DeClercq and Gennaro (1987) report significantly higher score for the experimental group that received computer instruction in addition to hands-on experiences vs. the control group that did not received any kind of supplemental instruction. The question remains whether higher achievements where due to the computer assisting instruction or just a result of more instruction, more time exposed to content in the experimental group.

Ronen and Elihau (2000) examined the role of using a simulation in conjunction with the real phenomena and diagrammatic representation as a potential aid that may help students achieve higher. All students had to perform hands-on experiments but the experimental group could opt for additional instruction using a simulation environment with which they also completed homework assignments. They report an increase in success rate, self-confidence in science, and time on task for students who used computers for science. Further, they found that the use of the computer was a better predictor of students' success than exam's grades. Yet, in their sample of high school students who were asked to perform two difficult tasks in electric circuits, the simulation did not aid learning for about 30% of the students who were either poor achievers, expressed aversion to using the computer, or were very bright and would perform equally well regardless of method. For the remaining 70%, computer usage led to higher achievements and time on task. The increased performance of students might have been due to additional exposure to content rather than the specific instructional method. The study does not indicate whether low achievers used or didn't use the computer at school; it may well be hypothesized that low achievers for whom the difficult hands-on unit (mandatory) was already extremely demanding did not attempt to use the computer. As for homework, there was no possible control casting some doubts about the conclusion of computer not aiding their learning.

During the lab sessions, the computer simulation was available as an optional aid for solving the tasks for the experimental group but the monitors were off and teachers did not mention that students could turn them on. This suggests that the use of the computer could have depended on individual personality traits such as self-confidence (shy students may not turn the monitors on if not explicitly told to do so). The tasks were so difficult that some students harshly expressed frustration, which cast doubts about the validity of research results. Virtual experimentation with computer simulations, however, does not fully reproduce the reality of lab work. It also puts students more exposed to computers at an advantage because it demands advanced computer skills as compared to other forms of computer-mediated instruction, such as videotaped real experiments. This study however can hardly be ascribed as discovery learning because students received theoretical instruction prior to the application tasks. However, this study is extremely worthy in that it suggest that the benefits of using computers in instruction may be associated with individual differences.

Another study that suggests a relationship between instructional technique and individual differences is a PhD dissertation study conducted by Occhhuizzo (1993). He compared achievement of physics secondary students investigating the period of the pendulum. One group of students worked in a complete hands-on environment with stop-watches, manual graphs and calculations. The other group used a microcomputer connected to the pendulum. But that was not the only difference between groups; microcomputer students receive much more written material than hands-on students, could use the word processors on the computer to write the lab reports, and could use more data due to the nature of the program. Occhuizzo's findings indicate increased learning in the microcomputer condition but he consistently notes that the amount of learning was not uniformed for all students, rather some students benefited more than others from the microcomputer and at the same time some students were better served by the manual task while other were disadvantaged.

Other kinds of comparisons involve substituting teacher interaction with student-computer interactions, for example Snyder's study (2001). She conducted a study to compare the extent of learning students of physiological psychology experience under two different teaching methods. The first method was the instructor's primary method of instruction and consisted of lectures followed by demonstrations and discussions. The second teaching strategy also delivered by the same instructor consisted of lectures followed by computer-based demonstrations and Internet discussion groups. Both methods were applied on the same subjects on consecutive classes on related topics (stimulants and depressants). Results suggest that students scored significantly higher on material presented through active teaching without the computer. However, these study not only compared the effect of direct real-life experiences with their parallel on the computer but also the substitution of teacher-led debriefing with Internet group discussions; results then cannot be attributed to just the comparison between hands-on and computer-mediation.

Only few pieces of "true" comparative research were found. "True" comparisons between hands-on and computer mediation means when both groups received equivalent instruction in the physical science (time exposed to content, teacher assistance) so that results could be attribute to the different teaching strategies rather than other factors. The educational level to focus is from upper elementary school to early college levels.

Hughes (1974) found no significant differences in science problem solving ability between students in laboratory, combined computer laboratory, and computer simulation groups.

Moore and Thomas (1983) proposed that science experiments demonstrated or performed on the computer could be a valuable alternative to traditional laboratory activities in secondary science, in fact they argue that lab work is not superior than its counterpart on the computer. Helgeson (1988) reviewed a few comparative studies that included computer-mediation and suggests that microcomputer simulations are at least as effective as hands-on experiences for some cognitive outcomes and may in fact enhance these outcomes when the simulations are sequenced to follow hands-on instruction.

Shaw and Okey (1985) conducted a 10-day study to compare the effects of using microcomputer simulations on the achievement and attitudes of sixth and seventh graders from a rural school where computers were not a novelty. Six science classes from two different teachers were randomly assigned to one of the three experimental conditions: (1) simulations demonstrated by the teacher for the whole class; (2) hands-on instruction with students working on small groups of two or three; (3) simulations presented prior to hands-on activities. Three English and Social Studies classes from yet another teacher served as a control group that received traditional instruction. Achievement was measured as concept identification. Teachers introduced the topic prior to each activity and circulated among groups. The topics to cover during the lessons included observation, hypothesizing, testing, classifying, and data recording. Their findings indicate that achievement in the treatment groups was higher than in the traditional instruction group but there were no statistical significant differences among the three treatments. For attitude, there were no statistical significant differences among all groups.

Smith, Jones, and Waugh (1986) prepared computer lessons that combined videotaped laboratory experiments and computer instruction and compared achievements of samples of college chemistry students exposed to this kind of training versus students exposed to traditional laboratory work. They found that those who experienced computer-based instruction outperformed students in the hands-on condition. They argue that the self-paced lesson and the immediate feedback allowed by the computer are the main reasons for such finding. In their study, they found that students in the hands-on condition were more likely to use rote memorization of any example that came to their mind from the lab manual to explain a specific science phenomenon that was presented to them, even when the example retrieved was in clear opposition to the observation. Smith et al. argue that the ability to closely and immediately relate theoretical concepts to observations is an additional advantage of computer packages, yet they conclude stating that ideally, computer instruction is best when combined with hands-on that could teach students about the difficulties inherent in lab work, refine their manipulative skills, and expose their limitations as experimenters.

Choi and Gennaro (1987) compared the instructional value of microcomputer-based experiments versus the hands-on approach to teach the concept of volume displacement to junior high school students. They selected 128 eight graders who had experience with computers prior to the study and within each class they assigned students to one of the two groups. The computer group completed the task in shorter time than the hands-on group. Post-discussion of the five experiments was conducted for the whole class together as the computer and wet lab activities were parallel. They administer a 20-item multiple-choice test and report that not only both groups learned regardless of the method employed but also both groups performed similarly in test administered immediately following the experience and after 45 days of delay.

Bourque and Carlson (1987) conducted an experiment comparing parallel computer and wet lab instruction on three related units: acid-base titration, equilibrium constant for a weak acid, and Avogadro's number. They split their 51 subjects who had no prior experience with computers into the two experimental conditions and made them work in pairs. The hands-on group received a pre lab tutorial exercise and post lab questions and problems, the computer group did not receive such preparation but they could work many times through the program over within the available time as they took less time to finish the assignment. The computer program did all the calculations for the students. To assess learning, the researchers administered a 10-item quiz composed of five theory-based questions and five problems. They found that hands-on subjects achieved higher scores for the first two experiments and there were no statistical differences between the groups for the third experiment. The authors argue that this last finding is probably due to the fact that the format of the task was so structured that the students in both groups could follow the calculation routine without understanding what was happening.

Rivers and Vockell (1987) argue that peripheral tasks related to traditional laboratory may consume time without developing problem solving skills. They conducted a series of three studies to compare the effects of various simulation programs on scientific or general problem solving development and transfer in high school biology. Experimental students for study 1 were subdivided into guided and unguided groups according to the amount of guidance for the simulation but for studies 2 and 3 only the guided condition was included; the control groups receive traditional instruction with laboratory work. Problem solving skills were measure according to numerous subscales. The students in two studies were inner city, minority, low SES whereas in study three students were suburban, white, and higher SES. Time interacting with content was controlled for both experimental and control groups. For certain subscales of problem-solving, there was no statistical significant differences among the groups but for other subscales, guided students outscored the unguided students in study 1 and in all studies computer simulation students outperformed control students.

Gardner, Simpson, and Simpson (1992) compared the effects of three methods of instruction: use of hands-on activities, hands-on activities in combination with computer-assisted instruction (CAI), and text-based activities, on elementary student achievement and attitude learning a unit on weather. Their results indicate that students receiving a combination of hands-on activities with CAI scored significantly higher on both measures.

Geban, Askar, and Özkan (1992) compared science achievements in chemistry among three groups: a verification hands-on laboratory, a problem-solving hands-on laboratory, and a computer-based experiment. Verification laboratory students scored much lower than the other two groups, problem-solving lab and computer-based, between which there were no statistical differences (although the computer-based group scored slightly higher).

Rosen and Petty (1992) compare performance of physiology undergraduate students exposed to simulation/tutorial sequences vs. hands-on techniques. No statistical significant differences were found.

Baxter (1995) compared the performance of 100 sixth graders on simulated experiments as a valid alternative to hands-on assessment. The students receive hands-on instruction in electric circuits and were also assessed trough hands-on techniques; three weeks later, they were given the computer simulation assessment. Aggregated scores and level of difficulty for the whole group were in both methods comparable but individual scores varied so greatly that there was a low correlation ($r = .35$) and therefore she concluded that simulations are not equivalent to hands-on assessment.

Ayres and Melear (1998) compare science learning (gain scores on connections and concept understanding measured by multiple choice quizzes) of elementary school students aged 8 to 13 interacting with either a simple machine exhibit or a multimedia version of it on a school visit to at a science museum. The two exhibits were similar in attractiveness and holding power of visitors. Their findings not only support increased learning when students interact with the multimedia exhibit over the hands-on exhibit but also suggest a gain score not statistically significant different from 0 when students experience the hands-on exhibit.

2.3.1 Summary

All researchers report learning through both methods but the extent of that learning varies greatly. On the one hand, Moore and Thomas (1983), Shaw and Okey (1985), Choi and Gennaro (1987), and Rosen and Petty (1992) suggest that computer-mediated instruction and traditional laboratory activities are equivalent. On the other hand, Bourque and Carlson's (1987) and Snyder's (2001) studies seem to favor hands-on strategies, demonstrations, and active teaching over computer strategies whereas DeClercq and Gennaro (1987), Rivers and Vockell (1987), Geban, Askar, and Özkan (1992), Occhuizzo (1993), Ayres and Melear (1998), and Ronen & Elihau, (2000) report higher performances for computer-mediated instruction. All these studies measured learning through multiple-choice quizzes but they reach different conclusions. It may well be the case that the effectiveness of the instructional strategy depends, among other factors, upon the topic at hand (solubility and solutions was never studied comparing the two teaching strategies) and mainly the achievement level the students, which is the strongest predictor of further educational achievements as will be detailed below. Therefore studies should be conducted in all areas of the science curriculum, solubility and solutions among others, to determine the best teaching method for each topic for different science achievement subpopulations of students.

2.4 PRIOR ACHIEVEMENT AS A PREDICTOR OF LEARNING

This thesis attempts to find out which of two instructional techniques yields higher academic achievement of students. However, predicting achievement with only one predictor, type of instruction, neglects the complexity of the learning process. Educational outcomes are always complex issues affected by other numerous educational variables, such as age, gender, prior achievement, socio-economic status, attitudes, learning styles, previous exposure to computers, etc. Among all these other factors, there is solid evidence in the literature that prior achievement is most likely the strongest predictor of students' posterior attainments.

Gamoran and Hannigan (2000) used a national survey data of over 12,500 students to examine the impact of high school algebra on college entering students. All students benefited from taking algebra but the effect was smaller for those with very low prior achievement. Many other researchers, such as Brookhart (1997), Johnson and Walberg (1989), Grover and Smith (1981), Miller and Ellsworth (1979), Rodriguez (1996), BouJaoude and Giuliano (1994), Jensen (1989), and Touron (1987), also report prior achievement as a strong predictor of posterior student achievement.

When comparing prior achievement to other predictors of academic success, still prior achievement results among the strongest ones. Kuyper, van der Werf, and Lubbers

(2000) examined educational attainment of 2,038 Dutch secondary school students and found that motivation, student background and prior achievement were stronger predictors than metacognition and self-regulation. House, Hurst, and Keely (1996) studied 335 undergraduates enrolled in introductory psychology courses and found that prior academic achievement was the single predictor variable of whether students earned satisfactory grades. Reynolds and Walberg (1992) tested a structural model of mathematics achievement and attitude with a sample of 3,116 adolescents from the Longitudinal Study of American Youth. They concluded that prior achievement and home environment influenced subsequent achievement most powerfully. Lunt (1996) attempted to identify variables for predicting academic success in electronics; his results indicate that student's prior success in math and science in high school is a good predictor of their success in college. Case and Richardson (1990) studied 28 educational variables as predictors of graduates and non graduates attainment; their findings indicate that the optimal predictors of grade point average and completion of the program were previous academic success, ethnicity, and gender.

Specifically in the area of chemistry, Chandran, Treagust and Tobin (1987) investigated the role of four cognitive factors, formal reasoning ability and prior knowledge among them, on achievement in high school chemistry for students who followed the same curriculum. They measured learning by tests of lab application, chemical calculations, and content knowledge and report the significance of prior knowledge and formal reasoning ability on achievement. More recently, House (1994) investigated the relationship between students' achievement expectations and academic self-concept and their subsequent achievement in college chemistry. His findings suggest that students' academic self-concept and achievement expectations are significant predictors of overall grade performance but prior achievement was the only significant predictor of high-grade performance.

2.5 SOLUBILITY AND SOLUTIONS

As stated before, there is not as much literature on students understanding of solubility and solutions as there is on other areas of the science curriculum. Gennaro (1981) tested 385 eleven graders and reports conceptual difficulties in solving problems related to solubility and computing solutions' concentrations. He hypothesized that some of the difficulties may involve the use of several variables in the problem (quantity of solvent and of solute, temperature) and/or the need to apply proportional reasoning. Gennaro calls for more research on the topic to better determine the nature of the conceptual difficulties that students experience, in particular research with students that follow a different curriculum than the I. P. S. used by his subjects. The second published report by Longden, Black and Solomon (1991) found that students in junior high school still hold naïve ideas about the process of dissolution such as the disappearance of the solute and the non-homogeneity of the resulting solution. The authors contend that these ideas change as a result of instruction on the particulate nature of matter.

Another piece of research by Abraham, Grzybowski, Renner, and Marek (1992) investigated the understanding of dissolution of 247 eighth graders who were also to solve related problems. They found that the average level of understanding was 2.40 out of 5 (2 = partial understanding with specific misconception; 3= partial understanding). No student referred to the microscopic level (atoms, molecules) to explain the phenomenon. 34% of students showed no understanding and other 34% showed partial understanding. Misconception regarding the solubility process referred to chemical changes, phase change, and density of solute.

Abraham, Williamson and Westbrook's (1994) research involves a cross-age study of persistent students' misconceptions of the solution process after instruction. They conducted an ANOVA designed and reported marginal significance for the effect of reasoning ability (four levels) on understanding of the concept (five levels). The combined score on understanding of dissolution for all the levels of reasoning ability for junior high school students was 2.09 and for high school students 2.70 of a possible total of 4 (2 = partial understanding with specific misconception; 3= partial understanding). From tests given to one hundred junior high students and one hundred high school students, the authors identified the following misconception: (a) sugar particles floated or sank to the bottom of the beaker instead of evenly mixing (9% of junior high students and 17% of high school students); (b) the sugar undergoes chemical change into a new substance (6% junior high students and 8% high school students); (c) sugar breaks down into its ions or elements (4% among junior high students and 4% among high school students); (d) the sugar undergoes a phase change, melts or evaporates (5% among junior high students and 3% among high school students); and (e) water absorbed the sugar (1% in junior high and 4% in high school). They also report that often the terms "solute" and "solvent" were used interchangeably and that the use of terms such as "atoms" or "molecules" (not included in the wording of the test) increased with age (13% in junior high and 30% in high school). However, these last terms were not always correctly applied, and some students even referred to “sugar atoms".

Ebenezer and Erickson (1996) identified six categories of explanations of solubility given by thirteen grade 11 students. They conducted short clinical interviews in which students had to introduce a cube of sugar into a beaker containing hot water (task 1), pour alcohol into a beaker containing water (task 2), and observe a closed bottle containing a saturated solution of table salt with recrystallized salt settled out in the bottom. Students had to perform the tasks and after each task the interviewer asked them a few questions to elicit their understanding of the phenomenon. The six categories involved in explaining solubility were: (a) physical transformation of solute from solid to liquid: some students even called “melting” to the dissolution process their were observing, (b) chemical transformation of solute: either by reacting with the solvent or by occupying the “air spaces in water”, (c) density of solute: if lighter it “goes up”, if heavier, it “goes down”, (d) amount of space in solution: if it is not enough, there is no dissolution, (e) size of solute: small particles, like those resulting from braking substances by heating them up, will dissolve better, and (f) property of solute, including the need for a “special element” in the solute that makes it to mix well with water, and the pure nature of the solute which in crystal state does not get dissolve in water. Ebenezer and Erickson argue that in explaining solubility, students draw from their everyday experiences much more than on formal instruction and extend properties and behavior from the macroscopic world into the microscopic world. This study brings some new insights into identifying students’ ideas of solutions, however further research is needed to validate and generalize this phenomenography obtained from only thirteen subjects in one school.

3.0 CHAPTER III: METHODOLOGY

This study involved a comparison of two learning methods: computer-mediated instruction vs. hands-on experiences. Different students, blocked according to their level of prior school science achievement, were exposed to one of the two methods and their learning of the topic, in terms of concept understanding and development of problem solving, and total learning, was assessed during and immediately after instruction. Also, students' conversations were audio-taped in order to better understand the possible causes of any differential learning.

3.1 RESEARCH QUESTIONS AND WORKING HYPOTHESES

The specific research questions presented in Chapter I are:

When middle school students are exposed either to hands-on science or computer-mediated instruction,

1) For each of the three dependent variables (understanding of the concepts of solubility, problem-solving skills, and total learning), are there any significant interactions between instructional method (hands-on and computer mediated instruction) and prior science achievement (high, middle, and low)?

