

**Learning Strategies Used by Honors Students
in an Investigative Introductory Biology
Laboratory Program**

by

Diah Aryulina

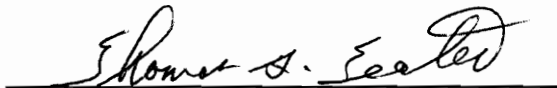
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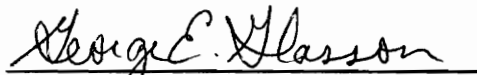
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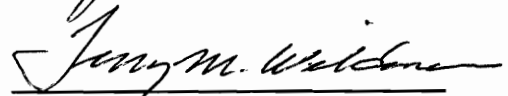
APPROVED:


Dr. Thomas G. Teates, Chairman


Dr. Arthur L. Buikema Jr.


Dr. Larry J. Weber


Dr. George E. Glasson


Dr. Terry M. Wildman

August 1995

Blacksburg, Virginia

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1995

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**LEARNING STRATEGIES USED BY HONORS STUDENTS
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Committee Chairman: Dr. Thomas G. Teates

(ABSTRACT)

The use of investigative laboratory programs is one of the recommended methods of instruction for improving the outcomes of college science laboratory work. In such programs, students are expected to take more responsibility for their learning and to exercise manipulative skills as well as their thinking. One factor that contributes to students' learning success is their learning strategies.

In order to increase our understanding of students' learning strategies in an investigative laboratory program, a qualitative research design was used in this study. The participants for this study were ten students who were enrolled in Principles of Biology Laboratory H115 which used an investigative approach. The primary data were gathered through interviews with the students. Additional data to provide a more holistic description of some aspects of the students' use of learning strategies were obtained from assessment of the students' learning style, a review of

course syllabus and handouts, non-participant observations, and interviews with the instructors.

The interviews were transcribed, coded, and analyzed to identify learning strategy themes. The data from other sources also were used to identify the learning environment characteristics of the program. The study identified three students' learning strategy themes: understanding the learning situation, active learning, and interactive learning. The results of this study suggest that students use of certain learning strategies to complete laboratory activities because of the interactions between students' characteristics and the learning situation in the program. Instructors as well as students need to be aware of the importance of appropriate learning strategies for a program and how the application of the strategies is affected by students' individual characteristics and the learning situation.

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In memory of
my mother
whose strength and love to learn
have inspired me

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CHAPTER 1

INTRODUCTION

The United States has been a world leading country in the field of technology since World War II (Bloch, 1986). Bloch argues that as a leader in technology, the United States needs to have a sound educational system in science, mathematics, and technology from primary school through college. Educational improvement in science and technology needs to be focused especially in undergraduate colleges (AAAS, 1990; Bloch, 1986). Undergraduate colleges are considered to be the primary places where most students who will become future national leaders experience their last formal learning in science and technology subjects. Some of these students will become teachers, the front lines in the educational system, who are expected to be able to improve science, mathematics, and technology education.

Undergraduate biology education has been one of the targets for improvement in college science education. The National Science Foundation pointed out that the main goal of undergraduate biology is to provide opportunities for nonmajor and major students to learn scientific, critical, and creative reasoning skills (NSF, 1989). The scientific, critical, and reasoning skills were specifically described by the NSF as "the ability to explore nature, to generate

multiple tentative answers, and to test these through deduction of their logical consequences and a comparison with evidence" (p. 76). The American Association for the Advancement of Science suggested an approach to develop these skills by applying interdisciplinary science courses that integrate aspects of science with other aspects of liberal education such as language (AAAS, 1990).

In undergraduate biology laboratory, most attempts to help students learn scientific skills have involved having the students conduct laboratory activities. The roles of laboratory in science learning have been reviewed as part of the efforts to address the issue of improvement of science education. The conventional roles of science laboratory described by Blosser (1983) as a place for practicing observational and manipulative skills and for stimulating students' interest were considered to be insufficient for improving scientific process skills. According to Hofstein and Lunetta (1982), besides developing manipulative skills and increasing students' interest, appropriate laboratory activities should also be able to promote logical development and develop inquiry and problem solving skills. Holt et al.(1972) argued that the investigative role of laboratory, that is, engaging students in the processes of scientific investigation, should be the primary role. This investigative role as the primary role of laboratory also is stressed by The National Science Foundation (1989). In supporting their

argument, Holt et al. (1972) stated that considering the efforts and expensive financial support used to provide science laboratory programs, the laboratory should not be used for activities that can be learned via other instructional methods. For example, they suggested that if laboratory activities are used primarily to illustrate concepts from lecture courses, this purpose can be served through the use of audio-visual aids or demonstrations. They also stated that focusing on training students with manipulative skills was inefficient for laboratory activities because many of the skills that the students learn may not be applicable in the future. Investigative laboratory activities are more efficient and effective for science laboratory because these activities stimulate thinking and interest for science as well (Holt et al, 1972).

Although current thinking suggests that the primary role of laboratory work should be for engaging students in the processes of scientific investigation, many introductory science laboratory activities do not seem to support this concept. According to Stewart (1988), most laboratory experiments in introductory college science do not really introduce students to science processes. She noted that students usually only follow a set of instructions in doing experiments that are already designed to most likely produce useful data. The students' responsibility appears only to be to collect data to illustrate or verify concepts they already

have learned in a lecture. During the laboratory, students may not really understand or need to understand what they are doing because they just follow what is listed in the instructions. This approach to laboratory work that many educators describe as "cookbook" may be helpful for some students in guiding their collection of data. However, it can limit opportunities for students to learn other processes of scientific work. A study conducted by Tamir and Amir (1987) revealed that students who were able to do technical aspects of experiments were not necessarily able to do other scientific skills such as formulating hypotheses, designing experiments, or analyzing data. They concluded that four major science process skills: planning and designing, performance, analysis and interpretation, and application, are independent skills. These skills all need to be practiced.

Another disadvantage of using experiments that rely heavily on clear step-by-step instructions is that they may mislead students about the ways of knowing in science which involve not only confirmation of concepts but also inquiry about concepts. Stewart (1988) stated that it is important for college students to understand the processes of investigation which in reality do not necessarily follow a set of clear directions.

The introductory biology laboratory in college is one course taken by many college students to fulfill the science

core requirement. For some students who are not majoring in science related fields, the laboratory may be their last formal learning of scientific work. Stewart (1988) stressed the importance of non-science majors to learn science processes because some of these students in the future will be involved in making decisions related to scientific research. For students who are science majors, learning science processes in an introductory biology laboratory can be good practice for developing a better understanding of the processes (Seago, 1992; Thornton, 1972).