2) a) If no interaction exists for understanding the concept of solubility,

which instructional method better promotes learning?

b) If no interaction exists for problem-solving skills, which instructional method better promotes learning?

c) If no interaction exists, which instructional method better promotes overall learning?

3) What are the kinds of pair students' conversations elicited by each instructional technique: hands-on and computer-mediated instruction during performance of the tasks? Do these conversations revolve around the content, the process, manipulative demands of the task, features of the computer package, or other issues? How long do these conversations last? Is there collaborative learning, tutoring, or dominance of the more capable student of the pair?

To address these research questions, students in both groups filled out end-of-class practice worksheets and an end-of-unit exam that assess deep understanding of the concepts and application of those to solve problems. The end-of-class worksheets constitute a measurement of immediate learning and the end-of-unit exam is a measure of delayed learning at the end of the week. The worksheets and the exam contain multiple-choice, short-answer, and open-ended questions as well as problems. Multiple-choice and short-answer questions assess concept understanding whereas open-ended questions and problems assess concept understanding and problem-solving. The problems used in this study were identification of substances and designing of an experiment. The practice worksheets are included in Appendix A and the end of unit exam in Appendix B.

My working hypotheses were that on the one hand, the noisy environment and manipulative demands of the hands-on science lab with the additional reading demand of the lab manual may prevent students from receiving simultaneous visual and verbal stimuli which may be detrimental for low achievers. For these students then, the computer approach may work better. However, to the extent that hands-on technique, which per sec involves more physical activity than the computer approach, invited more verbal engagement and peer negotiation of meaning, that may compensate for the great demands of hands-on on low achievers. These students would then receive more peer scaffolding in the hands-on condition and similar visual and verbal stimuli. Therefore, if indeed hands-on contributes to more meaningful verbal engagement, then that would be the preferable strategy for low achievers. For high achievers, because of the increased ability, I hypothesized that the differences between conditions will tend to become smaller but yet, the benefits of interacting with real objects in the hands-on approach still rendering higher learning outcomes.

In statistical terms, my research question could be formatted as follows.

Question 1: Test for interactions between type of instruction (hands-on and computer-mediated instruction) and students' ability level (high, medium, and low):

H_0: all interactions = 0

H_a: all interactions $\neq 0$

Question 2: Test of main effects of type of instruction:

H_0: $\mu_{HO} = \mu_{CM}$

H_a: $\mu_{HO} \neq \mu_{CM}$

Question 3: The hands-on condition requires students to be more physically, not only intellectually, engaged in the tasks. For these reasons, I expected students in hands-on condition to converse mostly around the physical setting, manual requirements of the tasks, materials and equipment, experimental process, and results of the experiments. For students in computer-mediated condition, I expected students to converse mostly around computer usage and results of the experiments. I also hypothesized that these conversations would be longer for students in the hands-on condition because the completion of the task demands longer time. Because the intellectual demands of both hands-on and computer mediated instruction are equivalent, I expected to find similar collaboration and tutoring between the students in small groups regardless of the condition.

This chapter addresses the issue of research design, which includes sample of students, treatment, measurement, experimental design, and statistical tests.

3.2 RESEARCH DESIGN

3.2.1 Basic layout of the study

In this research, one group of students worked in the science lab on a hands-on unit on solubility and solutions performing scientific experiments in real life, handling equipment. The other group of students worked on a parallel unit in a computer-mediated learning environment, they did not perform real life experiments, rather they watched them on the computer screen. During the execution of experiments, either in the lab or on the computer, the students working in small groups wrote down the results and conclusions of the experiments. Once the experiments were concluded, students reviewed the definitions and examples contained in the booklet (for both groups) and/or on the computer (only for the computer group), and filled out worksheets to assess their immediate learning. Students filled out the worksheet individually but they were allowed to discuss them with peers. The booklets given to the computer group were the same as those given to the hands-on group. Results from experiments and worksheets were part of the data collected in this research. Another portion was scores on the end-of-unit exam and yet a third portion of the data of this study was students' conversations.

Hands-on activities can be very demanding of students who have to incorporate knowledge at the same time they manipulate variables and use equipment (Tamir, 1989). If the students work in small groups, the hands-on task may be less overwhelming. Indeed, small group work is a much recommended and most common practice in school science as can be shown from the pieces of research reviewed in Chapter II.

The hands-on group received a few minutes of instruction from the teacher the first day where they were shown how a solution looks as opposed to precipitate at the bottom on the flask. The computer group received a similar tutorial at very beginning of the content unit, before Activity 1 that taught them how to use the computer program and what to look for in the test tubes. The hands-on group performed real-life experiments while the computer-mediated group watched those experiments videotaped on the computer's screen. It was hypothesized that the setting up of the experiment would be much more time-consuming than just watching it on the computer, and hence the hands-on group would be exposed to handling the equipment for longer periods of time. To compensate for that, the computer group was allowed to watch the experiment over and over again as they pleased and students in this group were also able to stop the videotape at any time during the experiment.

The lesson plan and content-unit are detailed in Appendix A and takes four classes for completion. Figure 3 compares the two treatment groups.

The goal of the whole unit is deep learning of solubility and solutions in terms of concept understanding and problem solving skills. Immediately after instruction and at the end of the week, all students were given the same questions to work on and scores of hands-on students were compared with scores of computer students. The final exam, which took one class period, was composed of multiple choice and short-answer questions (to assess understanding) as well as open-ended questions and problems (to assess understanding of concepts and problem solving skills). The practice worksheets and the exam were validated by a number of experts (science teachers, a science education instructor, and a chemistry professor).

Also, students were audio-taped non-intrusively. A sample of audio files of students' conversations were transcribed and analyzed for time on task, time devoted to the performance of the experiment, time devoted to reading definitions and examples, time to complete the worksheet, amount of verbal exchange between subjects, observations, discussion of results, misconceptions, reference to daily life examples, explanations provided between subjects, and motivation comments.

	Hands-on	Computer-mediated
Content-unit	Same	Same
Students groups	Small groups of 2	Small groups of 3
Teacher instruction	Tutoring on demand	Tutoring on demand
Experiments	Performed once in real life manipulating real objects	Viewed on the computer screen, as many times as desired. Possibility of stopping the experiment any time during performance. Virtual objects. No manipulation
Experimenter	Students	Somebody else on computer videotape
Results and conclusions of the experiments	Written individually on a booklet (paper-and pencil)	Typed per group on the computer
Definitions and examples	Contained in the booklet	Contained in the computer program and in the booklet
Practice worksheet	Paper and pencil	Paper and pencil
Exam	Individual, paper and pencil.	Individual, paper and pencil.
Analysis	Results from experiments, scores on worksheets and exam, conversations.	Results from experiments, scores on worksheets and exam, conversations.

Figure 3: The treatment groups

3.2.2 Target population

According to Piaget, it is at the middle school age, when students have not yet developed formal thought, that the manipulation of concrete objects (wet lab activities) particularly results in the development of logical thought (Hineksman, 1973; Karplus, 1977; Lawson & Wollman, 1976). It follows that it is reasonable to use as subjects for this study the middle school student population. Middle school children are most often classified as concrete operational, they tend to solve logical problems through direct experiences (Shaw & Okey, 1985); at this age, formal thought only begins to appear, and children began to use hypothetical reasoning based on logic of all possible combinations and to perform controlled experiments (Inhelder & Piaget, 1958). This gives further support to targeting middle school students to assess first stages in the development of experimental design skills, the ability to use equipment in the design of scientific experiments.

In addition, younger children, elementary schoolers, are reported to not have yet developed the basic reasoning skills to grasp the concepts behind the topic and older students, in high school, may have already studied the topic of solubility and solutions.

Further, in a meta-analysis conducted by Lott (1983), he concluded that the hands-on strategy had its most marked and positive effect at the intermediate level as compared to other educational levels and is more useful for developing higher thinking. It is then, this level of schooling that may better show any differential effect when compared to other instructional methods. Hence, the middle school students are the appropriate target population of this study.

3.2.3 Blocking variable

As expressed earlier, the demands of a wet lab may be different for students of diverse abilities (Occhuizzo, 1993; Ronen & Elihau, 2000). In fact, Tamir (1989) reports that the careful attention required at the science lab could be particularly overwhelming for low achievers. Prior school achievement is an ineludible variable in a study of students' academic attainment. At the middle school level, Reynolds (1991) argues that prior achievement had the highest dominant influence in schooling process over other variables including parental expectations, motivation, and classroom context and Ma and Douglas (1999) report that prior achievement plays a more important role than attitude or socioeconomic status in students' drop-out rates.

Prior achievement level was also an important variable in Ronen and Elihau's (2000) study. They found that the computer aids learning for most students except for those who were either very bright (they would perform equally well regardless of instruction type), poor achievers (with insufficient understanding of the domain), or students who expressed aversion to using the computer.

In conclusion, at the middle school level, prior academic achievement is the most relevant variable that may affect study results and hence it was included in the statistical analysis.

3.2.4 Treatment groups

The two groups that were compared in the study were similar in all educational relevant variables prior to the treatment; that is, other than differing in the treatment and individual differences of students, both groups shared the same prior educational experience: the same teacher, the same previous instruction received, the same textbook used, the same school environment, etc. Therefore, the research design for this study involved the splitting up of each grade level (6^{th} and 7^{th}) into two groups and each group was exposed to a different treatment: hands-on or computer-mediated instruction.

For the sampling procedure, each grade level (6^{th} and 7^{th} graders) was divided into three approximately equal size groups according to students' science grades: high achievers, medium achievers, and low achievers. This addressed the individual differences of students. One of the two 6^{th} grade classes and one of the two 7^{th} grade classes were then randomly assigned to one of the two conditions: hands-on or computer-mediated instruction. I obtained then a 3X2 design.

3.2.5 The outcome variables

Previous research has extensively used paper-and-pencil techniques to assess students' learning in terms of concept understanding and acquisition of problem solving skills as described in Chapter II: Literature Review (see for example Glasson, 1989; Shymansky, Hedges, & Woodworth, 1990; Stohr-Hunt, 1996 among many others).

As expressed earlier, the subjects of this study were not exposed to instruction in solubility and solutions prior to this treatment. Thus, it would seem unreasonable to suspect that some students would be significantly more knowledgeable on the topic than others at the start of the unit and therefore there was no need for a pretest in this study -- the students would score low and only by guessing. In addition, a pretest necessarily similar to the posttest might give away some hints for the posttest making it a less reliable measurement instrument for the study. Hence, a posttest only design was used in the study.

Within the course of instruction, at the end of each class, students responded to practice worksheets. This constitutes the set of immediate learning scores. In addition, they took an end-of-unit exam at the end of the week and these scores constituted the delayed learning measurement. The exam included multiple choice questions and open-ended questions. The purpose of the concept questions is to measure students' understanding of solubility and solutions whereas the purpose of the open-ended questions is to measure students' acquisition of problem solving skills (which necessarily includes concept understanding as well).

Therefore, from each student's responses, two sets of two scores each were extracted, each addressing the two measurements of learning adopted in this study: concept understanding, and acquisition of experimental design skills, immediately after instruction and delayed at the end of the week. The two immediate scores for concept understanding and for problem solving were combined to give a composite measure of immediate learning and in turn the delayed measurements were combined to obtain a composite measure of delayed learning.

The whole content unit, including conclusion questions and exam to be scored, was designed by the researcher based on school science textbook end-of-chapter questions and problems and validated by four experts (two science teachers, one science teaching instructor, and a faculty member from the chemistry department).

3.2.6 Treatment

Because the target population of this research is middle school students who are exposed to the topic for the first time, the kind of learning that these students may experience is not at a sophisticated level. As expressed earlier, these students may not have yet developed formal thought and therefore the unit to be learned had to be kept as simple as possible.

The researcher had to develop the computer component because suitable computer programs were unavailable. Caprico and Brown (1985/86) conducted a survey of science microcomputer programs suitable for secondary school. They found that 73 percent of software were related to physical science (38 percent in physics and 38 percent in chemistry) and form those, less than 1 percent were appropriate for middle school age children and the great majority were drill and practice, simulation programs constituted only 15 percent of the total available software. Nuccio (1990) examined educational software and tutorials for classroom application and found that the majority were poorly constructed and actually thwarted the objectives of the lesson. I examined more recent computer software (Organic Reaction Animations, 1998; Physical Chemistry 6.0, 1998;

Spectool Teaching Version, 1997; Computer Programs for Physical Chemistry, 1998; Chemistry in Motion, version 1.0, 1997; among others) and found that they were either too commercial with a lot of fancy colors and figures that could distract middle school students, too advanced for middle school students, or presented experiments that could not be paralleled in the science lab. For these reasons, existing programs could not be used in this study. Hence, I developed both the hands-on and the computer-mediated instruction units suitable for the study.

The hands-on unit, shown in Appendix A, is a guided-inquiry lesson (Domin, 1999) on solubility and solutions, adapted from selected school science textbooks, Science Interactions – Course 1, Science Directions 8 and Mixtures and Solutions from the Foss series. The computer-mediated unit parallels each step of the hands-on experience and both are kept at a simple level. The computer component was designed in such a way as to present verbal and visual information concurrently instead of successively -- the visual and verbal systems of the student then would process the information at the same time and referential connections would be established. It is argued that in this manner there is higher development of learners' problem solving skills (Mayer & Sims, 1994). In addition, the researcher selected some of the features recommended by Burke, Greenbowe, and Windschitl (1998) for the computer unit. The selection of features was made on the basis as to render a unit that would closely compare to the hands-on one and include:

- 20-60 seconds clips (one for each step of the procedure)
- Accurate Chemistry concept
- Option for accompanying text or audio narration explanations

- Panel with pause and exit controls
- Option to jump (forward or backwards) to any step in the procedure
- Text and narration kept to a minimum (text same as the hands-on group, narration reading the text)
- Some small degree of interactivity

3.2.7 Statistical Analysis

First, the equivalency of the groups in terms of prior achievement, grade level, and gender was assessed through a series of Chi-Square tests.

The statistical procedure used in this research was a 2X3 two-factor ANOVA for each of the three outcome variables: concept understanding, problem solving, and total achievement at both the immediate and delayed level. I estimated that in order to conduct the interaction tests with power of approximately .50, at alpha level of .05, and for a large effect size, I would need at least 13 observations per cell (n).

In addition, the sample of 34 (18 hands-on files and 16 computer-mediated files) out of 80 students' conversations transcripts was submitted to analysis. The selection was at random within each of the four activities (Monday through Thursday) and within the two conditions hands-on and computer-mediated instruction. For this content unit, students worked in mixed ability groups, selected by the teacher based on social interactions of students. It was not possible for example, to have groups of all low achievers working together to compare with groups of all high achievers, and also all medium achievers groups, etc. For the hands-on condition, where the students worked in pairs, the total possible combinations were 6, but for the computer-mediated conditions the total possible combinations were 18; the analysis of conversations by achievement level would get unwieldy. In addition, the sample size selected for analysis was not big enough to provide a good number of transcripts per achievement level as to conclude accurately. Instead, whole group comparisons were performed between hands-on and computer–mediated conditions.

At a first level of analysis, from the audio recordings the following data was extracted: time spent on performing the experiment, time doing the practice worksheet, total time for completion of the lesson, number of words per unit time (minutes), and number of comments per unit time (minute), number of procedural comments (statements that refer to actually doing the experiment or operating the computer), observations and explanations as defined by Chi, de Leeuw, Chiu, and LaVancher (1994) "any utterance that went beyond the information given, namely, an inference of new knowledge … excluding monitoring statements, paraphrases, comprehension, or bridging inferences" (pp. 454-455). Explanations could be partial or explicit. Potential partial explanations would be in the form of discussion of results and observations: when students talked about the findings of their experiments or offered a statement that did not directly derive from the study material. Explicit explanations are complete statements where the students articulate possible reasons for phenomena or logic of a definition. A comment refers to each instance of a person's talk. The numbers of words and comments had to be computed per unit time because not all recordings lasted the same. Independent sample t-tests were performed to compare hands-on and computer-mediated groups. Other dimensions noted from transcripts were misconceptions, collaborative learning, and curious remarks.

The classification of statements as: on or off task, procedural comment, observation, or explanation was performed by two coders who reached 87% agreement.

3.2.8 Fidelity of Implementation

To control for variations in the kind of instruction delivered, all groups of students received instruction from the same teacher and at the same school during the same week of classes. The teacher was provided with detailed lesson plans to follow (included in Appendix A) and had several meetings with the researcher to assure that no group (hands-on and computer-mediated) received more scaffolding than the other. Finally, the researcher observed all classes to verify fidelity of implementation.

4.0 CHAPTER IV: RESULTS

This chapter presents the results of the study: final sample used, statistical analyses of the outcome measurements, and the analysis of students' conversations.

4.1 FINAL SAMPLE

Middle school students (from the 6th and 7th grades) from a small private school in Western Pennsylvania were selected for this study. Students from 8th grade were excluded from the study because they had some prior knowledge of the content-unit. All students in the study had prior experiences with computers and with lab experiments but no prior knowledge of solubility and solutions concepts and terms. Within each grade level, the school randomly distributes the students into two classes, no tracking of students of any kind. The two 7th grade classes were conducted in mid and late morning: the first class was assigned to the computer-mediated treatment and the second class the hands-on treatment. The two 6th grade classes were conducted in the early afternoon: the first one received hands-on treatment and the last one received computer-mediated treatment. All the classes in this study were conducted in the science lab, the usual location of regular science classes. For the computer condition, laptop computers were brought to the science lab. The same teacher taught all classes.

The study was conducted over a week of classes early in the school year. Prior grades for 6th grades and 7th were provided in percentages but the distributions were different. The grades for each class level were given by different teachers who used different scales of measurements: prior science grade for 6th graders was the average of the last three science achievement tests in 5th grade whereas prior science grade for 7th graders was their prior year science score.

Because of the different distribution of scores for 6th and 7th graders, based on different measurements of prior achievement, the formation of achievement level groups (high achievers, medium achievers, and low achievers) was performed separately for each grade level and then combined. Three approximately balanced groups of high achievers, medium achievers, and low achievers were formed according to prior science grades for 6th graders. A similar procedure was followed for 7th graders and then, all high achievers, medium achievers, and low achievers were combined together to form the three achievement level groups (perfect balance design was not possible to obtain because the number of students in each class differed slightly).

It is important to comment here about the particular features of the school where the study was conducted. This was a university lab private school, with a very selected population of students of middle and middle upper level highly educated families. The school adopts an educational philosophy based on latitude and choice; students who do well in this school (high achievers in this study) are students who not only are academically talented but also students who can successfully manage lack of structure. Conversely, students who struggle in this school (low achievers in the study) are students who may perform much better in other more structured learning environments.

From an initial pool of 64 students, one student had to be excluded from the study because her parents did not consent to her participation. Five students were new to the school so their prior grades were not available (even if they were, they would have been yet on a different distribution not comparable to the prior grades of the other students); hence, they could not be assigned to any achievement level group and had to be excluded from the study. There were two students who were absent two of the four days of treatment (Monday through Thursday) and were excluded from the sample. The students were aware that the content unit was part of a research study and that their performance in this content unit would not directly affect their school grades. Hence, on occasion, a few students did not collaborate. The decision adopted in this research was to include all practice worksheet and exams where the students wrote at least one word and to exclude documents where the student did not write at all. This resulted in the exclusion of one student's paper for immediate problem solving measurement and consequently total learning and three exams. The final distribution of students in the study is presented in Table 1.

Table 1: Distribution of Students

	CM	HO	Total
Low achievers	10	8	18
Medium achievers	9	11	20
High achievers	8	9	17
Total	27	28	55

A Chi-Square test of association was performed to verify that there was no association between group affiliation and treatment; no significance was detected (Chi-

Square = .463, p = .793). Because of the way in which groups were formed, there was also no significant association between achievement level and grade. The six cells also exhibited no significant association between condition and grade level (Chi-Square = .067, p = .796). Finally, association between condition and gender was tested and found not significant (Chi-Square = 1.111, p = .292). Therefore, these groups were deemed appropriate for the study.

Students worked in pairs for the hands-on condition and in groups of three for the computer condition because of the number of computers available. The same groups were kept throughout the week. The teacher formed the groups based on social interactions of students.

The classroom was staffed with a head teacher who provided assistance to students as needed and reported no differences in the assistance provide to any group (HO vs. CM), an intern teacher who only provided limited assistance to students, and the researcher as an observer who set up the computers and lab material for the students but did not interact with the students at all. The classes progressed in the following manner: on the first day (Monday) the students performed their experiments, wrote their results and conclusions, and filled in the practice worksheet. The next day, the teacher provided a few minutes of general debriefing on the previous day's concepts and terms for the whole class and students were instructed to correct their answers to the worksheet. Then, they proceeded with the lesson of the day. This sequence of instruction repeated for the four days of treatment except for the last day when the teacher reviewed briefly all the topics, not only the previous days'. Hands-on and computer-mediated groups received similar teacher lecturing.

4.2 MEASUREMENT OF LEARNING

Two persons, the researcher and one collaborator, independently classified the questions on the worksheets and the exam as either assessing concept understanding or problem-solving. Both persons have a degree in Chemistry and extensive teaching experience. The classification criterion used was as follows: (a) concept understanding items: questions where students had to rephrase a definition in their own words, give examples, apply a concept to a new situation, or explain a phenomenon; (b) problem solving items: questions where students were presented with an unresolved scenario for which they had to develop a strategy to use and find a solution. The two coders had an agreement of 100% in the classification of questions. Classification of items is shown in Appendix C.

Two other persons, the researcher and another collaborator, scored the worksheets and the exam. Both persons have degrees in Chemistry. The scoring rubric appears in Appendix C. Scoring agreement was 90% for immediate learning scores and 87% for delayed learning scores. Disagreements were discussed and resolved.

There was one blocking variable, achievement level (ACH_LEV when used for immediate learning measurements and ACH_EXAM when used for delayed learning measurements) and six outcome variables: AV_IM_CU, IMM_PS, AV_IM_TO, DEL_CU, DEL_PS, and EXAM_TOT that measured immediate and delayed learning of concept understanding, problem solving, and total learning (a composite measure of the former). To compute immediate learning scores, worksheet scores were averaged over 3 or 4 days depending on whether the student was present the four days of treatment or absent one day. Because the possible maximum score on each day was slightly different, daily raw scores for concept understanding were rescaled before averaging them. The immediate problem-solving score was evaluated on a single scale (on Tuesday) and therefore needed not to be rescaled for its independent analysis. However, the immediate problem solving score had to be rescaled to combine with the immediate concept understanding score to obtain a composite measure, the total immediate learning score. For delayed measurements of learning, independent measurements of concept understanding and problem solving were rescaled to obtain delayed total score.

For immediate learning measurements, students who were present at school at least three days were entered in the analysis. This resulted in the above presented sample of 55 students. However, for delayed measurements of learning, only students who were present the four days of treatment and collaborated were entered into the analysis, resulting in a sample of 35 students. It was hypothesized that if a student was absent on a certain day, his/her performance on the pertinent question of the exam would be poorer due to not being in class rather than to treatment or group affiliation. That poor performance on certain items would introduce noise into the analysis. A smaller sample size was preferred over a larger one with noise.

4.3 RESEARCH QUESTIONS

Correlation tests between prior science grade and the six outcome variables were run separately for the 6th and 7th graders. The obtained correlation coefficients ranged between .4 and .6. A two-way ANOVA with prior science grade as a blocking variable was conducted. ANOVA tables and graphs for the six dependent variables are shown below. Post hoc power was computed using alpha = .05

Table 2: ANOVA for Average Immediate Concept Understanding[2]

Descriptive Statistics

HO/CM	ACH_LEV	Mean	SD	N
CM	1	6.52	1.79	10
	2	6.56	2.17	9
	3	8.28	1.38	8
	Total	7.05	1.93	27
HO	1	5.17	3.34	8
	2	7.52	2.92	11
	3	9.30	1.78	9
	Total	7.42	3.11	28
Total	1	5.92	2.60	18
	2	7.09	2.59	20
	3	8.82	1.64	17
	Total	7.24	2.58	55

Source	SS	df	MS	F	p	Power
Condition	.610	1	.610	.111	.740	.062
Achievement level	76.062	2	38.031	6.940	.002	.909
Condition x Achievement level	16.340	2	8.170	1.491	.235	.303
Error	268.509	49	5.480			

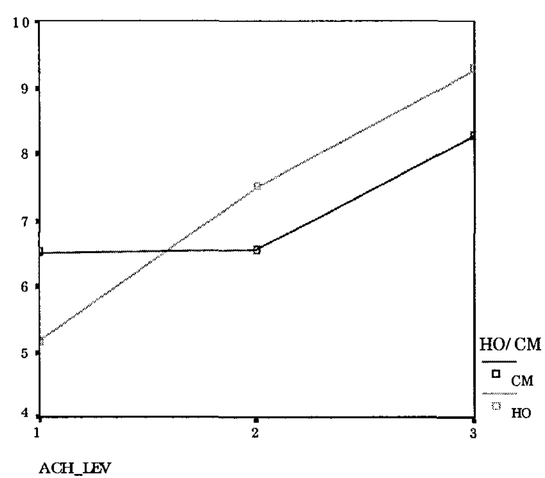


Figure 4: Cell means of average immediate concept understanding

[2] Maximum possible score = 12

Table 3: ANOVA for Immediate Problem Solving[3]

Descriptive Statistics

HO/CM	ACH_LEV	Mean	SD	N
CM	1	2.30	1.70	10
	2	2.00	1.41	8
	3	3.13	2.23	8
	Total	2.46	1.79	26
HO	1	2.00	1.69	8
	2	2.73	1.68	11
	3	3.11	1.83	9
	Total	2.64	1.73	28
Total	1	2.17	1.65	18
	2	2.42	1.58	19
	3	3.12	1.97	17
	Total	2.56	1.75	54

Source	SS	df	MS	F	p	Power
Condition	.252	1	.252	.081	.778	.059
Achievement level	8.938	2	4.469	1.430	.249	.291
Condition x Achievement level	2.557	2	1.279	.409	.667	.112
Error	150.046	48	3.126			

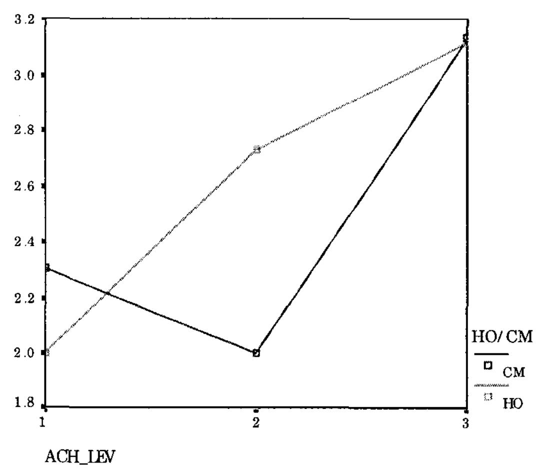


Figure 5: Cell means of immediate problem solving

[3] Maximum possible score = 6

Table 4: ANOVA for Immediate Total Learning[4]

Descriptive Statistics

HO/CM	ACH_LEV	Mean	SD	N
CM	1	11.12	4.70	10
	2	10.76	4.09	8
	3	14.53	5.29	8
	Total	12.06	4.83	26
HO	1	9.17	6.65	8
	2	12.97	5.83	11
	3	15.52	4.73	9
	Total	12.71	6.09	28
Total	1	10.25	5.56	18
	2	12.04	5.16	19
	3	15.06	4.87	17
	Total	12.39	5.48	54

Source	SS	df	MS	F	p	Power
Condition	2.373	1	2.373	.085	.772	.059
Achievement level	212.111	2	106.055	3.796	.029	.664
Condition x Achievement level	41.275	2	20.638	.739	.483	.168
Error	1341.134	48	27.940			

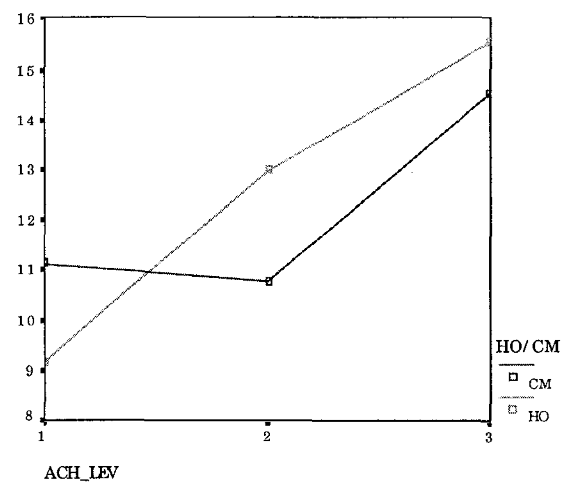


Figure 6: Cell means of average immediate total learning

[4] Maximum possible score = 24

Table 5: ANOVA for Delayed Concept Understanding[5]

Descriptive Statistics

HO/CM	ACH_EXAM	Mean	SD	N
CM	1	5.06	1.40	8
	2	5.25	1.33	6
	3	5.50	2.29	3
	Total	5.21	1.45	17
HO	1	2.33	1.53	3
	2	5.79	.99	7
	3	7.88	1.81	8
	Total	6.14	2.45	18
Total	1	4.32	1.86	11
	2	5.54	1.14	13
	3	7.23	2.14	11
	Total	5.69	2.05	35

Source	SS	df	MS	F	p	Power
Condition	.027	1	.027	.012	.915	.051
Achievement level	39.786	2	19.893	8.667	.001	.952
Condition x Ach. Level	29.364	2	14.682	6.397	.005	.869
Error	66.564	29	2.295			

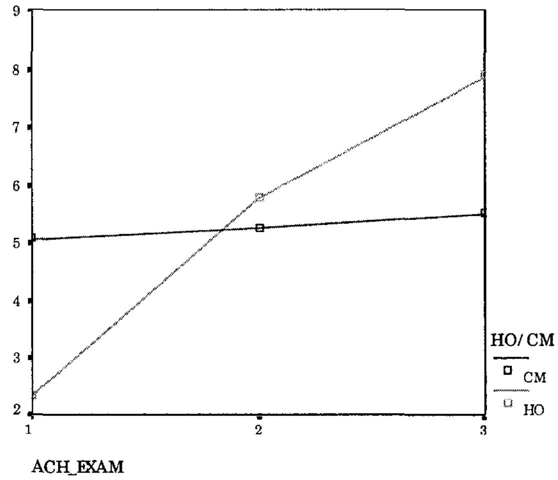


Figure 7: Cell means of delayed concept understanding

[5] Maximum possible score = 9

Table 6: ANOVA for Delayed Problem Solving[6]

Descriptive Statistics

HO/CM	ACH_EXAM	Mean	SD	N
CM	1	3.56	.18	8
	2	3.25	1.60	6
	3	2.33	.76	3
	Total	3.24	1.05	17
HO	1	1.50	.00	3
	2	3.57	1.62	7
	3	4.38	1.16	8
	Total	3.58	1.59	18
Total	1	3.00	.97	11
	2	3.42	1.55	13
	3	3.82	1.40	11
	Total	3.41	1.35	35

Source	SS	df	MS	F	p	Power
Condition	.074	1	.074	.054	.817	.056
Achievement level	4.581	2	2.291	1.688	.203	.326
Condition x Ach. Level	18.580	2	9.290	6.847	.004	.892
Error	39.350	29	1.357			

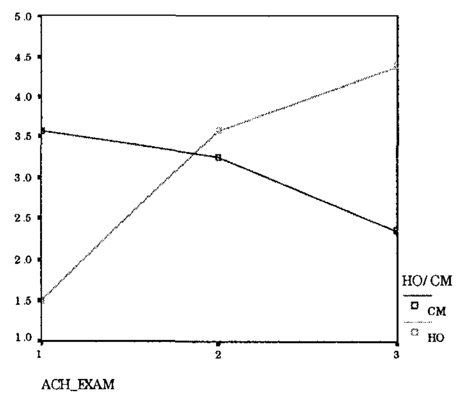


Figure 8: Cell means of delayed problem solving

[6] Maximum possible score = 6

Table 7: ANOVA for Delayed Total Learning[7]

Descriptive Statistics

HO/CM	ACH_EXAM	Mean	SD	N
CM	1	10.41	1.30	8
	2	10.13	3.33	6
	3	9.00	3.03	3
	Total	10.06	2.37	17
HO	1	4.58	1.53	3
	2	11.14	2.97	7
	3	14.44	2.78	8
	Total	11.51	4.37	18
Total	1	8.82	3.01	11
	2	10.67	3.05	13
	3	12.95	3.70	11
	Total	10.81	3.57	35

Source	SS	df	MS	F	p	Power
Condition	.326	1	.326	.048	.828	.055
Achievement level	85.690	2	42.845	6.297	.005	.863
Condition x Ach. Level	141.0440	2	70.522	10.364	.000	.978
Error	197.3160	29	6.804			

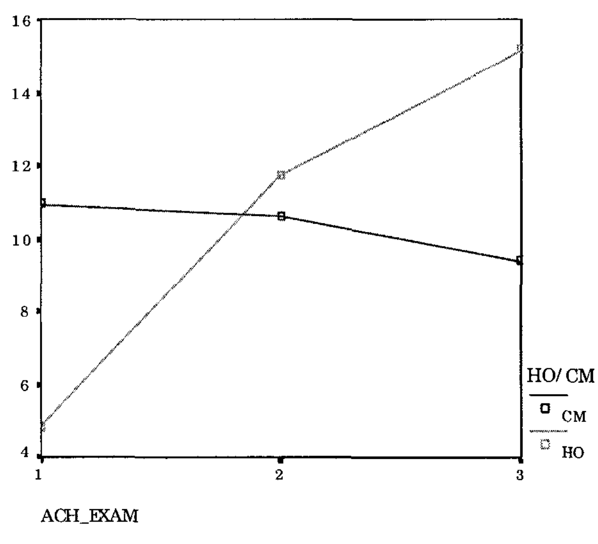


Figure 9: Cell means of total delayed learning

[7] Maximum possible score = 18

4.3.1 Tests of interaction between condition and achievement level

At an alpha level of .05, there were no statistically significant interactions between condition and achievement level for the immediate measurements of learning ($p = .235$ for Immediate Concept Understanding, $p = .667$ for Immediate Problem Solving, and $p = .483$ for Immediate Total Learning). Also, the post hoc power of these tests was low (power = .303 for immediate concept understanding, power = .112 for immediate problem solving, and power = .168 for immediate total learning) suggesting that the sample size was small or more likely that there was no big effect to detect.

At the delayed measurements of learning however, a consistent pattern of disordinal significant interactions was found ($p = .005$ for Delayed Concept Understanding, $p = .004$ for Delayed Problem Solving, and $p < .0005$ for Delayed Total Learning). These tests had high post hoc power (power = .869 for delayed concept understanding, power = .892 for delayed problem solving, and power = .978 for delayed total learning) suggesting the interaction effect is large so that even with a smaller sample size of $n = 35$ the interaction was detected. The achievement level (in the presence of an interaction) was significant for delayed concept understanding and delayed total learning. To investigate such differential effects, post-hoc comparisons of groups were performed to assess significance of simple main effects at each level of student achievement. Results of this test are presented in Table 8.

Table 8: Post-hoc Analysis of Simple Main Effects

Outcome variable	Simple main effect for	Significance
	Low achievers	.115
DEL_CU	Medium achievers	.987
	High achievers	.220
	Low achievers	.126
DEL_PS	Medium achievers	.996
	High achievers	.132
	Low achievers	.028 *
EXAM_TOT	Medium achievers	.980
	High achievers	.047 *

For Delayed Concept Understanding and for Delayed Problem Solving, no statistical significant differences were found for the simple main effects. This seems to occur because interactions were significant suggesting that the effects for high and low achievers were different, even of a different sign (disordinal interaction), but differences in simple main effects were not yet big enough to exhibit significance. In fact, the p values of these post hoc tests were low, ranging from .115 to .22. If we consider this research as an exploratory first study and relax the alpha level, that is, if we are willing to admit a larger Type I error, we would be wrong 11.5% to 22% of the times in rejecting the null hypothesis. Indeed, the estimated power of these post-hoc comparisons (computed by hand and tables of power) range from .3 to .6, which indicated that even if there was an effect we were about 30 to 60 % likely to not find it.