To address the role of the introductory biology laboratory in providing opportunities for students to learn science process skills, NSF (1989) recommended greater use of open-ended investigative laboratory and field activities. Other authors also suggested that investigative laboratory approaches are considered to be the best approaches for meaningful introductory biology laboratory work (Fogle, 1985; Gottfried et al., 1993; Holt et al., 1972). These approaches provide less direction for students to do the laboratory experiments, and allow students to be more directly involved in the processes of scientific work. The characteristics of the investigative approaches are the opposite of the ones in more traditional laboratory approaches in which the students' activities are designed to verify concepts or to study concepts through linear step-by-step instructions.

Several studies of college science laboratory work have been conducted to compare the educational benefits of investigative approaches with more traditional ones. Leonard (1989), in his review of college science laboratory research published since 1978, reported that investigative approaches generally produced greater educational benefits than traditional approaches. The approaches seem to promote the development of students' intellectual skills such as problem solving, critical, and reasoning skills because the students are involved in the processes of scientific investigations that require the use of scientific skills. In his report, Leonard (1989) also stated that there are at least three characteristics of productive instruction in college science laboratory: (1) students are involved in scientific investigation processes, (2) students have opportunities to have hands-on experience in manipulating instruments, and (3) students have opportunities to learn science process skills and science concepts simultaneously.

Even though the advantages of open-ended investigative approaches in improving students' scientific skills are known by many educators, the approaches have not been widely applied in introductory biology laboratories (Fogle, 1985; Gottfried et al., 1993; NSF, 1989; Sundberg & Armstrong, 1993). Sundberg and Armstrong (1993), who conducted a survey study on laboratory instruction for introductory biology in American universities, found that even though the

investigative approaches have been adopted in some small liberal arts colleges, these approaches have not been widely adopted in larger universities. Sundberg and Armstrong reported that of the 73 institutions that responded to the survey, only three reported that they had fully adopted an investigative approach in their biology laboratories. Half of the responding institutions reported that they use the approach in some of their laboratory activities. Further, the authors explained that most institutions reported the use of laboratory activities that were designed by instructors, adopted from workshops and conferences, or modifications of materials in commercial laboratory manuals. Two institutions reported that they exclusively used commercial laboratory manuals.

There are several reasons given by educators to explain why the investigative laboratory approach has not been widely applied. According to Sundberg and Armstrong (1993), reasons for not using the investigative laboratory are related to personnel, space, budget, and support facilities factors. They found that the majority of universities participating in their study mentioned at least one of these four factors at their institutions as insufficient to support an investigative laboratory program. However, from their study on universities that offered such programs, a determinant factor in the decision to do so is the commitment of instructors to put extra time into the program. This

includes having training for instructors on how to conduct this type of laboratory activity.

Another common reason for not using the investigative approach was the instructors' perceptions of students' abilities to do investigative laboratory work. Costenson and Lawson (1986) noted that many teachers perceive investigative work as difficult for most students because of its lack of sufficient specific directions. However, Cavana and Leonard (1985) suggest that investigative laboratory can work well for all ability levels of secondary and college students, not just academically talented students. A study conducted by Leonard (1989) in college general biology laboratory classes demonstrated that students who used the open-ended investigative approach that he called Extended Discretion (ED) can perform as well as students who used a guided investigative (GI) approach. In the ED approach the students were given a limited amount of guidance for conducting the laboratory experiments, whereas, in the GI approach students were given clear step-by-step procedures to guide them through the laboratory work. Even though the result of the study showed that there were no significant differences between the two approaches on students' performance on a multiple-choice exam, laboratory reports, and quizzes, the author suggested that students are capable of doing open-ended investigative laboratory work that is more difficult than the guided investigative one.

Few studies have been reported which examined students' learning experiences in an investigative laboratory for undergraduate biology from the students' perspectives. One such study was conducted by Murray (1972) who explored students' perceptions of investigative activities by interviewing fifty undergraduate students from five universities. He found that, generally, as the activity progressed, the students expressed more positive responses toward the activities even though they expressed a feeling of anxiety at the beginning of the activity because of uncertainties about what they had to do. Two survey studies administered at different times to 600 enrolled students by Davis and Black (1985) to gather opinions of the investigative laboratory showed that a majority of responding students felt that their problem solving skills improved during the laboratory work. The students also reported that they had gained more appreciation and understanding of the processes of scientific work. A relatively small percentage of students, 15% from the first survey and 13% of the second, preferred a more structured laboratory. In a study conducted by Leonard (1989), students who participated in open-ended investigative laboratory commented that the activity was more challenging and described it as real science work compared to the more structured laboratory they were used to.

Several authors noted that few research studies have been done from students' perspective on how they learn in

science (Tobin, 1990) and in biology (Gottfried et al., 1993). These authors suggest that more studies in this area should be conducted. These studies are considered to be necessary for improving science teaching.

Statement of the Problem

In an open-ended investigative laboratory the students are expected to take more responsibility for doing laboratory activities. This means the students need to be resourceful in solving the problems they encounter in the laboratory. One factor that may contribute to students' success in solving problems in the laboratory is their use of learning strategies. According to Hegarty-Hazel and Prosser (1991), students' ability to use appropriate learning strategies is one critical factor for successful learning.

Studies of students' learning strategies in an investigative biology laboratory were not found. The available literature has not reported what the students actually do to solve the problems they encounter when they conduct investigative activities. In view of the lack of information about students' learning from the students' perspective, this study attempts to provide information about some of the learning strategies used by the students in an investigative laboratory program.

Purpose of The Study

The primary purpose of this study was to examine learning strategies used by college students in an investigative laboratory program of introductory biology. Additional information on characteristics of the students and the instructors, and the themes of learning in the laboratory also was gathered.

The study addressed the following main questions:

1. What were the perceived difficulties the students experienced in the investigative laboratory?
2. What learning strategies did the students report using in overcoming the difficulties and completing laboratory work?
3. What were the characteristics of students and instructors participating in this study?
4. What were the characteristics of the learning processes in the program?

Importance of the Study

The findings from this study should provide a better understanding of learning strategies used by students who participate in an investigative science laboratory. Better understanding of this area of knowledge could help those who are involved in the implementation of this type of program.

Sundberg and Armstrong (1993) stated in their report that success in applying this approach is mostly determined by the willingness of the instructors to devote time to implement the approach. Information from the current study should help instructors who are concerned with the processes of teaching this type of laboratory become aware of students' learning processes. As a result of this study, instructors may be better prepared to help students when they are faced with difficulties in laboratory activities. They could share alternative strategies that have been used by students in this study to solve problems encountered in the laboratory. In this respect, students can learn how to solve laboratory problems from other students' experiences. They can also possibly obtain a better understanding of the nature of investigative laboratory work.

Limitations

1. The number of student participants in this study was small (ten students) and limited to students who were enrolled in Principles of Biology Laboratory H116 at the Virginia Polytechnic Institute and State University in Fall Semester 1994. All participants were in an honors program.
2. The interviewer is a foreign student with a different mother language.

Definition of Terms

The following terms used in this dissertation are defined as indicated:

Open-ended Investigative laboratory method: an instructional method that engages students directly in the processes of scientific research with less guidance from the instructor.

Honors program: A program for students who met the following criteria:

- Freshman students who had a minimum 1200 SAT score with both math and verbal score above 550 and who were in the top ten percent of their high-school graduating class.
- Students who had completed one or more semesters of study at Virginia Polytechnic Institute and State University or another college with a cumulative GPA of 3.4 or above. (University Honors Program, informational booklet. Fall 1993).

Principles of Biology Laboratory H1115: an introductory biology laboratory that used an open-ended investigative approach.

Learning strategies: "strategies and thoughts that a learner engages in during learning and that are intended to influence the learner's encoding process" (Weinstein and Mayer, 1986).

CHAPTER 2

LITERATURE REVIEW

Learning strategies are considered to be part of learning processes (McKeachie et al., 1986). There is a large body of literature that presents discussions and research about learning strategies. Some of the foci of research related to learning strategies include the function of learning strategies on students' learning, the influence of students' cognitive and motivation characteristics on learning strategies, the influence of the learning situation on learning strategies, and the results of the teaching of learning strategies. The examination of the types of learning strategies utilized in certain subjects or learning situations also has been the subject for research. However, only a few studies about the types of learning strategies used in science laboratories have been reported. Reports of research on learning strategies used in a more specific learning situation such as an investigative college biology laboratory were not found.

This review of literature includes four areas pertinent to the examination of students' learning strategies and the context for their use in science learning: definitions of learning strategy, functions of learning strategies, effects of characteristics of individual students on learning

strategies, and the use of learning strategies in relation to a learning situation.

Learning Strategy Defined

Learning strategy has been defined in various ways. In the literature, the term *learning strategy* has been used interchangeably with *learning approach*. The term also seems to have overlapping meaning with the term *learning style*. Pask (1976) used *learning strategy* to refer to students' preferences in handling an individual task. He differentiated the term from *learning style* that is frequently related to general learning preferences.

Rigney (1978) defined learning strategies as general procedures that students may use to acquire, retain, and retrieve different kinds of knowledge and performance. Dansereau (1985) explained learning strategies in relation to learning objectives. He described learning strategies as a plan for a sequence of actions to achieve learning objectives. Therefore, learning strategies are manifested not as simple actions but as a complex link of intentional actions. Weinstein and Mayer (1986) defined learning strategy as any thought or action in which a student engages. This definition includes memory strategies such as rehearsal and elaboration, as well as general problem solving strategies such as organization and monitoring. Applications

of these strategies are intended to influence cognitive processes during learning such as selection, organization, and integration of new information with students' prior knowledge.

McKeachie et al. (1986), in their literature review, provided several definitions of learning strategy. Some of the definitions were similar to those described by Weinstein and Mayer (1986) and may include intentional and unintentional processes of learning. Other researchers including Dansereau and McKeachie have limited their definitions of learning strategies to cognitive processes that are intentional and under the control of the student. Marton and Saljo (1984) included intentions as well as processes to describe learning approaches. The term *learning approaches* has been used by other researchers to mean *learning strategy*.

Even though learning strategy has been defined differently according to the extent of thinking and actions involved, the definitions are all based on the same information processing theory of learning. The information processing theory of learning refers to "the study of how humans perceive, comprehend, and remember the information they gain from the world around them" (Woolfolk, 1990). Within this framework, for example, Weinstein and Mayer (1986) suggested that four components of information processes of learning - selection, acquisition, construction, and

integration - are affected by learning strategies. McKeachie et al. (1986) use the terms of attention, encoding, organization, and retrieval to describe the same concepts of information processing described by Weinstein and Mayer (1986). The first process of learning, attention, refers to the control of attention to certain information and transfer of that information to student's short-term memory. The encoding process involves the transfer of information from short-term memory to long term memory for permanent storage. In the organization process, information is connected and organized. And in the integration process, new knowledge is connected with previous knowledge, so that retrieval is facilitated in the future.

The definitions of learning strategies suggest the primary influence of the strategies is on the processing of new information to facilitate learning. However, with regard to the whole learning process, different learning strategies can serve different functions as indicated in the next section.

Functions of Learning Strategies

Based on functions of learning strategies, researchers have developed classifications or taxonomies of the strategies. Dansereau (1985), McKeachie et al. (1986), Rigney (1978), and Weinstein and Mayer (1986) provide

examples of learning strategy classifications. Rigney (1978) classified learning strategies into three groups of capabilities: representational capabilities such as reading and imagery, selectional capabilities such as attention and intention, and self-directional capabilities such as self-regulating and self-monitoring. Dansereau (1985) developed a classification system consisting of two main groups: primary strategies such as comprehension retention, retrieval, and utilization; and support strategies such as goal setting, mood setting, and self-monitoring. Weinstein and Mayer (1986) proposed a similar classification of learning strategies in their eight categories of strategies: basic rehearsal strategies; complex rehearsal strategies; basic elaboration strategies; complex elaboration strategies; basic organizational strategies; complex organizational strategies; comprehension monitoring strategies; and affective-motivational strategies.

A more elaborated classification of learning strategy has been developed by McKeachie et al. (1986). The classification consists of three main groups of learning strategies: cognitive, metacognitive, and resource management strategies (Table 1). Each learning strategy group contains several specific strategies. These strategies influence each other and affect the overall learning.

Table 1. A Taxonomy of Learning Strategies

Cognitive Strategies	Basic Tasks (e.g., memory for lists)	Complex Tasks (e.g., test learning)
Rehearsal strategies	Reciting list	Shadowing Copy material Verbatim note taking Underlining text
Elaboration strategies	Keyword method Imagery Method of loci Generative note taking Question answering	Paraphrasing Summarizing Creating analogies
Organizational strategies	Clustering Mnemonics	Selecting main idea Outlining Networking Diagramming
Metacognitive Strategies		All Tasks
Planning strategies	Setting goals Skimming	General questions
Monitoring strategies	Self-testing Attention-focus	Test-taking strategies
Regulating strategies	Adjusting reading rate Rereading	Reviewing Test-taking strategies
Resource Management Strategies		All Tasks
Time management	Scheduling	Goal setting
Study environment management	Defined area Quiet area	Organized area
Effort management	Attribution to effort Mood Self-talk	Persistence Self-reinforcement
Seeking help from teacher Seeking help from peers	Support of others Tutoring	Peer/group learning

Source: Teaching and Learning in the College Classroom: A Review of the Research Literature by McKeachie, Pintrich, Lin, and Smith. 1986. Ann Arbor: National Center for Research to Improve Postsecondary Teaching and Learning, University of Michigan.