When the two measurements of delayed learning for concept understanding and problem solving were combined to give a measure of Delayed Total Learning, the composite simple main effects became large enough to show statistical significant differences for low and high achievers ($p = .028$ for low achievers and $p = .047$ for high achievers). The computer treatment seems to works better for low achievers whereas the hands-on treatment seems to work better for high achievers.

It was particularly interesting that the same pattern of disordinal interaction was consistently found throughout the statistical analysis of the data, at times significant (for delayed measurements) and at times not significant (for immediate measurements), with greater or lower power, but it was always the case that for low achievers, the computer group means were higher than the hands-on group means whereas for the high achievers the situations was reversed. This consistent result will be discussed in Chapter V.

4.3.2 Tests of main effect for condition when there is no interaction

For the immediate measurement of learning, where interactions were non-significant, the tests of the main effect for condition were also non-significant ($p = .740$ for Immediate Concept Understanding, $p = .778$ for Immediate Problem Solving, and $p = .772$ for Immediate Total Learning). At first, these results suggest that on average for all students regardless of achievement level, as just two groups: hands-on condition vs. computer-mediated condition, for immediate learning, either for concept understanding, problem-solving or combined, both treatments appear to have the same effect on learning.

4.4 CORRELATIONS AND RETENTION MEASUREMENTS

The correlation between immediate and delayed scores was also investigated for the whole sample and for the computer and the hands-on groups separately. As expected, the correlation coefficients were all positive and statistically significant but moderate in strength. Table 9 shows the correlation coefficients

Table 9: Correlation Coefficients for Immediate and Delayed Measurement of Learning for the Whole Sample and for Each Treatment.

	Whole sample	Computer group	Hands-on group
Concept understanding	$r = .590$ $p = .000$ $n = 55$	$r = .401$ $p = .038$ $n = 27$	$r = .669$ $p = .000$ $n = 28$
Problem-solving	$r = .473$ $p = .000$ $n = 54$	$r = .428$ $p = .029$ $n = 26$	$r = .519$ $p = .005$ $n = 28$
Total learning	$r = .618$ $p = .000$ $n = 54$	$r = .527$ $p = .006$ $n = 26$	$r = .674$ $p = .000$ $n = 28$

These correlation coefficients are consistent and add to the discipline literature. Rosenquist, Shavelson, and Ruiz-Primo (2000) found a correlation coefficient of .53 for students exposed to hands-on instruction at two different occasions, from late spring to early fall. The correlation coefficients that I found for these students range from .519 to .674 for occasions separated only a few days. Rosenquist et al. however, could not test one of their research hypotheses (an interaction between students expertise and assessment method) because they did not have data on correlation coefficients at two points in time for students exposed to computer simulation instruction. I found those correlation coefficients to vary from .410 to .527 for a few days of delay.

From the factorial analyses presented in the previous section, it appears that the pattern of achievement is the same at the immediate and delayed levels of measurement, low achievers benefited more from computer instruction whereas high achievers benefited more form hands-on instruction. However, the question that arises is whether at each achievement level the acquired knowledge was comparably retained for both groups. On the theoretical grounds of the generation (Slamecka & Graf, 1978), one could hypothesized that computer students might not retain knowledge as much as hands-on students, that is, the difference between immediate learning measurements and delayed learning measurements for computer students would be larger (but negative in sign) than that for hands-on students because hands-on students produced ("generated") the solutions whereas computer students had the solutions generated for them by the computer.

A series of repeated measures ANOVA tests with immediate and rescaled delayed subjects' scores as crossed factor and two between factors, condition (hands-on and computer-mediated) and achievement level, were run for the three learning outcomes: concept understanding, problem solving, and total learning. The sphericity condition was met in all cases (Huynh-Feldt epsilon = 1.000). Except for problem solving measurements, no statistically significant interactions were found suggesting that hands-on and computer mediated experiences may be equally retained at all levels of students' achievement. For problem-solving, a significant interaction was found between trial (immediate and delayed measurement) and achievement level ($p = .016$; post hoc power $= .745$) but this is not an interaction with condition and hence goes beyond the scope of this research study.

4.5 ANALYSIS OF STUDENTS' CONVERSATIONS

From a total of 80 recorded student conversations, a sample of 34 audio files (18 hands-on files and 16 computer-mediated files) were selected for transcription and analysis. The selection was at random within each of the four activities (Monday through Thursday) and within the two conditions hands-on and computer-mediated instruction. For this content unit, students worked in mixed ability groups, selected by the teacher based on social interactions of students. It was not possible, for example, to have groups of all low achievers working together to compare with groups of all high achievers, and also all medium achievers groups, etc. For the hands-on condition, where the students worked in pairs, the total number of possible combinations was 6, but for the computer-mediated conditions the total number of possible combinations was 18; the analysis of conversations by achievement level would get unwieldy. In addition, the sample size selected for analysis was not big enough to provide a good number of transcripts per achievement level so as to conclude accurately. Instead, whole group comparisons were performed between hands-on and computer–mediated conditions.

At a first level of analysis, from the audio recordings the following data was extracted: time spent on performing the experiment, time doing the practice worksheet, total time for completion of the lesson, number of words per unit time (minutes), and number of comments per unit time (minute). A comment refers to each instance of a person's talk. The numbers of words and comments had to be computed per unit time because not all recordings lasted the same amount of time. One computer-mediated file was an outlier for total time for completion of the lesson (less than 10 minutes) and was excluded from the analysis. The poor sound quality of four computer-mediated and three hands-on files did not warrant a reliable transcription of students' conversations and hence could not be included in the analysis of words and comments per minute. In other files, it was not clear when the students finished the experiments and started the practice worksheet.

It was hypothesized that while total lesson time was the same for hands-on and computer-mediated students, distribution of class time would be different with the hands-on group devoting more time to the experiment at the expense of practice time. Also, with regards to students' exchanges, Shay (1980) argues that computer-mediated instruction increases peer interaction. However, in this study, hands-on students had to read the instructions, and hence it was reasonable to expect that the number of words for the hands-on group would be much larger than for the computer group who were read to by the computer. A series of independent sample t-tests (two tailed) was conducted to test these hypotheses. Results of the t-tests along with descriptive statistics are presented below in Table 10.

Table 10: Descriptive Statistics and T-test of Time Doing the Experiment, Practice Worksheets, Total Time, Words per Minute, and Comments per Minute.

	COND.	N	Mean	SD	T	p
EXPERIMENT	CM	17	0:09:06	0:02:53	-2.219	.027
	HO	17	0:11:46	0:03:46		
PRACTICE	CM	15	0:09:03	0:03:41	1.961	.060
	HO	16	0:06:40	0:03:03		
TOTAL TIME	CM	15	0:20:07	0:04:26	.335	.740
	HO	16	0:19:41	0:02:44		
WORDS/ MINUTE	CM	13	32.61	16.69	-.455	.653
	HO	13	35.57	16.46		
COMM./ MINUTE	CM	13	6.35	2.56	-.361	.721
	HO	13	6.73	2.79		

The data does not support the hypotheses of differential verbosity or exchanges among peers between the two conditions. Taken together, these tests indicate that both groups, hands-on and computer-mediated, seem to have been equally verbose and with comparable amount of exchange between peers. A word of caution is necessary here: these numbers are valid for comparison purposes but should not be viewed as exact measurements of the number of words or comments students articulated, the classroom was very noisy constantly due to students' activities and/or the audio of the computer program; at times it was very hard to understand what they say and for that reason the true number of words and comments uttered in class is probably much larger than reported here.

However, talk per se does not indicate engagement of students in the task at hand. Talk could be on or off task. Two coders working independently classified each comment of the conversation transcripts as on-task, off-task, or unclear. On-task comments were comments related to the task at hand (doing the experiments, operating the computer, answering the practice sheet, keeping track of time, cleaning up after work, etc.); off-task comments were comments overtly unrelated to the task (e.g., talk about other class periods and their out-of-school entertainments). Unclear comments were statements that could not be clearly classified into any of the previous categories or were it was not possible to understand the words students were saying (due to poor quality of recording or excessive noise in the classroom). Agreement between the persons was 90%. Because a great proportion of unclear statements could bias the analysis and because the lesson time of each file was slightly different, it was necessary to find a valid comparative measurement of on-task behavior. That measurement was the percentage of on-task comments in relation to total on- and off-task comments. This measurement is very convenient: it is symmetric for on- and off-task (which reflect reality: students are either on-task or off-task), it is easily interpretable: higher numbers (up to 100) mean more on-task and vice versa, and files with a considerable number of unclear statements are not "penalized" (i.e., excluded from the analysis, misleadingly showing low on-task behavior). Results indicate that the percentage of on-task comments for the hands-on students appeared to be slightly higher (87% vs. 79%) but did not achieve statistical significance ($t = -1.387$, $p = .176$); moreover, the post-hoc power of this test is low (post hoc power = .26).

From class observations and also evidenced in the transcripts, students in the HO condition tended to distribute the work; for example, if they had to prepare four solutions, each student in the pair prepared two solutions. As a consequence, all students in the HO condition truly experienced hands-on instruction. As expected, this also at times generated some arguments about who does what. In the computer condition, there were at times discussions that revolved around who does the typing on the computer or who gets to click the mouse. Another difference between groups that emerged from class observations and transcripts is that the HO group often had to gather more materials (e.g., they used up all the salt provided) and some of them elaborated on the procedure much further than was required (e.g., when it said pour about two inches high of water, they asked for a rules to measure or they used a stop watch to take exact stirring or waiting times). This kind of engagement was obviously not observed in the CM group.

I also performed a content analysis of conversation transcripts. To select the dimension to analyze in the conversation I reflected on the literature review. A tenet of constructivist philosophy is that the acquisition of knowledge requires the use of general procedural knowledge. Lawson (1991) argues that development of reasoning is highly correlated with performance but Tamir (1989) argues that the manipulative demands of the lab work could be detrimental for low achievers. Lehman (1990) analyzed students' conversations during lab sessions and found that much of verbal interaction concerned figuring out the procedure rather than understanding the concepts. Therefore, procedural knowledge statements are important to code in this analysis.

Another dimension worth examining in the transcripts of conversations is explanation. Webb (1989) reviewed 19 published studies on learning mathematics and computer science in small groups and found that giving explanations was positively correlated with higher achievement. Chi, de Leeuw, Chiu, and LaVancher (1994) gave evidence that self-explanation improves understanding; the more explanations the students generated, the higher the achievement. Chi et al. define explanations as "any utterance that went beyond the information given, namely, an inference of new knowledge ... excluding monitoring statements, paraphrases, comprehension, or bridging inferences" (p. 454-455). Explanations could be partial or explicit. Potential partial explanations would be in the form of discussion of results and observations, for example, when students talked about the findings of their experiments or offered a statement that did not directly derive from the study material. Explicit explanations are complete statements where the students articulate possible reasons for phenomena or logic of a definition. Explanations were not categorized as right or wrong because even when the explanation generated is wrong it is not detrimental to learning and it is even conceivable that it could provide a learning experience (Chi et al., 1994). Hence, explanation is another dimension to examine in students' conversations.

Each statement of the transcripts was classified as: (a) a procedural or manipulative skills statement when the comment directly related to doing the activities (lab work in the hands-on condition or difficulties operating the computer program in the computer-mediated condition), (b) discussion of results and observations (partial explanations), and (c) explicit explanations. The classification of comments into the three categories was performed by two independent coders who achieved agreement in 87% of the cases. Because the length of the transcripts differed significantly, the number of procedural comments and explanations in each transcript was divided by the number of clear statements (total statements – unclear statements) and then multiplied by 100 to express it in percentage. Table 11 shows the independent sample t-test performed.

Table 11: Results of the T-test Comparing HO and CM for Procedural Comments, Partial Explanations, Explicit Explanations, and Total Explanations.

	COND.	N	Mean	SD	T	P
PROC. COMMENTS	CM	15	2.93	3.40	-6.275	.000
	HO	14	13.48	5.48		
PARTIAL EXPL.	CM	15	9.07	7.38	-2.239	.034
	HO	14	14.98	6.79		
EXPLICIT EXPL.	CM	15	1.74	1.63	1.312	.201
	HO	14	1.07	1.05		
TOTAL EXPL.	CM	15	10.81	8.02	-1.861	.074
	HO	14	16.05	7.05		

As expected (Lehman, 1990), the first and foremost difference between the HO and CM groups was the amount of procedural comments articulated. Examples include: "*Place stopper on each test tube place stopper on test tube. I don't know how to put the stopper on...How are you supposed to put the stopper on...Ok I put mine on what do I do...put it on the other ones don't do it really hard...*" (Activity 1 Group K), "*-mix them after we're all done; -how are we supposed to mix it then? -no, we mix them all with the same one but we use that -yea, that's what I meant*" (Activity 3 Group J), "*When you add a spoonful you have to fill it all the way to the top and you have to go like this, flatten it off, a little bit more go ahead and pour a little bit more in and then flatten it off*" (Activity 4 Group I). As expected, the computer group did not produce nearly any comparable number of procedural exchanges due to the different nature of their task. Some few comments regarding the use of the computer still appear in Activity 1 but not in subsequent activities.

Statements considered potential partial explanations included discussion of experimental results and observations. Again, the HO group produced significantly more of these comments. Examples of discussion of results include: "*-Did it dissolve? –No, look ...it didn't dissolve, right?" (Activity 1 Group I),* "*-look, this didn't dissolve, and this did; -what? no, they both dissolved; -did this dissolve?; -it looks like one mixture; -alright; -ok*" (Activity 2 Group B), *"[name] it didn't dissolve - A little bit of it did"* (Activity 4 Group I), "*Ok, it hasn't completely dissolved. – Yes, it has – I mean it has completely dissolved" (Activity 4 Group K).* For the CM group, discussion of results was also encountered in the transcripts but fewer instances. Examples are: *-Does B dissolve or not dissolve? –Does not dissolve; -Uh, yea, that's dissolved. That's B. Yea, dissolves; -Does dissolve? –Do you know? –On B though; -B didn't dissolve. B didn't dissolve; -B didn't dissolve? – No; -B didn't dissolve, look; -No, B did dissolve"* (Activity 1 Group 3), "*Yes, it has dissolved; -No, there's not, it's at the rim, see? –Yes, it has dissolved; -No, it's at the rim; -It's dissolved"* (Activity 4 Group 10).

Examples of observations (including expectations and predictions) found in the transcripts are: *"It's been one minute – now it* [dissolved] *– not completely it's not – Yea but we put in more than that"* (Activity 1 Group B), "*Test tube 4 yes, definitely yes - yes - it's still fizzing – So, it's still dissolved, it looks like one substance, doesn't it? –No, there's residue on the bottom –I think eventually it will all dissolve but it hasn't dissolved yet –Yes, it was – No, it doesn't dissolve, it says but then it goes back to the bottom. It doesn't dissolve – There's nothing –Let it stay like that alright – Alright" (Activity 2*

Group B), "It looks like tomato juice" (Activity 3 Group D), *"I'm just guessing that's gonna be darkest. I'm guessing one is gonna be the lightest"* (Activity 3 Group J), *"Oh, there's some dissolved and some left over, it's not all the salt, we put more than that in"* (Activity 4 Group E). The CM also made some observations and predictions but in fewer amounts: *"Then, that's gonna taste so bad; -So bad? I like strong lemonade; -What? –I like strong lemonade; -Yea, but not that strong"* (Activity 3, Group 1), *"Look, it says white but it turns red"* (Activity 3 Group 6), *"I hope it didn't dissolve this time; -It looks like it's gonna"* (Activity 4 Group 10).

The number of explicit explanations (right and wrong) did not significantly differ for both groups. Examples from the HO group include: *"Is this a substances because all of it evaporated? – No, because some of it is being evaporative, that's why it's a pure substance, there's still a residue, like if you put water and salt in a beaker and the water evaporated what would that make water? – Air – Yea, because the salt is still left in there"* (Activity 1 Group B), *"If you perform and experiment of dissolution in water, can you distinguish salt and sugar? –No; - No, water dissolves ..,; -Wait, no you can ....; -No ...; -Yes, you, wait, hold on ...; -No, because sand and salt, no, no, no, no. Everything dissolves except the rock particles that make up sand. The salt dissolves but so does that. –But sugar dissolves in what kind of substance? –Sugar in vinegar and water and salt dissolves in water. So no, you can't tell the difference"* (Activity 2 Group B), *"How did yours dissolve? Because we stirred it for half a minute; - You didn't stir it, did you? – We did ... but not for half a ... we stirred it for a while"* (Activity 4 Group I), [stirring] *"waves, that's what makes the salt dissolve"* (Activity 4 Group K), *"It's time but it hasn't dissolve. I like stirring; -No, it doesn't have to dissolve; -But I'd like it to dissolve; -No,* *it won't dissolve if it won't dissolve. It won't dissolve if it's saturated; -Please, dissolve. Why didn't you dissolve? It did dissolve. It's starting to dissolve; -That's because you keep stirring. You are still stirring, you're not suppose to stir anymore; -I'm done stirring; you were stirring for no good reason; -ok, it didn't dissolve"* (Activity 4 Group K).

Explanations from the CM group include: *"So we are looking for a pure substance; I think a pure substance is something without"* (Activity 1 Group 5), *"Is it a water-loving substance? –Because it's scared of water, will not go in water; -water-fearing; -is it water-loving or water-fearing? –water-loving; -ok, then that is hydrophilic; -ok"* (Activity 2 Group 4), *"hey, what's the solvent? –Solvent is what it dissolves in. That would be the water."* (Activity 3 Group 1), *"Concentrated means there's more solutes in a given solvent"* (Activity 3 Group 6).

However, when potential partial explanations and explicit explanations were combined, marginal significance was found with HO students producing higher number of explanations.