The first strategies of McKeachie's classification, cognitive strategies, are "strategies related to the students' learning or encoding of material as well as strategies to facilitate retrieval of information" (McKeachie et al., 1986). The functions of the strategies are for processing new information. The three cognitive strategies described are rehearsal, elaboration, and organization. Rehearsal strategies refer to memorizing and rote rehearsal. Elaboration strategies are defined as efforts to learn the information in detail for understanding. And organizational strategies refer to identification of important ideas and organizing them. McKeachie et al. (1986) further distinguished each of the three groups of cognitive strategies in response to two types of learning tasks, basic tasks and complex tasks. For example, a rehearsal strategy used for a basic task which requires remembering materials in an ordered list usually is a memorization strategy. McKeachie and his colleague's differentiation of cognitive strategies suggest that each of those strategies results in a different quality of learning. Marton and Saljo (1976) differentiated two qualitative characteristics of students' cognitive strategies: surface learning and deep learning. Surface learning is used by students who direct their attention toward rote learning. Deep learning is adopted by students who study for the purpose of attaining greater understanding of the content. Marton and Saljo's as well as

Weinstein and Mayer's and McKeachie's differentiation of cognitive processes of learning are similar to Ausubel's (1968) distinction between rote and meaningful learning. According to Ausubel (1968), the difference between the two approach of learning is the degree of student's effort to connect new knowledge to the student's existing knowledge. Therefore, meaningful learning may involve the changing of existing knowledge to incorporate additional meaningful knowledge.

The second dimension of McKeachie's learning strategies is related to metacognition. Metacognition refers to a person's knowledge and awareness of his or her knowledge and the control and regulation of his or her learning. The control and regulation aspects of learning strategies involve students' planning, monitoring, and regulating (McKeachie et al., 1986). The first planning activities refer to strategies students use to process the learning material in order to achieve learning goals. A second strategy, monitoring, covers the metacognitive strategies that assist students in understanding the material and integrating it with their existing knowledge. The third activity of metacognitive strategies is self regulation which helps students in evaluating their learning as they do the task. According to Paris and Winogard (1990), because self regulation requires effort it also involves motivation.

The third dimension of learning strategies, resource management strategies, refers to a variety of strategies that help students in managing the environment and the resources available to meet their needs (McKeachie et al., 1986). These strategies can be seen as both cognitive and metacognitive. The management strategies include time management, study environment management, effort management, and seeking support from others.

The taxonomy of learning strategies developed by McKeachie and his colleagues provides a broad description of the strategies. Each individual may use different strategies for a certain task, but there are general strategies that are common to a wide range of subject matter. Sternberg and Davidson (1992) suggest six general problem solving processes: (1) identifying the problem, (2) forming an internal representation, (3) encoding, (4) planning, (5) strategy selection, and (6) solution monitoring.

Even though strategies vary from specific to general in their application, their effectiveness depends on students' abilities to select appropriate strategies in a certain learning situation. Characteristics of individual students are factors that influence their ability to select appropriate strategies (McKeachie et al., 1986).

Learning Strategies and Individual Differences

The importance of strategies in learning suggests that successful learning depends largely on the student's effort. Because the student plays a central role in learning, the application of learning strategies is directly related to his or her individual characteristics. Differences in learning strategies, therefore, can be linked to differences in students' characteristics. Students' characteristics, according to McKeachie et al. (1986) can be categorized into cognition and motivation characteristics. These two broad categories of individual characteristics will be explained in relation to learning strategies.

Students' Cognition and Learning Strategies

A review of the literature provided reports that aspects of students' cognition in relation to learning strategies may involve thinking abilities, prior knowledge, and cognitive style. According to Biggs (1980), students' thinking abilities influence the way they process information. He reported that students can only process information deeply when they reach the stage of formal operations which is the highest stage of thinking skill beyond the other three successive stages of Piaget's cognitive developmental stages (Piaget, 1964). When a person reaches the formal operational stage, he or she is believed to be able to think abstractly.

The rate of reaching this stage of thinking skill may be different from one person to another. According to Neimark (1975), most people do not reach the level of formal operations by the end of adolescence. Research done by Killian (1979) shows that only 25% of college freshman students are at the formal operational stage. In addition, about one-half of the students enrolled in college introductory biology are predicted to be not fully formal operational (Lawson, 1980). Vu (1977) in Schmeck (1983) found that a student that is formal operational in one content area may not have reached it in other areas. In science, which consists of many abstract concepts, students' who have not reached formal operational thinking may have difficulty understanding the content. This difficulty with understanding may be related to the inability of the students to process abstract information in a deep level (Biggs, 1980). A study conducted by Fleener (1993) in high school science showed that there is a relationship between the level of students' thinking skill and the strategies used for solving reasoning tasks. Students who had high scores on the formal operational level tended to be able to select appropriate strategies.

The influence of prior knowledge on learning has been widely studied. Ausubel (1968) proposed that prior knowledge and learning strategy are important factors for meaningful learning to occur. Studies conducted by Glasson (1989) and

Lawson and Thompson (1988) showed a positive correlation between the students' knowledge and level of understanding after instruction. According to Hegarty-Hazel and Prosser (1991), successful learning is determined not only by students' prior knowledge on the subject but also by their prior knowledge of learning strategies. Paris, Lipson, and Wixson (1983) proposed three types of knowledge about learning strategies that are important to the application of the strategies. The three types of knowledge involve: (1) declarative knowledge, that is the knowledge about learning strategies, (2) procedural knowledge, which is the knowledge about how to use the strategies, and (3) conditional knowledge, which is the knowledge about when and why to use the strategies. Jakoubek and Swenson (1993), in their research on undergraduate students at different grade levels, found that higher grade level students who are considered to have more knowledge of the subjects and strategies apply deeper learning strategies compared to lower grade level students. According to Thomas and Rohwer (1986), experienced students develop a more a complex knowledge than inexperienced students. They also argued that students who learn a new subject tend to process it at a shallow level using rote strategies. A novice in a new learning situation or a young child often does not know how to use the appropriate strategy that an expert or adult might use (Siegler, 1985).

Prior knowledge or experience a student has seems to influence his or her learning style. According to Kolb (1985), experience in a certain learning situation is one factor that forms the learning style of a student. He stated that this past experience, together with heredity and the demand of the present environment, produce a student's learning style. Each student is believed to have certain preferences or style in learning. This learning style seems to influence students' use of strategies since, according to Pask (1976), learning style is actually a student's general learning strategy.

Students' Motivation and Learning Strategies

According to Biggs (1985), students tend to use learning strategies that correspond to their motives. He classifies students' motives as surface, deep, and achieving and suggests that these determine the use of corresponding surface, deep, and achieving strategies. A surface motive is more extrinsic motivation in which the goal is to fulfill the minimum requirements of a course. The corresponding strategies of surface motives are the use of rote learning. A deep motive is based on a student's interest in the course that results in the application of learning strategies for understanding. To excel in a course is a goal of the students with achieving motives. Students with achieving

motives use learning strategies that are well organized. Watkins and Hattie (1992) found that students who have deep and achieving motives use more effective learning strategies that result in better academic achievement than students who have surface motives. According to Pintrich (1988), the learning motives the students have during a course are related to their perceptions on their own learning ability (self-efficacy) and perceptions on tasks for the course. Students' self-efficacy affects how they expect themselves to succeed. Students who have high expectations of success are more involved and persist in completing a task. According to Zimmerman (1990), student's self-efficacy in completing a task is closely associated with effective use of learning strategies. He explained that self efficacy is the characteristic of self-regulated students who are able to monitor, evaluate, regulate, and modify the learning process, whenever necessary. The self-regulated students are also able to use and manage contextual factors such as course and instructor demands, where and when to study, who, when and where to go for assistance, etc. Based on Zimmerman's description, it is evident that motivation mediates the use of both cognitive and environmental resources as described by Borkowski, Carr, Rellinger & Pressley, 1990). Individuals who have high self efficacy are more likely to use cognitive and metacognitive strategies and to seek appropriate forms of assistance when they need it (Karabenick & Knapp, 1991).

Regarding students' perceptions of tasks for a course, Pintrich (1988) describes them in terms of the value the students' perceive for the tasks. He divides the task values into attainment, interest, and utility values. The attainment value is the student's perception of the importance of doing well on the task. Interest value refers to a student's perception of how interesting the task is. And the utility value relates to student's perceptions of the use of the task for their immediate or later goals. According to Entwistle (1987), a student's perception of the learning situation most directly influences his or her learning. Students' learning approaches are likely to prefer and define effective teaching in ways which reflect those approaches (Entwistle and Tait, 1990). Students who constantly rely on a surface approach prefer and rate more highly those instructors who provide predigested information ready for learning, while students with a deep approach prefer instructors who challenge and stimulate them.

While related studies on the influence of characteristics of individual students show direct effects on the application of learning strategies, a learning situation including subject matter and teaching methods is considered to be an influential factor.

Influence of the Learning Situation on Learning Strategy

The learning situation influences students' use of learning strategies through interactions with their cognitive process and their motivation (McKeachie et al, 1986). Certain learning situations such as a project-based learning can increase students' motivation and encourage the development and use of deep cognitive processing for better understanding (Blumenfeld et al., 1991). The project-based learning suggested by Blumenfeld and colleagues is based on the authentic learning situation of the situated cognition proposed by Brown, Collins and Duguid (1989). Authentic learning situation refers to an academic learning situation that has similar characteristics to a real-world situation of activities or subject matter to be learned. This similarity with the real world situation that is faced by the students can make the learning more meaningful. Meaningful learning, because of its parallel to students' personal goals and interests, may increase students' motivation to learn. According to Pintrich and Garcia (1991), students' motivation can increase the development or use of appropriate cognitive and self-regulatory strategies. Studies conducted by Murray (1972), and Davis and Black (1985) on students opinions of investigative biology laboratory that was project-based learning revealed that students' had positive responses to the learning activities. The students reported that the

laboratory activities were more interesting and improved their problem solving skills.

Even though an ideal learning situation is supposed to arouse students' motivation to learn, which, in turn can encourage the use of deeper learning approaches, a learning situation may simply encourage the use of certain strategies as students' ways to cope with the demand of the situation. A study conducted by Decarlo and Rubba (1991) on the relationship between teacher behavior and student behavior during laboratory activities in high school chemistry, showed that teacher's use of a teaching method that provided few directions actually forced students to think and conduct the investigations on their own. Sheppard and Gilbert (1991) found that students' approaches to learning were influenced by the teachers' theories of teaching that were manifested in their course structure and their teaching. In a study on a college investigative biology laboratory, Glasson and McKenzie (1995) showed that the ways teachers present themselves as scientists in front of the students can provide a learning model for students and introduce a new learning approach that is appropriate in that learning situation. Assessment as a part of the teaching method may also influence students' learning. Thomas (1986) found that the assessment procedures that emphasized students' understanding of learned concepts change students' surface approaches of learning to deeper approaches.

Because students have different cognitive and motivational characteristics, they may have different coping strategies for situations that vary from one teaching method to another one. For a certain instructional method, some students may get considerable learning benefits whereas others may experience many difficulties that can hinder their learning. Van Aken and Wildman (1993) suggested that teachers have influential roles in facilitating learning for all students by providing a variety of instructions based on student needs. Instructions should provide learning opportunities that can promote successful learning.

Summary of Literature Review

This review of literature on learning strategies and related studies in science indicates that students' learning strategy is an important factor in the learning process. The use of learning strategies is influenced by individual student characteristics and by the context of the learning situation. Students' characteristics including cognition and motivation determine the application of appropriate strategies in a certain learning situation that differentiates more and less effective learners. Applications of learning strategies also may be a result of students' adaptations to learning situations.

CHAPTER 3

METHODOLOGY

Research Design

The purpose of this study was to examine students' learning strategies in an investigative biology laboratory program. To obtain in-depth information about the strategies, a qualitative research design was used. A qualitative research design is an essential method for studying a phenomena in a wide ranging inquiry from the participants' perspective (Marshall and Rossman, 1989). The use of qualitative research was also intended to obtain information on the meaning the participants made of particular situations in relation to their experience (Seidman, 1991). What learning strategies the participants used, and how and why they used them are a complex phenomena due to the interrelated influences of their perceptions, motivations, experiences, and the context of learning. Qualitative research using in-depth interviews was used to address the research questions of this study. The interview method also was appropriate to reveal qualitative differences in the procedures and strategies of student learning as suggested by Ropo (1986).

Selection of Participants

The students who participated in this study were enrolled in Principles of Biology Laboratory H1115 in Fall Semester 1994. The Principles of Biology Laboratory H1115 was a program that was available only for honors students. The laboratory used an investigative approach in teaching and learning.