In addition, comments related to collaborative learning (monitoring peers' performance and supporting peers' learning), motivational comments, misconceptions and relevant comments were noted. Collaborative learning between peers was viewed as either monitoring peer performance and learning as well as providing support and explanations. On a subjective assessment, it appears that in the HO condition, there was much peer interaction in terms of monitoring each other's activities and learning. Examples of this are: *"I will read them out loud* [the definitions] *are you listening?"* (Activity 1 Group B), *"On the basis ...*[reading the question] *-What? -What what? Just* *listen for a second, maybe we can figure this out"* (Activity 2 Group B), *"How would you do the experiment* [reading the question from the worksheet] … *-put it in water, that's all you have to do –it dissolves in them –yea, but like make steps –you don't have to, do you? -yea*." (Activity 2 Group B), *:"Alright, take one spoon. Just one spoonful and put it in A …Make sure it's one. Ok, now pour it in"* (Activity 3 Group I). Peer monitoring also occurred in the CM condition but to a lesser extent. For example; [off topic chat] "*we have to finish this up; -this one? –umm, we're still deciding"* (Activity 2 Group 4), *"-We have two substances. One's salt, one's chalk, how do we determine which is which? -they dissolve? --you need to write down what you would do"* (Activity 2 Group 10).

From class observations, it appeared that in general students were much more enthusiastic about doing the hands-on than about experiencing computer-mediated instruction. This observation was reflected in the transcripts of conversations. HO students expressed comments such as: *"This is fun"* (Activity 1 Group I), *"Look at this, it's like so cool –ooh, it's -ooh, look at that, it's like a little tornado"* (Activity 2 Group B), *"Smells good"* (Activity 3 Group D), *"Sweet, that's awesome"* (Activity 3 Group E), *"This is super fun, super fun, super di duper guys, fun fun fun"* (Activity 4 Group E) and only one instance of a negative comment *"I hate this*" (Activity 4 Group B) but it was in reference to the practice worksheet that was common to the HO and the CM groups. Among CM group, I also found some enthusiastic comments such as *"It's funny. I think it'd be cool"* (Activity 1, Group 1), *"Oh, that is so cool"* (Activity 2 Group 4), *"That's impressive …[]…Wow, that's amazing"* (Activity 2 Group 10) but they also articulated a number of negative comments such as *"This is just so dumb"* (Activity 1 Group 3), *"That's dumb, why are we doing this experiment?"* (Activity 2 Group 7).

Finally, a number of misconceptions also emerged in student's conversations. From the HO group: "*Maybe it's like three or more chemicals mixed together; -yea; -Mixed together to make one?,,,Water evaporated, what would that make water? -Air* " (Activity 1 Group B), "*Oh, then saturated fat is; -So what do they mean by saturated fat? Like so much fat that is just...*" (Activity 4 Group E), "*What kind of name is saturated fat? [] -So if you put some salt in here and it all complete disappears is it all saturated?-Yea, do they mean saturated fat? It disappears [] Isn't saturated fat where is a form of fat they put on Wendy's hamburgers? –They don't have a bottle that has saturated fat in it*" (Activity 4 Group I). Misconceptions from the CM group included: "*No, you could have like salt in there or something; -A liquid; -The liquid evaporates but a solid stays in solution*" (Activity 1 Group 5), "*It's not all liquefied*" (Activity 1 Group 8) in reference to all being dissolved, "*Wouldn't water dissolve everything though?*" (Activity 2 Group 4), "*Boiling helps things dissolve!*" (Activity 3 Group 6), "*There is solvent in water*" (Activity 4 Group 10).

There were two comments from two HO groups that were very pertinent to this research. In Activity 2 Group G, during the reading of the definitions, a student had difficulties with vocabulary and said: "*I cannot pronounce that word*" in reference to the word "hydrophobic"; however the CM did not have that problem, the computer pronounced the words for them. In any case, this anecdote may indicate that there could have been more instances of reading/pronunciation difficulties in the hands-on group. In Activity 3 Group I, when a peer instructed her partner to read the definitions, the partner expresses: "*I don't like to read.*"

An instance worth of mentioning, in the Activity 4 Group B, the hands-on condition seemed to have facilitated students' inquisitiveness and discovery. The concept being explored was saturation and after reading the definitions and examples, the students wanted to verify that a saturated solution would not dissolve more solute. *"It's all saturated; -Can I try something? I just want to test. I know what they are saying on the last page is right. I just want to see. If we keep adding more salt, will it just sink straight to the bottom? –Wait, keep on stirring it; -Yeah; -You can get the bigger stirring thing. I mean stick; -It doesn't do anything; -It doesn't stir well; -Here use a teaspoon; -Ok, we've stirred long enough."*

In the computer group, students were frequently observed playing with the features of the computer program, the volume and the sound of opening windows. This observation is also accounted for in the transcripts. Particularly, the sound of opening the definitions window seemed to amuse the students so much that at a certain point the whole class coordinated to make that sound at the same time. *"Apparently everybody likes that sound; -Everybody at the same time! 1, 2, 3!* [to the whole class]*; -If this doesn't stop, I'm gonna ban you from the computer* [the teacher]" (Activity 3, Group 9).

As a side note, the CM students were extremely curious about who performed the experiments. They hypothesized that the researcher present at the classroom did (as indeed was the case) but most of the audio was a male voice so that confounded them.

5.0 CHAPTER V: DISCUSION, CONCLUSIONS, LIMITATIONS OF THE STUDY, AND FURTHER RESEARCH

In this chapter, the results described previously will be discussed in relation to the literature reviewed in Chapter II and in the light of new findings. Some new knowledge emerged from this research and its significance for the discipline will be presented along with the limitations of this study. Finally, I will draw conclusions and suggest further lines of research.

5.1 DISCUSSION OF RESEARCH RESULTS

5.1.1 Interaction between treatment and ability

The findings of this study confirm previous assertions of hands-on strategy having the most marked effect at the middle school level (Lott, 1983). Hands-on students exhibited the most pronounced difference between high and low achievers in all measurements of learning, confirming that this population was the appropriate target of the study. Yet, my research suggests that hands-on strategies may not be the preferred teaching method for all middle school students.

The first and most consistent finding of this study is the disordinal interaction between treatment and achievement level. This same pattern seems to be so strong that it emerged in all cases of measurement of learning, whether immediate or delayed, concept understanding, problem-solving, or total learning suggesting that indeed the two treatments may have a differential effect at different levels of student ability; the computer instruction seemed to have worked better for low achievers and the hands-on instruction better for high achievers. In chapter I, I presented a table (Table 1: Comparison between Hands-On and Computer-Mediation, page 12) that includes some dimensions in which hands-on and computer-mediated instruction differ. After conducting my study, I could add to that table two other dimensions of comparison, as presented below in figure 10.

	HO	CM
Stimuli	All senses	Visual, audio
Time	More time-consuming Real time	Less time-consuming Self-paced
Procedural demands	Manipulation of objects	Operating the computer
Path of instruction	Sequential	Contiguous
Cognitive demands	Reading and writing	Listening and typing
Experimental results	Uncontrolled variables and measurement error	More reliable
Nature of conversation	More procedural comments More partial explanation	Less procedural comments Less partial explanations
Distribution of time	More for experiments Less for practice Less teacher scaffolding	Less for experiments More for practice More teacher scaffolding

Figure 10: Instructional approaches conclusion

Now the question is how these factors explain the disordinal interaction observed. figure 11 presents a brief summary of the factors that had a different effect for low and higher achievers in this study. A description of the effect of each factor at the different ability levels follows the table.

Stimuli	Low achievers in **HO** more likely to rely on senses rather than new knowledge
Procedural demands	**HO** more on task but time consumed in procedure, difficult for low achievers
Experimental results	Higher achievers, **HO** triggered more discussion of results and observations (partial explanations) than **CM**
Time	**CM** faster experiments more time for practice, more teacher scaffolding of low achievers (mostly for PS)

Figure 11: Instructional approaches by achievement level

These findings may have a parallel in another content area of schooling. Ascher (1984) conducted a literature review on the problems of improving the mathematical skills of low achieving elementary school children. She found that successful remedial programs include computer-assisted instruction and rapid pacing. Indeed, computer-mediated students in my study completed the experimental part of each lesson in shorter time than hands-on students, experiencing faster pacing of the experimental part of the unit. The computer program included real time videotapes but it was programmed in such way that it allowed students to jump to the next procedural step instead of waiting in real time (an actual minute when required or shaking the test tube ten times, etc.). Conversely, hands-on students experience lower pacing due to gathering of the material, real time phenomena, cleaning up, etc. Slower pacing or more waiting time may invite distractions (off-task behavior) or lack of concentration for less focused students, most likely low achievers. Unfortunately, this hypothesis could not be tested due to the fact that it was not possible to analyze conversations by achievement level.

The findings of this study can also be understood in the light of the characteristics of the school where this research was conducted. The school educational philosophy is based on latitude and choice; students who do well in this school (high achievers in this study) are students who not only are academically talented but also students who can successfully manage lack of structure. Conversely, students who struggle in this school (low achievers in the study) are students who may do better in a more structured learning environment. The computer condition provides a more structured way of approaching the content and hence students who need more guided scaffolding (low achievers) would do better in this environment than in a less structured learning condition such as hands-on. Conversely, the hands-on condition is less structured and allows more freedom of choice; students who strive successfully in environments where they have much latitude and control benefited more from the hands-on condition than from the computer-mediated condition.

Previous studies in science education have employed a one-way ANOVA design to compare computer-mediated instruction and hands-on strategies. Some studies have indicated that computer-mediated instruction and hands-on instruction produce no significant differences in students' achievement (Choi & Gennaro, 1987; Helgeson, 1988; Moore & Thomas, 1983; Rosen & Petty, 1992; Shaw & Okey, 1985, among others). Other studies suggested that computer instruction may be superior than hands-on approaches (Ayres & Melear 1998; Geban, Askar, & Özkan, 1992; Smith, Jones, &

Waugh, 1986). Yet, a third group of research reports supports the idea that hands-on strategy may be preferable than computer-mediation (Bourque & Carlson, 1987; Zohar & Tamir, 1986). The One-Way ANOVA is a comparison of points, higher or lower scores for whole groups.

My research departs from the previous one in that I compare lines of achievement. By introducing an element of students' individual differences, prior achievement, I unfolded points into lines. The factorial design explains the above findings of no statistical significant differences or small effects favoring one or the other instructional strategy if whole groups (points), that is computer students of all achievement levels vs. hands-on students of all achievement levels, are compared. Indeed, main effects for condition were non-significant in all of my measures. However, these previous research designs hide potential significant differences that may come about when including other potentially influential factors in the study. I advance the knowledge of the discipline by partitioning the sample of subjects according to a main predictor of school achievement. I explain previous results by arguing that the higher achievement of hands-on high achievers (as compared to computer high achievers) may have been counterbalanced by the lower achievements of hands-on low achievers (as compared to computer low achievers) and thus on average, no significant differences or small differences were detected. When a blocking variable was included in the study design, the picture that emerged was significant and provided more accurate information.

My research significantly adds to the current knowledge of the discipline in the area of analyzing students' achievement under different teaching strategies as a function of their prior academic ability. My finding coincides with Ronen and Elihau's (2000) finding that the computer did not particularly aid learning for high achievers, for this group of students the hands-on experience might have been the critical factor for learning. But they also argue that low achievers did not benefit from the computer environment; I challenge this assertion and contend that the computer does aid learning for low achievers when it provides an alternative to manipulative and reading demands.

Tamir (1989) has articulated that hands-on activities can be very demanding of students who have to incorporate knowledge at the same time they manipulate variables and use equipment. Such additional demand of the lab work may still constitute a cognitive overload for low achievers, even when lab performance is kept at a very simple level and conducted in small groups. The data from my study support the argument of Tamir in two ways: based on time analysis and students' comments.

First, time spent on doing the experiments was significantly longer for hands-on students than for computer-students and conversely, time doing the practice worksheet was marginally significantly larger for computer students than for hands-on students. This suggests that lab work was indeed more demanding and hectic (reading, writing, doing, understanding) than the computer task and time spent on experiments came at the expense of doing the practice sheet. My findings give support to Rivers and Vockell's (1987) argument about peripheral tasks related to traditional laboratory that may indeed be time consuming but not conducive to developing problem solving skills. Doing the experiments could contribute to acquisition of procedural knowledge but the worksheets and exam measured declarative knowledge. The fact that computer students spent more time on the less chaotic activity that may better contribute to acquisition of declarative knowledge may explain the higher performance on worksheets and exam of computer-mediated low achievers as compared to hands-on low achievers.

The second way in which my study supports the Tamir (1989) assertion is based on the analysis of procedural comments produced by the students. Coinciding with Lehman (1990), my sample of hands-on students produced far more procedural comments than computer-mediated students indicating that hands-on students struggled with manipulation of equipment much more than computer students. This factor may explain the lower achievement of hands-on low achievers as compared to computer-mediated low achievers.

Saunders (1992) theorized that learners need abundant sensory experiences only reflected through hands-on. However, Rivers and Vockell (1987) argue that traditional laboratory data, which is tainted with measurement error and uncontrolled variables, is more difficult for students to interpret than data produced by simulations. My research findings support and advance both seemingly contradictory hypotheses. The analysis of experimental results, the results that students obtained in their lab or computer experiments, shows marked differences among groups. Except for the conclusions of activity 2, students in the computer group reported markedly more accurate experimental results than students in the hands-on group. This finding was expected according to what has been reported in the literature as one on the advantages of computer usage in education (Geban, Askar, & Özkan, 1992; Lunetta & Hoftein, 1981). Hence, for low achievers, debatable and inaccurate lab results in the hands-on condition could have been detrimental for learning as compared to more accurate lab results in the computer condition. For high achievers, however, those inaccurate hands-on experimental results could have triggered discussion among peers. Indeed, high achievers were more elaborative in their lab reports, within the reduced space allowed for writing in the manual and on the computer interface. These high achieving students gave more fine-grained descriptive responses like *"sort of dissolve," "semi dissolved, " "misty," "fog," "exploded,"* and *"almost dissolved"* as opposed to just "*Yes*" or "*No*" from low achievers. The computer group did not have the opportunity to choose their own words; they had to select their answers from a pop-down menu and hence we do not have data to compare high and low achievers' lab reports in the computer condition.

When examining lab reports, it is interesting to comment on activity 2. Activity 2 was a substance identification problem; students were to perform experiments of dissolution in two solvents to observe results and deduce the identity of the substances labeled A, B, and C as sugar, chalk, or sand on the basis of their dissolution properties. Lab results were again far more accurate for the computer group than for the hands-on group but conclusions follow the reversed pattern, the hands-on group asserted more often the identity of the mysterious substances than the computer group. When they had to explain their reasoning, hands-on low achiever students tended to base their decisions on sensory perceptions of the substances (color, texture, etc.) rather than lab results of dissolutions. The possibility of sensory experiences is indeed an advantage of hands-on over computer-mediated instruction. However, in this case, it may have hindered learning problem solving and chemistry qualitative analysis of dissolution properties.

Another possible explanation for the interaction between achievement level and method arises from expert-novice literature. "*Because of the expert's richer and more complete understanding of her domain* [in this case hands-on procedural knowledge], *she* *is able to see beyond surface features and focus on the mechanism driving the particular problem or situation. Compared to the novice, who sees surface features as the most salient attributes of a problem (but has only partial understanding of the underlying features) ... the expert's schemata contain a great deal of procedural knowledge, with explicit conditions for applicability,"* (Chi, Feltovich, & Glaser, 1981, p. 151). All students in this study were novices with regards to declarative knowledge of the scientific concepts learned, which was the basis of sample selection. However, it may not be true that students were all novices or all experts in procedural knowledge (whether necessary to operate the computer or to perform lab experiments). For computer procedural knowledge, it is reasonable to assume that they all shared the same level of expertise; the demographics of the sample (small private school; children of highly educated parents) indicates that it is very likely that all students of the sample have and probably use computers not only at school but also at home for various purposes. Also, it would be illogical to assume that high and low achievers have different access to computers. However, for hands-on procedural knowledge, high and low achievers may have differed in their expertise. High achievers may have mastered expertise in hands-on procedural knowledge (from successful previous lab experiences at school), which aided their learning of this content-unit, whereas low achievers may not have yet successfully mastered hands-on procedural knowledge and therefore that lack of expertise may have hindered their learning of the content unit. In this line of reasoning, "procedural knowledge experts" (high achievers) experiencing hands-on could integrate the acquired new knowledge into their procedural prior knowledge schemata better than same "procedural knowledge experts" who experienced computer-mediated instruction who could not use as much their procedural knowledge expertise.

Cognitive theories (Mayer & Sims, 1994; Pavio & Csapo, 1983) may provide another possible explanation for the interaction so consistently found. The simultaneous presentation of words and pictures (contiguity principle) in the computer condition may have facilitated low achievers' construction of the three internal representational connections (visual connections, verbal connections, and joint connections between corresponding elements of the learner's internal visual and verbal connections or referential connections). Low achievers are more likely to exhibit poor reading abilities; in the computer condition, students were read to by the computer and did not have to perform the experiment. In contrast, in the hands-on condition, students were presented with the information sequentially and they had to not only grasp the concept under study, but also perform the experiments, and read the lab manual. That might have been an excessive cognitive demand for low achievers. Unfortunately, I do not have reading ability scores to test this hypothesis.

My findings have important implications in science education. Some researchers (e.g., Shaw & Okey, 1985) tend to recommend computer-mediated instruction for mastery of science concept understanding; other science educators (Carin, 1997; Ginsburg & Opper, 1969; Zohar & Tamir, 1986) argue that computerized labs should be used only when hands-on experiences are somehow inconvenient (dangerous, too expensive, would require unavailable equipment, too time-consuming, too complex, etc.). My research puts a word of caution to those recommendations; there is no method that works best for all students.

5.1.2 A note on the unexpected shape of the problem solving lines

Problem-solving measurements yielded an unexpected result: there was no statistical significant difference between low and high achievers. This suggests that there is a problem in the measurement of problem solving learning.