The selection of participants involved two phases. In the first phase of the selection, the researcher used a telephone to contact each student who was enrolled in the program. Information about students' names, major, and academic level was obtained from a copy of the class roll provided by the instructor, whereas information about students' telephone numbers was obtained from the University Administration Office. The purposes of the contact were to briefly introduce the researcher to the students and to describe the proposed research study. In this first contact, the students also were informed about how the researcher obtained their names and telephone numbers. The students who were interested in participating in the study were identified for the second phase of selection. From 37 students enrolled in the program, 28 were willing to participate in the study.

In the second phase, ten students were selected from the total number of students willing to participate. The

limitation to ten participants was done in consideration of the researcher's resources and to obtain a reasonable number of participants for an acceptable data base. Ten students also were used in this study with the awareness that some participants might withdraw. To select participants from the students who were willing to participate, a purposeful sampling with a maximum variation approach was used. According to Seidman (1991), maximum variation sampling provides the most effective basic strategy for selecting participants for interview studies. The goal of this approach was to get the widest variation of students within the study to gather information from different perspectives. Selection was based on variations of gender, academic major, and academic level. The 28 students were first grouped by gender. Within the groups of female and male students, further selection was based on academic major and academic level to obtain maximum variation.

Data Sources

The data collection included the gathering of information from several sources. The primary data were obtained through in-depth semi-structured interviews of the participants. Additional information related to students' use of learning strategies was obtained

by examining students' learning styles. Assessment of students' learning styles was conducted in the lecture section of the course at the beginning of the Fall semester 1994. The instrument used for this assessment was Anthony Gregorc's learning style delineator.

Information about the topics learned and activities in the program was gathered from the laboratory syllabus, handouts, and informal interviews with the instructors. Non-participant observations of the laboratory activities also were conducted throughout the semester. Field notes were taken during the observations.

Development of Interview Questions

An interview guide with mostly open-ended questions was used in obtaining a description of participants learning strategies and their related characteristics. The interview guide for participants was developed based on the interview approach suggested by Seidman (1991) to explore not only students' use of learning strategies but also interrelated factors. Questions in the guide included the following areas: science learning experiences in high school and college, personal characteristics, learning strategies students to overcome problems in the program, and opinions of and suggestions for the program. The development of an interview guide was improved by critiques from committee members

including Dr. Arthur Buikema, Dr. George Glasson, Dr. Larry Weber, and Dr. Terry Wildman. A more thorough critique was provided by Dr. Thomas Teates. A copy of the interview guide is presented in Appendix A. Modifications were made after consideration of their suggestions.

Interview Procedures

Three pilot interviews with non-participant students were done to provide practice for the researcher for conducting the interview portion of the study. The interviews were conducted at the beginning of Fall semester, 1994. Three students who completed the investigative biology laboratory program in Spring 1994 were interviewed to gather similar information about learning strategies they used. The students also were asked for suggestions regarding the process of the interview. Based on the pilot interviews, modifications in questioning techniques were made for such things as clarification of questions.

Before interviews with participants for this study were conducted, consent forms (Appendix B) were distributed to participants. One participant who was 17 years old received parental permission to participate in this study. A copy of the letter asking parental consent for the student is presented in Appendix C. Consent forms for all participants were signed and returned to the researcher.

Interviews for this study were conducted in two sessions that covered three types of information: background learning; current learning; and reflection. This structure for the interviews was adopted from the 'three-interview structure' suggested by Seidman (1991). The structure is designed to reveal interrelated information involving the past, present, and reflection for the future. Information gathered using the interviews was intended to clarify the composite picture of the participants characteristics and to understand participants' learning experiences in the context of their lives. According to Patton (1989), knowing the context of participants' lives is necessary to explore the meaning of an experience.

The first interview session was conducted about a month after the Fall semester 1994 began. In this session, the participants were asked to describe their high school and college science learning experiences, and to describe their motivation for enrolling in the honors biology course. The second sessions of interviews were conducted a week before the end of the semester. In these interview sessions, participants were asked to elaborate on their learning strategies during their laboratory work and reflect on the meaning of their learning experiences in the program. Interviews for the first sessions ranged from about 40 minutes to one and one-half hour in length, whereas, the

second interviews lasted about one hour to one and one-half hours.

The interviews were conducted individually for each participant in quiet locations on the campus of Virginia Tech. All interviews were tape recorded and the tape of each interview was assigned a coded label to insure confidentiality. After all interviews with student participants were completed, interviews with the instructors were conducted. All tape were transcribed for analyses.

Data Analysis

The primary source of data for this study was the transcriptions of open-ended questions from the interviews. During the transcriptions, the locations of responses for interview questions in the tapes were noted for later review. Responses in the transcripts also were coded with letter codes for further analyses to find themes. The coding system for students' learning strategies was linked to information about learning strategies found in the literature whenever they were applicable to the data. A combination of general learning strategy and problem-solving theories provided a useful perspective for examining the data.

Coded responses were categorized and organized with the use of the AskSam software program (Version 4.2, 1989). After categories were developed, patterns or themes were

identified. The themes were developed using guidelines suggested by Ely et al. (1991). To develop themes, categories found for each student were compared for similarities and differences. The themes focused primarily on students' learning strategies in the investigative biology laboratory program. Characteristics of the learning processes in the program were also searched from the interview data with the instructor to provide additional information for the study. The report of the findings was presented in a narrative format with the use of excerpts from the interviews.

CHAPTER 4

FINDINGS

The primary purpose of this study was to examine students' learning strategies in an investigative biology laboratory program. The result findings this investigation into students' learning strategies is presented as the major portion of this chapter. Additional information and findings about students' and instructors' characteristics and program characteristics also are presented to provide a better understanding of students' learning strategies in the context of the program. The content of this chapter is presented in a following order: description of the student participants and of the program instructors, description of the program, emergent themes of learning in the program, and emergent themes of learning strategies.

Description of Participants

Students

The participants consisted of ten students, five females and five males. All of the participants were enrolled in the honors program at Virginia Polytechnic Institute and University. Their ages ranged from 17 years to 21 years; eight were freshmen, one was a sophomore, and one was a

senior. The participants' were majors in a variety of subjects: two were majors in biology, two in biochemistry, and two in environmental science, one was in animal science and one in math. Two students had not selected a major.

Most participants attended public high schools; only one went to a private high school and this was in a school in Malta. One student attended a public high school in Germany for his junior year when he participated in a student exchange program. Two students attended high schools in states other than Virginia; Philadelphia and Connecticut. Of the other seven students who went to Virginia's high schools, two, a male and a female, graduated from the same magnet school which had an educational program that stressed science and technology.

The science experience background of the participants was extensive and varied. In addition to the usual high school science courses (earth science, biology, chemistry, and physics), all participants had completed several other science courses as indicated in Table 2. Four students had completed advanced placement courses including one in biology, and all four in chemistry. Four students took human anatomy and physiology in their senior year, and of these four students, three also completed genetics. Three students were in gifted or honors science courses: one was in a gifted program for all classes in biology, chemistry, and physics; one was in honors physics; and another one was

Table 2. Science Learning Experience of the Participants from High school to College.

Courses	Number of students
Basic high school science courses (earth science, biology, chemistry, physics)	10
Gifted program	1
Honors program:	
Chemistry	1
Physics	1
Advanced placement (AP) courses:	
Biology	1
Chemistry	4
Human anatomy and physiology	4
High school science project	5
College chemistry	2
College physics	2

in honors chemistry. Five of the students participated in science fair programs in high school which involved an individual research project. At the time of the interviews, seven freshman participants were taking college chemistry, including two in organic chemistry and the other five in general chemistry. Two participants, a sophomore and a senior, had taken college chemistry and physics.

The learning styles of the participants also were varied. The results from the Anthony F. Gregorc Style Delineator showed that two of them had a Concrete Sequential (CS) learning style preferences, one was Abstract Sequential (AS), three were Abstract Random (AR), two were Concrete Random (CR), one was a combination of AS and CR, and another one was a combination of CS, AS, and CR (see Table 3). Based on the descriptions of the styles provided with the instrument, the Concrete Sequential (CS) students are characterized as instinctive, structured, practical, and thorough. The Abstract Sequential students (AS) are described as logical, analytical, and conceptual. The Abstract Random students (AR) are sensitive, sociable, imaginative, and expressive, and those who are Concrete Random (CR) are intuitive, original, inventive, and competitive. A complete description of the characteristics of each learning style these categories is provided in Appendix D.

**Table 3. Learning Styles of the Participants
According to Anthony F. Gregorc Style
Delineator.**

Learning Style	Number of Students
Concrete Sequential (CS) (instinctive, structured, practical, thorough)	2
Abstract Sequential (AS) (logical, analytical, conceptual)	1
Abstract Random (AR) (sensitive, sociable, imaginative, expressive)	3
Concrete Random (CR) (intuitive, original, inventive, competitive)	2
Combination of styles:	
AS and CR	1
CS, AS, and CR	1

In terms of their interest in science, apparently all participants had a personal interest in the subject. They also described science as one of subjects they had "been good at." Four students stated that biology is their main science interest area. When asked about people that they think influenced them in their interest in science, most of them identified their science teachers as the people who did this. They described these teachers as the ones who made science interesting and easy to understand. Some participants stated that members of their families including their parents had an impact on their preferences for science.

Instructors

The instructor in this investigative biology laboratory, Kevin, was in his mid-20s. He is a teaching assistant (TA), who at the time of the study had taught the investigative biology laboratory program for 2 years. Kevin is studying toward a doctoral degree after finishing his master's degree in aquatic ecology at Virginia Polytechnic Institute and State University. Besides teaching honors biology laboratory, he had also been teaching regular biology laboratory.

In designing the investigative biology laboratory, the instructor had been working with Dr. Arthur Buikema who had been teaching introductory biology courses for regular

programs as well for honors. The instructor noted that he and Dr. Buikema planned the laboratory together and always tried to make improvements in the laboratory content and work from previous semesters. Both seem to have similar perspective on the purpose of designing an investigative biology laboratory program. Informal discussions with Dr. Buikema revealed that he wants the students in the laboratory to learn first hand the skills for doing research. These include critical and reasoning thinking skills, verbal communication skills, and writing skills. He believes these skills are necessary to be learned by all students, not only for students who want to be scientists. Similarly, Kevin described his intention that the program introduces the students to the processes of science research that can be useful for all students. For example, when describing his requirement for the students to write a clear and concise scientific report, he stated that practice as,

... useful for all of them (the students) whether they go into science or business or whatever. They can write well, and if they can project their idea across in a clear and concise manner, then they'll be better off.

The instructor appeared to have high expectation for the students learning as indicated by the structure of the laboratory activities and the work he demanded from the students.

Description of The Course

The Principles of Biology Laboratory H1115 was a one credit course that was conducted as a 110-minute laboratory period each week. The laboratory was designed as an investigative type of experience in which the students were expected to be actively involved in the processes of scientific work. The laboratory was offered for honors students who were taking General Biology or Principles of Biology. At the time of this study in the Fall semester of 1994, there were two sections of investigative biology laboratory. The first section consisted of 18 students, and the second section consisted of 19 students. Both sections were taught by the same instructor.

The main objective of the laboratory was to educate students in research methodology (see the laboratory syllabus in Appendix D). The laboratory provided opportunities for students to use library services and standard laboratory and field techniques, to learn to collect, process, and interpret data, and to learn scientific writing. Topics covered in the laboratory were: (1) using library resources, hypothesis testing: data collection and processing, (2) roles of observation and prejudices in research (fish lab), (3) introduction to taxonomy, (4) plant ecology/molecular biology/biotechnology (Arabidopsis lab), (5) and fermentation.

At the beginning of each laboratory, the instructor usually gave a brief explanation, about 15 minutes, on the topic. In that session, the students were given opportunities to raise questions. Students also received a handout(s) containing some background information and procedures instead of an extensive set of instructions describing exactly what to do in the laboratory (see examples of handouts in Appendix D).

The grade for the laboratory was based primarily on individual written reports that comprised 90% of the overall grade, with the proportions of: 10% for library report, 20% each for fish report and taxonomic key, and 40% for Arabidopsis report. The report for each topic was expected to be completed before the students moved on to the next topic. Ten percent of the laboratory grade was assigned for the lab notebook that was submitted at the end of the semester. This was a means of having students adopt the habit of taking notes for laboratory work and a means of checking attendance for the laboratory work. This grading system is shown in the syllabus in Appendix D.

Emergent Themes of Learning Strategies

The analyses of the interviews produced three learning strategy themes. These learning strategies represent thinking and actions used by the students in their efforts to

complete the laboratory tasks. Despite the diversity of specific strategies they used, there were similarities in the general patterns of their learning strategies. These general learning strategy categories are: understanding the laboratory situation, active individual learning, and interactive learning with other students or the instructor. Within each of these themes there are descriptive categories. Even though the categories give evidence to help one understand participants' learning strategies, in reality they were not isolated from each other but frequently two or more strategies emerged or overlapped. Table 4 lists the themes and the categories. The results of analyses are presented with the inclusion of excerpts from the interviews.

Understanding the Laboratory Situation

Student participants came to the laboratory with different experiences, personal goals, and learning preferences. In trying to understand the laboratory situation, the participants described several characteristics of the laboratory tasks that were perceived as problems, and how they developed a means for dealing with them.

Table 4. Learning Strategies Used by Students in the Investigative Biology Laboratory Program.