The practice worksheets and the exam were composed of short answer questions to assess concept understanding and problems of the kind "Design an experiment to test ….." to assess problem solving skills. Responding to these two types of items requires considerably different effort. While short answer questions require the student just to circle the best answer, to fill in the blank, or to give an example, problems demand far more elaboration of strategies for solution and writing. As in the study by Ronen and Elihau (2000), when the task at hand is difficult, measurement of learning becomes unreliable because students' motivation decreases.

In this case, the teacher tended to gravitate toward the low achievers much more than the high achievers to provide assistance on the most difficult items, the problems. In the computer condition, because there was more time available for the practice worksheet, there was then more teacher time for assisting low achievers in problem-solving. That is probably why low achievers scored higher than medium achievers in problem solving measurements of learning, as teacher scaffolding came into play.

Moreover, the students in the sample were very much aware that the content unit under study was a research project and would not affect their school grades. The teacher made explicit to them several times over the week that she would not be grading, nor even looking at, the worksheets and exam; yet, she remarked, they still had to make an effort to answer the questions to the best of their knowledge. Because grades would not affect their school reports, some students probably chose not to make much of an effort and picked the "easy to answer question" leaving the problems aside. Selection of question introduces noise to the research findings and this aspect should be modified in future studies of this kind. One can hypothesize that those who chose to answer only short answer questions are probably those who would not know the answer to the problem anyway, but that is speculative and may need follow-up interviews for verification.

5.1.3 Students' conversations

The distribution of time in each condition was different; hands-on students needed more time to perform the experiments and that came at the expense of practice worksheets. It is reasonable to assume that the low achievers of this study could have benefited more from doing the practice worksheets (more guided learning) than from doing the experiments. In the hands-on condition, low achievers had less time for practice and therefore their computer-mediated counterparts outperformed them.

Words and comments analyses of the sample of transcripts indicate that both groups, hands-on and computer-mediated, were equally verbose and with comparable amount of exchange between peers. This poses a doubt to Shay's (1980) assertion that computer-mediated instruction increases peer interaction.

Due to the participatory nature of the science lab, students in the hands-on condition tended to distribute the work and to get a closer exposure to the nature of experimental science than computer students. Hands-on student conversations were richer than computer-mediated student conversations in terms of the number of exchanges related to experimental procedural knowledge, discussion of experimental results, observations and expectations, explicit and partial explanations, monitoring of peer's activities and learning and explanations. In addition, a number of misconceptions emerged but deep analysis of those is beyond the scope of this research. It also appears that students were much more enthusiastic about doing the hands-on instruction than about experiencing computer-mediated instruction. I found at least one instance of increased scientific inquisitiveness and discovery in the hands-on condition unparalleled in computer-mediation. However, poor reading abilities and pronunciation, more frequently encountered among low achievers, may have been better compensated for in the computer condition.

5.2 CONCLUSIONS AND RECOMMENDATIONS

So, what does this research say to the science educator? This study gives strong empirical evidence that there is no universal teaching strategy that works better for all students; individual differences of students play a definite role in recommending a teaching strategy for students. This research strongly supports the assertion that computer-mediated instruction, a more structured teaching method that allows for more practice time, may benefit low achievers, students who need more guided learning environments. Hands-on strategies, on the other hand, may be more effective for high achievers who successfully manage latitude and option.

So what does this research recommend as the best classroom practice for middle school science? As expressed by Lunetta and Hofstein (1981) both hands-on experiences and computer instruction should have a place in school science because each conveys to students different aspects of science; the question that this research contributed to answer is how to do that. The findings of this research may illuminate what the ideal sequence of infusion of instructional methodology is in middle school science. The question of where to place computer units in the sequence of instruction was first raised by Shay (1980). It appears that in order to facilitate learning for low achievers, a more structured method that would spare them the difficulties of lab work would be preferable as a first approach to the topic. Helgeson (1988) concluded from his review of few comparative studies that microcomputer simulations are at least as effective as hands-on experiences for some cognitive outcomes and may in fact enhance these outcomes when the simulations are sequenced to follow hands-on instruction. My research challenges such assertion: computer programs from late 1970's early 1980's did not have the same capabilities as more modern software and the studies did not analyze outcomes by achievement level. When achievement level is taken into account, the ideal sequence of instructional strategies seems to involve exposing students first to a simple unit in computer-mediation, and once they acquired some basic knowledge of the content then to give them hands-on experiences.

Another key factor in the success of an educational strategy that involves small group work is the pairing of students. In this research, the teacher paired the students based on social interactions; however, it would also be desirable to include an element of academic performance in the formation of the small groups. If groups are formed including high and low achievers, the high achievers could contribute to alleviate the manipulative demands of the lab work.

What other application outside of school can this research inform? Aside from school instruction, the finding from this research may serve to inform best practices for remedial programs as well as gifted programs.

However, in order to fully recommend one strategy over the other for these or other kinds of students, the research findings should be coupled with a more powerful test of retention, repeated measures ANOVA, over a longer period of time. It is the goal of education to infuse long lasting instruction; if one strategy produces immediate high achievements but those are not retained over time, the efficiency of such teaching strategy would come into question.

This study assessed academic achievement as an educational outcome, its findings cannot be generalized to other outcomes of instruction such as perceptions of science, use of technology, or acquisition of lab manipulative skills. Results of this research may only generalize to similar studies that employ comparable hands-on and computer units. The hands-on components of this study exposed students to traditional lab equipment such as test tubes and beakers. These materials are far from students' daily lives, which may have added to the difficulties of low achievers. It might be the case that in lab tasks that employ more familiar, less of "scientific/experimental" equipment low achievers would do better. The computer unit was based on real time videotapes of experiments with limited decision-making opportunities for students. More advanced computer simulations where students actually selected equipment, quantities, and drugs may be more challenging and produce different research results.

5.3 LIMITATIONS OF THIS RESEARCH

This research is the first in pointing out differential effects of hands-on and computer-mediated instruction for students of different ability levels. Its findings are consistent all throughout the study. However, several limitations of this investigation should also be pointed out in order to avoid overgeneralization (Eylon, 2000).

The first limitation of this study arises from the characteristics of the sample. Students in this research were mostly children of affluent families who attend a school that adopts an educational philosophy of latitude and choice. Students that were considered low achievers in this study might be medium or high achievers in more regular schools where more guided instruction is imparted. To score high in the school of the study, a student not only has to master curricular content but also has to be skillful in organizing his/her learning. In more regular schools, achievement is mostly based on academic performance following a more structured curriculum; students do not need to develop self-management of learning as much. Hence, a student who is capable of mastering knowledge but lacks ability to strive in unstructured learning environments could be a medium or even high achiever in a traditional school but would be a low achiever in the study school. Therefore, results of a similar study in a more traditional school might turn out differently.

A second limitation of this research arises from the way the teacher formed the groups based on social interactions of students. This criterion has the advantage of pairing students who work well together and then the research probably benefited from the most information that could be extracted from all groups. However, pairing students based on social interactions has the disadvantage of making the analysis of conversation by achievement level unwieldy.

Finally, a third limitation of this study arises from the naturalistic characteristics that were desired as the classroom atmosphere. In order to compare realistic path of instruction under the two conditions, the teacher was given ample freedom to conduct classes the way she would normally do. The teacher tended to gravitate toward low achievers to help them with the most difficult questions, the problems. The computer condition allowed more time for teacher assistance, which is an inherent part of the instructional strategy and desired feature of comparison but at the same time it introduces noise in the measurement of problem solving skills.

5.4 FURTHER RESEARCH

This research has merged two areas of study in science education: instructional strategies and individual differences. Before this dissertation, very little has been done in this respect and results were extremely unreliable. The present work has given consistent evidence about the strong relationship between students' achievement and teaching methods that account for individual differences. However, this is just the first study of its kind; replication studies at more conventional schools should be conducted in order to generalize more validly the conclusions of this research. This first study sets out a research agenda to improve the educational experiences of students. Such agenda would include comparative studies similar to this one, at different school levels and populations, under diverse lab conditions and computer environments for a myriad of individual differences, a variety of other educational outcomes (such as perceptions of science), and various content topics. A few examples of possible inclusions in that research agenda are detailed below.

The main venue of research that this thesis illuminates is the study of several other educational outcomes as dependent on a variety of individual differences. This research focused on academic achievement as a function of teaching techniques and prior achievement; it would be very enlightening to study, for example, students' perceptions of science as a function of teaching techniques and prior achievement or academic achievement as a function of teaching techniques and learning styles, and many other relevant combination of educational factors. Moreover, with all that information, I envision a macroanalysis including several individual differences and teaching techniques to model best instructional strategies to target different groups of students.

An additional line of research that could be conducted is a study of the retention qualities of each instructional strategy for different groups of students. If one of the goals of education is long-lasting learning, it would be desirable to choose a teaching technique that would have a strong retention impact. My work has pointed at this direction with the repeated measures ANOVA; however, I detected no significant differences but the post hoc power of these tests was extremely low. In fact, rescaled delayed measurements of learning yielded higher scores than immediate learning, suggesting various possible explanations, such as: students studying for the test at home, students' integration of concepts upon completion of the content unit, value of last day teacher wrap up of the content, etc. A retention study then should be conducted having a close control of all those sources of variation and probably over a longer than a few days' delay time.

The conversation transcripts are a very valuable source of information. In this thesis only a sample was taken for analysis. However, exhaustive content analysis of conversations will be conducted in a further research by the author to categorize and compare explanations and partial explanations, collaborative learning, misconceptions, and observations of each group of students. The transcripts will be entered into the QSR NUD*IST program for qualitative analysis in the light of pair composition and gender.

An additional source of variation in students' achievement upon differential instructional strategies may be the different views of computers in education that students hold. Rosenquist, Shavelson, and Ruiz-Primo (2000) compared whole group of students exposed to one or the other kind if instruction but again they did not control for achievement level. I hypothesize that low achievers may tend to rely more on what they see than what they do whereas high achievers do the opposite. If that is the case, it would also explain the disordinal interaction reported in this research. Further research in this direction may be worthwhile.

APPENDIXES

APPENDIX A

Lesson plans and student booklet

(Teacher's lesson plan)

Sections where the whole class proceeds together or where students work alone are common to computer and hands-on groups. Sections where students work in groups differ: students in CM condition go thru the experiments and write their results on the computer whereas students in HO condition perform the experiments in the lab and write their results on the booklets.

DAY 1: BASIC CONCEPTS

Learning objectives: After instruction, students are expected to:

- Understand what is and what is not a solution in chemistry and what it is composed of.
- Recognize that almost everything we use (drinks, cleaners, medicines, dental filling, air, stainless steel, etc.) is a solution.
- Be familiar with the terms and concepts "solution," "solvent," and "solutes."
- Identify the solvent and solutes in a solution.
- Be capable of providing examples and explanations of solutions, solvents, and solutes.

Introduction 2 min.	**Teacher introduces the topic of the class**	**Whole class**	Today we will conduct some experiments mixing different substances. We want to see if they mix together, in which case we call it solution, or if the components don't mix together and we can distinguish them apart in the mixture. In this part of the experiment we will learn the terms solution, solute, and solvent. Teacher directs students to get in pairs for the activity.
Activity 1 15 min.	**Teacher monitors students**	**Pairs**	**<u>Dissolving, solvents, and solutes</u>** (see the activity at the end of this appendix).
Definitions and practice 10 min.		**Individual**	See definition and practice problems at the end of the appendix.
Wrap up 5 min.	**Teacher responds to questions**	**Whole class**	Teacher hands out the Answer sheet for the class. Students' questions and handing in the booklets, clean up the room, announcements, etc.

DAY 2: IDENTIFICATION OF SUBSTANCES

Learning objectives: After instruction, students are expected to:

- Reinforce previously learned concepts.
- Realize that the dissolution properties of a substance could serve as the basis for its identification (qualitative analysis).
- Become familiar with the terms and concepts: hydrophobic, hydrophilic, and insoluble substances.
- Solve problems of identification of substances on the basis of their dissolution properties.
- Be capable of designing an experiment for the identification of substances according to their dissolution properties.

Introduction 2 min.	**Teacher introduces the topic of the class**	**Whole class**	Last class we learned that some solutes dissolve in some solvents but not in some others. Today we will study whether dissolution properties could serve as a basis to identify substances. Teacher directs students to get in pairs for the activity.
Activity 2 18 min.	**Teacher monitors students**	**Pairs**	**<u>Identification of substances</u>** (see the activity at the end of this appendix).
Practice 10 min.		**Pairs or individual**	See definition and practice problems at the end of the appendix.
Wrap up 5 min.	**Teacher responds to questions**	**Whole class**	Teacher hands out the Answer sheet for the class. Students' questions and handing in the booklets, clean up the room, announcements, etc.

<table>
<tr><th colspan="4">DAY 3: CONCENTRATION OF SOLUTIONS</th></tr>
<tr><td colspan="4">Learning objectives: After instruction, students are expected to:
• Reinforce previously learned concepts.
• Gain understanding and be familiar with the term and concept “concentration of a solution.”
• Identify when a solution is more or less concentrated.
• Gain understanding and be familiar with the term and concept “concentrated solution,” and “dilute solution.”
• Know how to increase or decrease the concentration of a solution.
• Be able to compare liquid solutions in terms of their volume, concentration, and amount of solute dissolved.</td></tr>
<tr><td>Introduction
2 min.</td><td>Teacher introduces the topic of the class</td><td>Whole class</td><td>Now, when we prepare a solution, like lemonade, some people like it sweeter and some others bitter. The difference resides in the amount of sugar in the cup, the concentration of sugar in the lemonade solution. Today, we will study solutions of different concentrations.
Teacher directs students to get in pairs for the activity.</td></tr>
<tr><td>Activity 4
15 min.</td><td rowspan="2">Teacher monitors students</td><td>Pairs</td><td><u>Concentration of solutions</u> (see the activity at the end of this appendix).</td></tr>
<tr><td>Definitions and practice
10 min.</td><td>Pairs or individual</td><td>See definition and practice problems at the end of the appendix.</td></tr>
<tr><td>Wrap up
5 min.</td><td>Teacher responds to questions</td><td>Whole class</td><td>Teacher hands out the Answer sheet for the class.
Students’ questions, handing in the booklets, clean up the room, announcement of an exam by the end of the unit (one more class), etc.</td></tr>
</table>

DAY 4: CONCENTRATION OF SOLUTIONS (cont.) and SATURATION

Learning objectives: After instruction, students are expected to:

- Reinforce previously learned concepts.
- Gain understanding and be familiar with the terms and concepts “saturated solution” and “solubility.”
- Identify saturated and non-saturated solutions.
- Relate the terms: pure solvent, dilute solution, concentrated solution, and saturated solution.

<table>
<tr><td>Introduction
2 min.</td><td>Teacher introduces the topic of the class</td><td>Whole class</td><td>Last class we learned about concentration of solutions. We may have a diluted solution but if we add more solute to it we get a concentrated solution. Today we will investigate whether we can add more and more solute to a solution and still have all solute dissolved. Teacher directs students to get in pairs for the activity.</td></tr>
<tr><td>Activity 5
15 min.</td><td rowspan="2">Teacher monitors students</td><td>Pairs or individual</td><td><u>Reaching saturation</u> (see the activity at the end of this appendix).</td></tr>
<tr><td>Definition and practice
12 min.</td><td>Pairs or individual</td><td>See definition and practice problems at the end of the appendix.</td></tr>
<tr><td>Wrap up
5 min.</td><td>Teacher responds to questions</td><td>Pairs or individual</td><td>Teacher hands out the Answer sheet for the class.
Students’ questions and handing in the booklets, clean up the room, announcement of next day exam, etc.</td></tr>
</table>

DAY 5: EXAM

Students work individually on a paper-and-pencil exam

Welcome to Solubility and Solutions Unit

This booklet contains: Pg.

ACTIVITY 1: Dissolving, solvents, and solutes

Problem: What substances dissolve and what substances do not dissolve in some liquids?

Materials:

1) 4 test tubes with stoppers in a test tube stand,
2) One teaspoon,
3) Solutes and solvents: colored water, cooking oil, baby oil, and salt.
4) Marker for labeling.

Procedure:

1. Pour about one inch high of colored water into two tests tubes.
   Label them A and B.

2. Pour about one inch high of baby oil into two other tests tubes.
   Label them C and D.

3. Using a teaspoon, put a little bit of salt into test tube A, which contains colored water.
   And again, using a teaspoon put a little bit of salt into test tube C, which contains baby oil.

4. Pour half an inch oil into test tube B, which contains colored water.
   And pour half an inch of oil into test tube D, which contains baby oil.

5. Place a stopper on each test tube.
   Shake the solutions by flipping each test tube 10 times.
   And now let them stand for 1 minute.

6. Observe each test tube closely and from different angles, from the side, from the bottom. Record in the appropriate cell at the table below whether the solute dissolved or didn't dissolve.

Results:

	Colored water	**Baby oil**
Salt	**Tube A = colored water + salt**	**Tube C = baby oil + salt**
Cooking oil	**Tube B= colored water + cooking oil**	**Tube D= baby oil + cooking oil**

7. Read the definitions that follow and fill in Practice #1 individually to turn it in.

DEFINITIONS

Solution: a mixture of two or more substances evenly mixed that looks as though it were all one substance due to the dissolution of the solute/s in the solvent. Most of the things we use (drinks, medicines, cleaners, etc.) are chemical solutions.

Examples:

1) Lemonade IS a solution because it has more than one component (water, sugar, and lemon juice) but it looks all the same.
2) Pasta sauce is NOT a solution because you can distinguish pieces of tomato, carrots, other vegetables, spices, etc.
3) Distilled water is NOT a solution because it only has one component, water. It is a pure substance.

Solvent: a single substance in a solution that dissolves another substance or substances, called solutes, to form a solution. Usually, the solvent is the component in the solution that is present in the largest amount. The solvent determines the state of matter of the solution (i.e. solid, liquid, gas).

Solute: one or more materials dissolved in the solvent. A solution may contain one or several solutes. Together, the solvent and solutes comprise the solution.

(1) Solvent	+	(1 or more) dissolved solutes	=	**solution**

Examples:

a) Lemonade: **sugar** and **lemonade powder** in **water**. The sugar and the powder are the solutes and the water is the solvent. This is a liquid solution.

b) "Silver" dental fillings (amalgams) are solid solutions of **8 parts tin** and **1 part mercury**. Tin is the solvent and mercury is the solute. Such metal alloys are sometimes called "solid solutions".

* **Gaseous solutions:** we do not usually define solute or solvent for these.

- Natural gas (kitchen stove) is a solution of methane and ethane gases.
- Air is a solution of 78% nitrogen, 28% oxygen, and other gases.

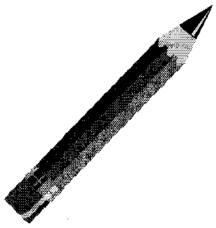
* **Liquid solutions:**

- Gasoline: complex mixture of hydrocarbons
- Blood plasma: water 92%, proteins 7%, salts 1%, small amounts of lipids, and glucose.

* **Solid solutions:**

- Stainless steel (for example a knife): mainly iron and chromium with some nickel and molybdenum
- Dental fillings.

Student ID number: ______________________



Activity 1: **PRACTICE**

1) Going back to your experiment after stirring, circle below all the mixtures that resulted in chemical solutions.

A: water-salt

B: water-cooking oil

C: baby oil-salt

D: baby oil-cooking oil

2) Using your own words, how would you explain to a friend what a solution is in Chemistry. Please, give examples

3) Maria had a liquid in a beaker. She left it aside for a while and when the liquid evaporated, she observed a residue in the beaker. Now she wonders, whether the liquid was a solution or a pure substance.

   a. What would you tell her, was it a solution or a pure substance? Circle your answer

      SOLUTION　　　　PURE SUBSTANCE

   b. How do you know?

2) Wine is composed of water 80-85%, alcohols 10-17% (mainly ethyl alcohol), and some grape-originated acids dissolved that give wine the sour or sharp aspect that enhances flavor.

   Is wine a solution? (Circle your answer)　　YES　　NO

   Explain your answer

If you think it is a solution:

What is the solvent? ______________________________

What are the solutes? ______________________________

3) The Korean War Memorial at PNC Park, the plaques at the Baseball Hall of Fame in New York, and many other statues, and plaques are made of bronze which is an alloy composed of copper about 85%, tin about 5%, lead about 5%, and zinc about 5%.

In this solid solution, the solvent is ______________ and the solutes are ___________, ____________, and _______________.

ACTIVITY 2: Identification of substances

(Students work in pairs)

Problem: To identify substances according to their dissolution properties in various solvents.

Materials:

1) 6 test tubes in a test tube stand,
2) 3 sticks,
3) Substances A, B, and C,
4) Water, vinegar,
5) Marker for labeling.

Procedure:

1. Label the test tubes 1, 2, 3, 4, 5, and 6.
2. Pour about two inches high of water into test tubes 1, 2, and 3.
3. Pour about two inches high of vinegar into test tubes 4, 5, and 6.
4. Using a stick, add a very small amount of substance A to test tube 1, which contains water. Shake the test tube from side to side and let it stand. Using the stick, add a very small amount of substance A to test tube 4, which contains vinegar. Shake the test tube from side to side and let it stand.
5. Using another stick, add a very small amount of substance B to test tube 2, which contains water. Shake the test tube from side to side and let it stand. Using the second stick, add a very small amount of substance B to test tube 5, which contains vinegar. Shake this test tube from side to side and let it stand.
6. Using a third stick, add a very small amount of substance C to test tube 3, which contains water. Shake the test tube from side to side and let it stand. Again, using the third stick, add a very small amount of substance C to test tube 6, which contains vinegar. Shake this test tube from side to side and let it stand.

7a. We put substance A into test tubes 1, which contains water, and 4, which contains vinegar. Compare these test tubes and write in the chart below whether substance A dissolved or didn't dissolve in each test tube.

7b. We put substance B into test tubes 2, which contains water, and 5, which contains vinegar. Compare these test tubes and write in the chart below whether substance B dissolved or didn't dissolve in each test tube.

7c. We put substance C into test tubes 3, which contains water, and 6, which contains vinegar. Compare these test tubes and write in the chart below whether substance C dissolved or didn't dissolve in each test tube.

Results:

	Water	**Vinegar**
Substance A	Tube 1	Tube 4
Substance B	Tube 2	Tube 5
Substance C	Tube 3	Tube 6

The dissolution properties of chalk, sugar, and sand are as follows:

Chalk does not dissolve in water but dissolves in vinegar producing effervescence (bubbles),
Sugar dissolves both in water and in vinegar, and
Sand does not get dissolved either in water nor in vinegar.

Conclusions:

On the basis of the dissolution properties just given, identify the substances
A (which appears in tubes 1 and 4),
B (which appears in tubes 2 and 5), and
C (which appears in tubes 3 and 6)
as either chalk, sugar, or sand:

A = ____________________

B = ____________________

C = ____________________

8. Read the definitions that follow and fill in Practice #2 individually to turn it in.

DEFINITIONS

❖ *Hydrophilic (water-loving) substances*

Water is the most widely used solvent, often referred to as the "universal solvent."

Substances that dissolve in water are called hydrophilic (water-loving substances).

Examples:

1) from Activity 1, we can conclude that salt is a hydrophilic substance because it dissolved in water but cooking oil is not.
2) from Activity 2, we can conclude that sugar is hydrophilic, it dissolved in water.

❖ *Hydrophobic (water-fearing) substances*

Substances that do not dissolve in water, like oil, are called hydrophobic (water-fearing substances).

Hydrophobic chemicals like some plastics and paraffin, are widely applied to the surfaces of fabric fibers to make them water (and stain) repellent.

Example: paraffin is applied to the surfaces of raincoats to make them water repellent.

A hydrophobic liquid like oil, is a good solvent for other hydrophobic substances.

❖ ***Dissolution in other solvents***

Scientists use numerous solvents (such as acids, bases, alcohols, benzene, acetone, etc.) to dissolve substances.

Examples:

1) In the experiment we used acid (vinegar) as a solvent to dissolve chalk.
2) Other substances, like menthol, require alcohol as a solvent to dissolve.

It is important to note that most substances dissolve not just in one but in several solvents.

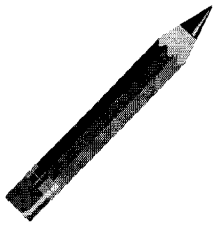
Examples:

3) In the experiment we saw that sugar dissolves in water and vinegar.
4) Caffeine dissolves in water, alcohol, benzene, and acetone.

❖ ***Insoluble substances***

Some substances, like sand in the experiment, just don't dissolve in any solvent.

Student ID number: ______________________



Activity 2: **PRACTICE**

1) If you perform experiments of dissolution of sugar in water and salt in water,

   a. Could you distinguish between sugar and salt? (Circle your answer)

      YES NO

   b. What kind of substances are sugar and salt? (Circle your answer)

      HYDROPHOBIC HYDROPHILIC

2) Can you distinguish between salt and chalk based on their dissolution properties?

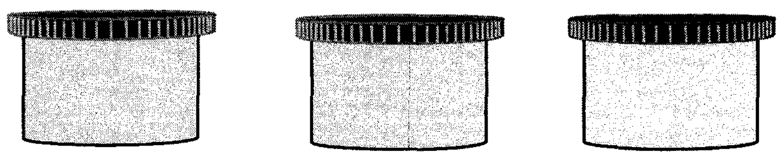
   (Circle your answer) YES NO

   How would you do the experiments?

3) If you are given an unknown substance in a container, what would you do in order to know whether it is hydrophobic or hydrophilic.

4) Sue has lactose, saccharine, and menthol in her kitchen. One day, the labels fell off and she now needs to identify the containers to put the appropriate label back on. She knows that:

Lactose dissolves in water but not in alcohol,
Saccharine dissolves both in water and in alcohol, and
Menthol does not dissolve in water but dissolves in alcohol.



| Lactose | Saccharine | Menthol |

Describe what she can do to identify the species. Make sure you give clear instructions she could follow, state the results you expect, and the conclusions to make.

ACTIVITY 3: Concentration of solutions

(Students work in pairs)

Problem: How do solutions of different concentrations differ?

Materials:

1) water
2) 4 disposable cups,
3) One one-milliliter spoon,
4) One stirring stick,
5) Blackberry lemonade powder
6) Marker for labeling.

Procedure:

1. Pour approximately half a cup of water in each of the 4 disposable cups.
2. Add 1 spoon of blackberry lemonade powder to the first cup. Label it A.
   Add 2 spoons of blackberry lemonade powder to the second cup. Label it B.
   Add 6 spoons of blackberry lemonade powder to the third cup. Label it C.
   Add 9 spoons of blackberry lemonade powder to the fourth cup. Label it D.
3. Stir each solution until all solute is dissolved.
4. Observe the color of each lemonade drink.

   Results: Which solution is darker?

   Which solution is lighter?

5. Predict the taste of each drink.

   Results: Which solution has a stronger sweetest taste?

   Which solution has the most sour taste?

6. Read the definitions that follow and fill in Practice #3 individually to turn it in.

DEFINITIONS

The concentration of a solution is the amount of solute dissolved in either a certain amount of solvent or dissolved in a certain amount of solution.

The concentration of a solution is usually expressed as grams of solute per 100 ml. of solvent or grams of solute per 100 ml of solution.

Examples:

- 12 grams of salt / 100 ml. of water
- 50 grams of sugar in 100 ml of solution

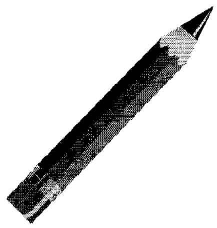
Dilute solution: a solution that has very little dissolved solute relative to the amount of solvent.

Examples: 0.1 grams of sugar / 100 ml. of water

Concentrated solution: a solution that has a large amount of dissolved solute relative to the amount of solvent.

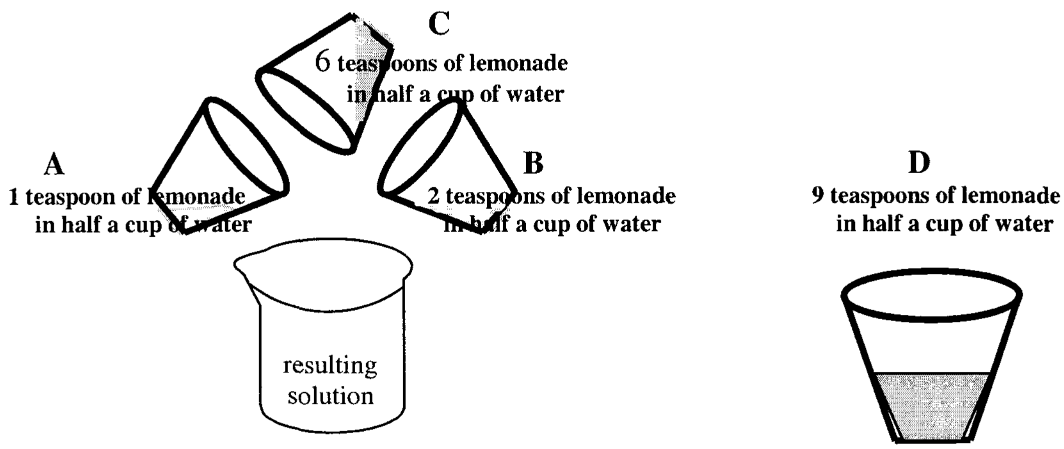
Examples: 180 grams of sugar/ 100 ml of solution

Student ID number: ______________________



Activity 3: PRACTICE

1) Mixing together solutions A, B, and C from the experiment into a big beaker results in a solution containing 9 teaspoons of lemonade because solutions A, B, and C have 1, 2, and 6 teaspoons of lemonade respectively.

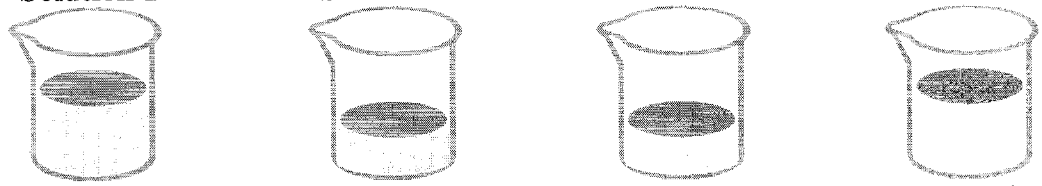


Is this resulting solution containing 9 teaspoons of lemonade the same as solution D in the experiment (9 teaspoons of lemonade in half a cup of water)?

YES NO

Explain your answer

2) Jamar has the following solutions:



Solution 1	**Solution 2**	**Solution 3**	**Solution 4**
One scoop of salt in 100 ml of water	One scoop of salt in 50 ml of water	Two scoops of salt in 50 ml of water	Two scoops of salt in 100 ml of water

A) Which of the solutions is the most concentrated? (Circle your answer)

1 2 3 4

Explain your answer

B) Which of the solutions is the most diluted? (Circle your answer)

1 2 3 4

Explain your answer

C) What can Jamar do to dilute the solutions?

A. Add water.

B. Add salt.

C. Boil the water.

D. Stir the solutions.

ACTIVITY 4: Reaching saturation

(Students work in pairs)

Problem: What happens if we add more and more solute to a solution?

Materials per pair of students:

1) water
2) One 100 ml. beaker,
3) One one-milliliter spoon,
4) One stirring stick
5) Salt

Procedure:

1) Pour approximately 20 ml of water into the beaker.
2) Add 1 one-milliliter spoon of salt. Stir for half a minute.
3) Let it stand. Observe if the salt has dissolved.
   Has all the salt been dissolved? YES (go to 4) NO (go to 5)
4) Add another spoon and repeat the procedure in steps 2) and 3). KEEP TRACK OF THE NUMBER OF SPOONS YOU ADD.
   Do this as many times as necessary until you observe that some salt settles at the bottom and does not dissolve.
5) Note the quantity of spoons added to the beaker.

Result:

A. How many spoons did you use? ____________________________

B. What is the powder at the bottom of the beaker? ______________________

C. Is all the salt that you added from the beginning of the experiment at the bottom of the beaker and nothing dissolved in the water or there is some salt dissolved in water and also some salt at the bottom?

   How could you know?

6) Read the definitions that follow and fill in Practice #4 individually to turn it in.

DEFINITIONS

Saturated solution. When a solution is so concentrated that no more solute can be dissolved, if we add more solute it sinks to the bottom. A saturated solution has the maximum amount of solute dissolved in the volume of solvent at a certain temperature.

Solubility The concentration of the saturated solution at the given temperature.

Solubility is expressed in the same units of any other concentration like grams of solute per 100 ml of solvent or grams of solute per 100 ml of solution.

Examples, at room temperature:

1) Solubility of salt in water is 36 grams of salt in 100 ml of water
2) Solubility of sugar in water is 204 grams of sugar in 100 ml of water

Summing up

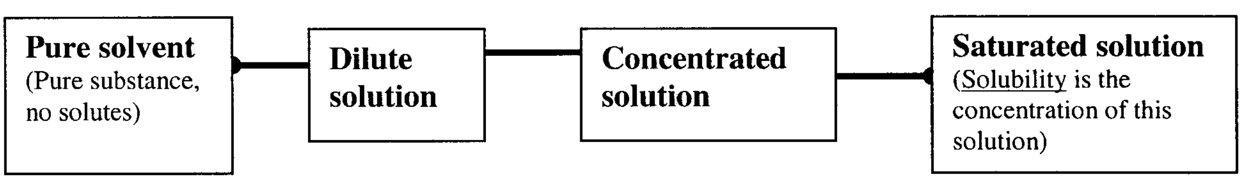
Solubility and **concentration of a saturated solution**

refer to the same concept.

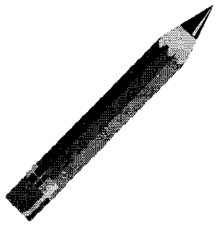
If we start with **pure solvent** and dissolve some solute, we will have a **dilute solution**.

If we keep adding more solute, we will have a **concentrated solution**.

Finally, if we add more solute we will reach **saturation,** no more solute can be dissolved in the solution and if we try adding even more solute it will sink straight to the bottom and will not get dissolved.

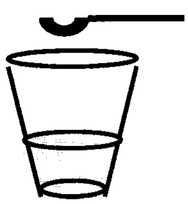


Student ID number: ____________________



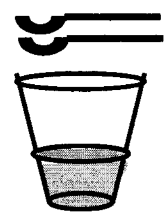
Activity 4: PRACTICE

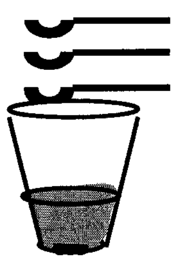
Rosita and Jacob are classmates in the same science lab. Rosita is performing some experiments and Jacob asks her a lot of questions.



At first, Rosita prepares a solution of dye by putting one scoop of yellow dye into a cup of water and stirring.

Then, she adds a second scoop of yellow dye,





Finally, she adds a third scoop and observes a residue at the bottom of the cup.

Here is an extract of the conversation between Rosita and Jacob.

Can you fill in the blanks for Rosita's responses?

Jacob: "Rosita, is the solution in the first cup saturated?"

Rosita: ____

Jacob: "How do you know?"

Rosita: ____

____

Jacob: "Which cup certainly contains a saturated solution, the first cup, the second cup, or the third cup?"

Rosita: ____

Jacob: "How do you know?"

Rosita: ____

____

Jacob: "What is the substance that sank to the bottom in the third cup?"

Rosita: ____

Jacob: "But if you add enough water to the third cup, would the solid in the third cup dissolve or it would not?

Rosita: ____

Jacob: "So if we add more water to the third cup, we will get a concentrated solution that is no longer saturated, correct?

Rosita: ____

Jacob: "So we went from a saturated solution to a non-saturated concentrated solution. What kind of solution will we obtain if we keep adding more and more water?

Rosita: ____

Jacob: "And if we add even more water, will we ever get pure solvent?"

Rosita: ____

Jacob: "Why?"

Rosita: ____

APPENDIX B

End-of-Unit Exam

1. Sarah made a pitcher of lemonade. What can she do to dilute it if she thinks it doesn't taste right? (Circle your answer)

    A. Boil the lemonade.

    B. Add water.

    C. Add sugar.

    D. Stir the lemonade.

2. Two saturated citric acid solutions at the same temperature always have the same

    A. Concentration.

    B. Volume.

    C. Amount of citric acid.

    D. Amount of water.

3. Solubility is the concentration of a

    A. Diluted solution.

    B. Concentrated solution.

    C. Saturated solution.

    D. Pure solvent.

4. Sea water contains a great number of dissolved substances, mainly salt (sodium chloride), magnesium, sulfates, calcium, and potassium.

    Is sea water a solution? YES NO (Circle your answer)

    How can you test that sea water is or is not a solution?

What is the solvent? ____

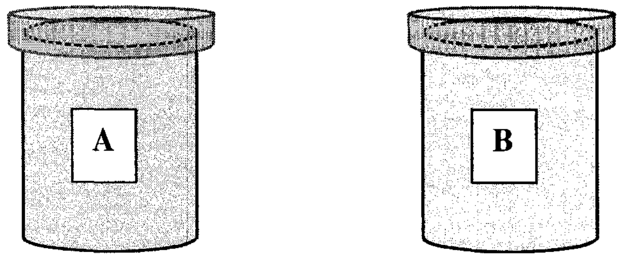
What are the solutes? ____

The solutes are: HYDROPHOBIC HYDROPHILIC (Circle your answer)

How do you know? ____

____

5. Dave has two unlabeled containers, one containing a hydrophobic substances and the other a hydrophilic substances. But he doesn't know which container has which substance. For identification purposes, he labeled the containers A and B.



Help Dave design an experiment to identify the substances.

6. A student is given a test tube containing just a little bit of water and lots of solid at the bottom. The student wants to know whether the solid cannot at all dissolve in water or if we could do something to dissolve it.

What would you do in order to try and dissolve the solid in water?

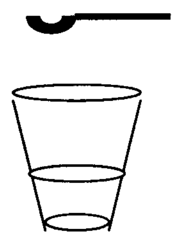
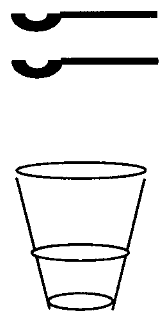
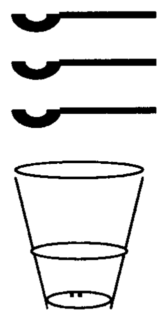
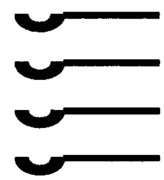
If the solid dissolves, how can you explain that it was not dissolved previously?

If the solid doesn't dissolve,

a) What can you say about the solubility of the solid in water?

b) Do you think it could dissolve in other solvents? Explain your thinking.

7. A student used salt and water to make solutions 1, 2, and 3 as shown below. The student stirred each one and observed the results.

Mixture 1	**Mixture 2**	**Mixture 3**	**Mixture 4**
1 Spoon of salt in 100 ml water  Clear – nothing on the bottom	2 Spoons of salt in 100 ml water  Clear – nothing on the bottom	3 Spoons of salt in 100 ml water  A bit of salt starts to appear on the bottom	4 Spoons of salt in 100 ml water 

If the student adds another spoon of salt to Mixture 3 to obtain Mixture 4, what do you think he/she would observe? Explain your answer with words and with a drawing in the table above.

APPENDIX C

Categorization of questions (CU or PS) and scoring of practice worksheets and exam

Activity 1: **PRACTICE**

1) **(CU)**

Score: A-D: 1 point

Other: 0 points

2) **(CU)**

Score:

For definition:

2 or more substances evenly mixed	*2*
2 or more liquids evenly mixed *2 substances evenly mixed* *2 or more substances together*	*1*
Other def.	*0*

Correct example: 1 point

3)

a. **(CU)**

Score: Solution: 1 point
Other: 0 points

b. (CU)

Score;

Because there were two things *Because it left a residue*	*1*
Other	*0*

4) Is wine a solution? (Circle your answer) **(CU)** YES NO

Score 1 point for YES

0 points otherwise

Explain your answer **(CU)**

Score:

There is more than 1 substance but you see one thing *All substances are mixed together as one*	*2*
There is more than one substance *Looks like one*	*1*
Other.	*0*

If you think it is a solution: **(CU)**

Score: 1 point for correct identification of solvent

1 point for correct identification of solutes

5) **(CU)**

Score: 1 point for correct identification of both solvent and solutes

0 points otherwise

<u>Activity 2: **PRACTICE**</u>

1) a. **(CU)**

b. **(CU)**

Score: 1 point for NO
1 point for HYDROPHILIC

2) **(CU)**

Score: 1 point for YES

How would you do the experiments? **(PS)**

Score

Correct procedure with consistent (right or wrong) results/conclusions	*2*
Just the procedure *Incorrect procedure* *Results/conclusions*	*1*
Other.	*0*

3) **(PS)**

Score:

Correct procedure with consistent (right or wrong) results/conclusions	2
Just the procedure *Incorrect procedure* *Results/conclusions*	*1*
Other.	*0*

4) **(PS)**

Score:

Correct procedure, stating possible results (dissolution properties) and conclude for at least two containers.	*2*
Just the procedure *Incorrect procedure* *Results/conclusions*	*1*
Other	*0*

Activity 3: **PRACTICE**

1) **(CU)**

Score: 1 point for NO

Explain your answer **(CU)**

Score:

The amount of water is different *It got diluted*	*1*
Other	*0*

2)
a. **(CU)**

Score: 1 point for solution 3

Explain your answer **(CU)**

Score:

Has the most solute (salt, dye) and least solvent (water)	*2*

Has the most solute *Has the least solvent*	*1*
Other.	*0*

b. **(CU)**

Score: 1 point for solution 1

Explain your answer **(CU)**

Score

Has the most solvent (water) and least solute (salt, dye, etc.)	2
Has the most solvent *Has the least solute*	*1*
Other.	*0*

3) **Score:** 1 point for A

Activity 4: **PRACTICE**

Jacob: "Rosita, is the solution in the first cup saturated?" **(CU)**

Rosita: *Yes = 0; No = 1*

Jacob: "How do you know?" **(CU)**

Rosita:

Because it's all dissolve *Because you then added another spoon and it still dissolved*	*1*
Other.	*0*

Jacob: "Which cup certainly contains a saturated solution, the first cup, the second cup, or the third cup?" **(CU)**

Rosita:

3rd because it has solute at the bottom 2nd because just a bit more would sink to the bottom	1
Other	0

Jacob: "How do you know?" **(CU)**

Rosita:

Because it has solute at the bottom Because when you added another spoon it went to the bottom	1
Other	0

Jacob: "What is the substance that sank to the bottom in the third cup?" **(CU)**

No points assigned to this question

Jacob: "But if you add enough water to the third cup, would the solid in the third cup dissolve or it would not? **(CU)**

Rosita: *Dissolve = 1; Not dissolve or other = 0*

Jacob: "So if we add more water to the third cup, we will get a concentrated solution that is no longer saturated, correct?

No points assigned to this question

Jacob: "So we went from a saturated solution to a non-saturated concentrated solution. What kind of solution will we obtain if we keep adding more and more water? **(CU)**

Rosita: *Dilute = 1; other = 0*

Jacob: "And if we add even more water, will we ever get pure solvent?" **(CU)**

Rosita: No = 1; Yes = 0

Jacob: "Why?" **(CU)**

Rosita: *Because there's always going to be some solute = 1; Other = 0*

End-of-Unit Exam: Solubility and Solutions: Scoring Rubric

Questions 1-3 **(CU)**, 1 point for each correct responses: B, A, and C respectively.

4) Is sea water a solution? **(CU)** YES NO (Circle your answer)

Score: 1 point for YES

How can you test that sea water is or is not a solution? **(PS)**

Correct procedure (for example evaporating the water and seeing residue, making some of the solutes react with something, etc.) that may lead to conclusion (even w/o stating conclusion)	2
No procedure but whiting the topic (for ex. Look at the ingredients) *Any other procedure including tasting and observing*	1
Other	0

What is the solvent? **(CU)**__________________________________

What are the solutes? **(CU)**______________________________

Score: 1 point for correct identification of both solutes and solvents

The solutes are: HYDROPHOBIC HYDROPHILIC **(CU)**

Score: 1 point for HIDROPHILIC

How do you know? **(PS)**

Because they are dissolved in water (for hydrophilic choice) *Because they are dissolved in water (for hydrophilic choice*	*1*
Other	*0*

5. **PS**

Score

Correct procedure with conclusion.	2
Correct procedure no conclusion (for ex: put them in water) *Conclusion without procedure (for ex: hydrophilic substances dissolve in water).* *Giving definitions.*	1

Other	0

6. What would you do in order to try and dissolve the solid in water? **(PS)**
Score

Stir *Add water* *Heat it up*	*.5*
Other	*0*

If the solid dissolves, how can you explain that it was not dissolved previously? **(PS)**

Score

Not enough water *Not stirred* *Above saturation*	*.5*
Other	*0*

If the solid doesn't dissolve,

a) What can you say about the solubility of the solid in water? **(PS)**

Score

Hydrophobic *Insoluble* *Low solubility*	*.5*
Other	*0*

b) Do you think it could dissolve in other solvents? Explain your thinking. **(PS)**

Score

Yes *It might*	*.5*
No *Other*	*0*

8 **(CU)**
Score

Drawing showing more particles than 3 at the bottom	*.5*
Other	*0*

Writing there would be more particles at the bottom	*.5*
Other	*0*

Explaining that #3 is already saturated so no more salt can be dissolved.	*1*
Other	*0*

Appendix D

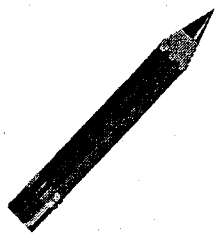
Samples of Students' Practice Worksheets from Activity 4

The whole data set (raw data) is available upon request.

The samples shown below correspond to two high achievers and two low achievers in different classes and under different conditions.

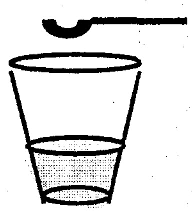
Low achiever

Student ID number: 37



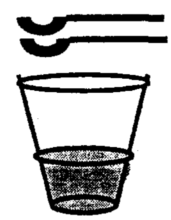
Activity 4: PRACTICE

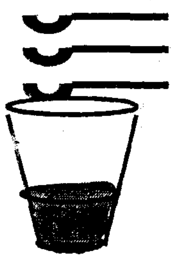
Rosita and Jacob are classmates in the same science lab. Rosita is performing some experiments and Jacob asks her a lot of questions.



At first, Rosita prepares a solution of dye by putting one scoop of yellow dye into a cup of water and stirring.

Then, she adds a second scoop of yellow dye,





Finally, she adds a third scoop and observes a residue at the bottom of the cup.

Here is an extract of the conversation between Rosita and Jacob.

Can you fill in the blanks for Rosita's responses?

Jacob: "Rosita, is the solution in the first cup saturated?"

Rosita: Yes

Jacob: "How do you know?"

Rosita: because you could see salt at the bottom

Jacob: "Which cup certainly contains a saturated solution, the first cup, the second cup, or the third cup?"

Rosita: the third cup

Jacob: "How do you know?"

Rosita: because the first cup was saturated so will the third.

Jacob: "What is the substance that sank to the bottom in the third cup?"

Rosita: Salt

Jacob: "But if you add enough water to the third cup, would the solid in the third cup dissolve or it would not?

Rosita: it would

Jacob: "So if we add more water to the third cup, we will get a concentrated solution that is no longer saturated, correct?

Rosita: Yes

Jacob: "So we went from a saturated solution to a non-saturated concentrated solution. What kind of solution will we obtain if we keep adding more and more water?

Rosita: it would become pure solvent

Jacob: "And if we add even more water, will we ever get pure solvent?"

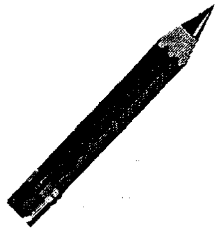
Rosita: no

Jacob: "Why?"

Rosita: because I think there will stay look pure but you could see if you look really hard you could see tiny bits of salt.

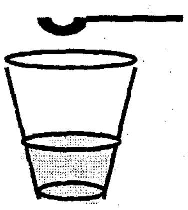
Low achiever

Student ID number: 31



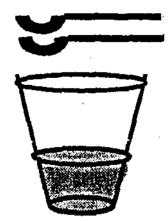
Activity 4: PRACTICE

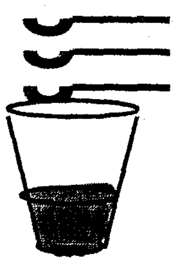
Rosita and Jacob are classmates in the same science lab. Rosita is performing some experiments and Jacob asks her a lot of questions.



At first, Rosita prepares a solution of dye by putting one scoop of yellow dye into a cup of water and stirring.

Then, she adds a second scoop of yellow dye,





Finally, she adds a third scoop and observes a residue at the bottom of the cup.

Here is an extract of the conversation between Rosita and Jacob.

Can you fill in the blanks for Rosita's responses?

Jacob: "Rosita, is the solution in the first cup saturated?"

Rosita: No

Jacob: "How do you know?"

Rosita: Because there is no salt left

Jacob: "Which cup certainly contains a saturated solution, the first cup, the second cup, or the third cup?"

Rosita: The third cup

Jacob: "How do you know?"

Rosita: Because I put the first two scoops in and they both dissolved, but in the 3rd there was some salt left.

Jacob: "What is the substance that sank to the bottom in the third cup?"

Rosita: Salt

Jacob: "But if you add enough water to the third cup, would the solid in the third cup dissolve or it would not?

Rosita: It wouldn't

? Jacob: "So if we add more water to the third cup, we will get a concentrated solution that is no longer saturated, correct?

Rosita: Yeah

Jacob: "So we went from a saturated solution to a non-saturated concentrated solution. What kind of solution will we obtain if we keep adding more and more water?

Rosita: A clearer substance.

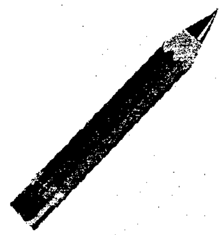
Jacob: "And if we add even more water, will we ever get pure solvent?"

Rosita: No

Jacob: "Why?"

Rosita: Because there's always salt that isn't dissolved.

Student ID number: 2



Activity 4: PRACTICE

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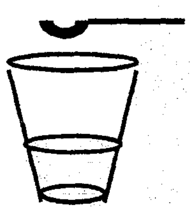
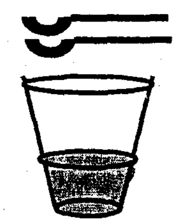
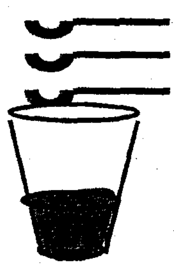


At first, Rosita prepares a solution of dye by putting one scoop of yellow dye into a cup of water and stirring.

Then, she adds a second scoop of yellow dye,





Finally, she adds a third scoop and observes a residue at the bottom of the cup.

Here is an extract of the conversation between Rosita and Jacob.

Can you fill in the blanks for Rosita's responses?

Jacob: "Rosita, is the solution in the first cup saturated?"

Rosita: No it is not.

Jacob: "How do you know?"

Rosita: Because there is no dye at the bottom of the cup.

Jacob: "Which cup certainly contains a saturated solution, the first cup, the second cup, or the third cup?"

Rosita: The third cup.

Jacob: "How do you know?"

Rosita: Because there is dye at the bottom of the cup.

Jacob: "What is the substance that sank to the bottom in the third cup?"

Rosita: Broken up dye.

Jacob: "But if you add enough water to the third cup, would the solid in the third cup dissolve or it would not?

Rosita: It would dissolve.

Jacob: "So if we add more water to the third cup, we will get a concentrated solution that is no longer saturated, correct?

Rosita: Yes, correct.

Jacob: "So we went from a saturated solution to a non-saturated concentrated solution. What kind of solution will we obtain if we keep adding more and more water?

Rosita: We will get a diluted solution.

Jacob: "And if we add even more water, will we ever get pure solvent?"

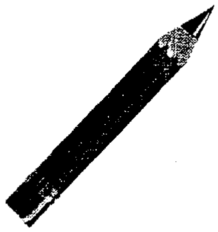
Rosita: No

Jacob: "Why?"

Rosita: Because evan if it's dissolved it's still there.

High achiever

Student ID number: 36



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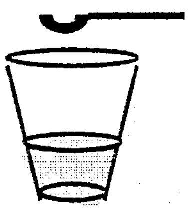
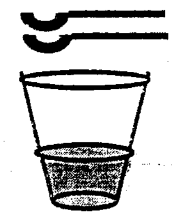
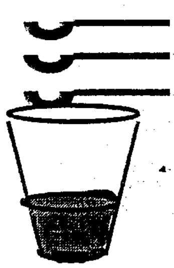


At first, Rosita prepares a solution of dye by putting one scoop of yellow dye into a cup of water and stirring.

Then, she adds a second scoop of yellow dye,





Finally, she adds a third scoop and observes a residue at the bottom of the cup.

Here is an extract of the conversation between Rosita and Jacob.

Can you fill in the blanks for Rosita's responses?

Jacob: "Rosita, is the solution in the first cup saturated?"

Rosita: Nope

Jacob: "How do you know?"

Rosita: Because it still dizzolved

Jacob: "Which cup certainly contains a saturated solution, the first cup, the second cup, or the third cup?"

Rosita: third cup

Jacob: "How do you know?"

Rosita: beacase that has alot of stuff in it

Jacob: "What is the substance that sank to the bottom in the third cup?"

Rosita: the dye

Jacob: "But if you add enough water to the third cup, would the solid in the third cup dissolve or it would not?

Rosita: Yes

Jacob: "So if we add more water to the third cup, we will get a concentrated solution that is no longer saturated, correct?

Rosita: corret

Jacob: "So we went from a saturated solution to a non-saturated concentrated solution. What kind of solution will we obtain if we keep adding more and more water?

Rosita: none

Jacob: "And if we add even more water, will we ever get pure solvent?"

Rosita: ~~Yes~~ NO

Jacob: "Why?"

Rosita: ~~because soon their will only be a little bit of stuff and alot of watch~~ ~~the~~ the stuff will always be there

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