Themes	Categories
Understanding the Laboratory Situations	<ul style="list-style-type: none">- Recognizing difficulties- Developing meaning of the laboratory work
Active Learning	<ul style="list-style-type: none">- Talking it out- Connecting knowledge- Following teacher's example- Exploring ideas and resources
Interactive Learning	<ul style="list-style-type: none">- Cooperative learning with peers- Seeking help from instructor

1. Recognizing Difficulties.

Difficulties with the laboratory materials and tasks were perceived by students in different ways and to different degrees. The level of difficulty each student experienced seemed to relate to his or her previous knowledge, experiences in a similar learning situation, and learning preferences. Some students experienced more difficulties than others. However, generally, the laboratory work was viewed as more challenging by most students than other science laboratory investigations they had experienced. Students' comments such as "it was hard", "it was confusing", "it made me think" and "it was a lot of work" frequently emerged when the students responded to questions about their opinions of the laboratory.

One area of difficulty described by several students was a lack of theoretical knowledge about particular laboratory topics. Some participants stated that their problems in the laboratory were caused mainly by their lack of knowledge:

A lot of people in the lab have done what we are doing before, either in a biology class or something. Because I know, I think, several people in that class have taken AP biology. So, they've already kind of had almost the same course. And so, I find it kind of difficult because I haven't had biology since tenth grade, and I don't remember anything. It's just kind of difficult without some explanations (P6, 1B, 18).
(The letters and numbers listed after each excerpt refer to the participant(s) being interviewed and the location of the excerpt in the interview tape).

At times, I found myself falling behind because I have never had a chance to do the stuff like this. And so the people I talked with, like, from the class, were saying they did the experiments we are doing in high school. When the only experiment I ever did in high school was cutting up earth worms, and that has nothing to do with what we are doing right now (P10, 1A, 202).

Tasks such as finding references for the reports in the library and peer critique were new experiences for most participants. Participants reported that they were uncomfortable or confused when they experienced the new tasks for the first time.

When I was in the library the first time to do things, I had no clue what we were doing because it's a pretty big library. I was kind of lost, but uhm .. it's really big. Like (I couldn't find) some of the stuff they have (required) in the library report, when I looked for it (P7, 1A, 244).

... and we are supposed to do, like, peer critique. That's (laugh), because I don't like to critique other people's work, because I don't want to upset them, telling them they did something wrong (P2, 1A, 104).

Several participants said they had difficulty in adjusting to a new method of laboratory teaching. Most of the students stated that initially they felt confused and frustrated with the new laboratory method that required them to be active and responsible for their learning. This feeling of confusion appeared to be related to their previous experience of not having used this approach.

Well, I don't know, I mean, if they expect we are supposed to be more responsible or something, things like that. I don't know. They always expect you to be more responsible on your own, I mean, more responsible

there, but, I think they just need to kick you a little bit (P5, 2A, 271).

Uhm .. at times it was hard, because it's basically "Here, do your experiment. But I am not going to tell you how." And at times, it did get really frustrating. I got really frustrated the first couple of classes because I had no idea what I was doing, and no one basically did (P10, 1A, 231).

Even though the students generally knew the purpose of the teaching method, some of them described the need for more explicit guidance and explanation from the instructor. The students learning style seemed to affect their preference for explicit and thorough guidance. As noted in the description of the students earlier in this chapter, the students completed a learning style delineator instrument in the class. The students who were more uncomfortable with the laboratory instructional method were the students who were identified having a Concrete Sequential (CS) learning style. One participant who had a Concrete Sequential learning preference described her confusion about the instructor's teaching method,

I am taking biological statistics right now, and I am doing very well in it. But he was ... I really have a problem with his teaching style or something. I really don't understand him. I remember when we did the computer program, I was like, he wasn't even talking about it. And most of the stuff I knew what they were, but he wouldn't teach. He wasn't telling what they were to everybody. I was like, for this sample I was saying this is it, but he didn't say what it means, you know. It was confusing. I didn't get anything out of that (P9, 2A, 230)

Most students talked about having difficulty in working on the big project in the laboratory, the Arabidopsis project. The Arabidopsis laboratory project that was a six-weeks long required research skills, including thinking skills, organization skills, and writing skills. Applying a combination of these skills in a relatively long research project was a new experience for most students.

I (Interviewer) : Did you have problems with the Arabidopsis lab?

P (Participant) : Yeah a bit. Not exactly .. a couple of instance problem with that. Like, when we were writing up our lab. Because we didn't exactly remember a lot of uhm .. the machine with the gel, and the DNA electrophoresis. I mean, we didn't get any handouts for those, so we couldn't study ahead of time. I couldn't remember what exactly we had done. ... We didn't really have time to write it up, we were just doing it {P1, 2A, 13}.

Yeah, because a lot of the stuff was thrown together, it seemed, like, at the end of the lab, and then (the instructor said) "Hey, write it up." ... Well, because it's spread over several weeks, a lot of the stuff and objectives are stuff that you have to remember to incorporate from weeks past, and that gives a little bit ... I can see where the anxiety came from trying to do stuff like that, because you want to make the lab write up good, but you are not exactly sure how to put together in light of having it happen over the semester (P4, 2A, 174).

Developing Meaning of the Laboratory

In response to difficulties, all of the students seemed to try to make the tasks or the topics learned in the laboratory meaningful by connecting them to their personal values and interests. Some students related the lab tasks to

their personal satisfaction of overcoming laboratory problems that were challenging for them.

That's good, I think, rather than having something set up that we can have ahead of time (saying), "Here is the report. Here are the objectives. Here is how you are going to do it," you know. That doesn't help you learn anything, and I enjoy being able to deal with the situations that kind of, like, come up on the moment, you know. That is important, I think, to have that ability, and uhm .. it's also challenging which is nice. So learning how to do that in the classroom setting was, I think, one of the greatest things about this class and the course, I guess (P4, 2B, 273).

... Biology, it makes you think, make up your own hypothesis, also background information, materials, and methods you have to write up yourself. Everything is done by yourself (P1, 1A, 232).

Some participants frequently mentioned interest and curiosity in a particular topic or topics that were presented in the laboratory. One particular topic that all students stated to be interesting was the Arabidopsis laboratory project. This interest might have helped them to keep involved with the laboratory activities.

The one we are doing now with the plants, we take the DNA out of the plants, I am really looking forward to that, because it's something .. and something that I've never seen anything like that or never heard anything like that. And uhm .. I don't know, I am really excited about that (P2, 1A 144)

Uhm .. basically the keys with the trees and things, that was new to me. Mainly other things I've done before. I mean, that's the main learning. I haven't done gel electrophoresis and things like that. That was interesting, the PCR reaction, uhm .. those two things. That was interesting, the PCR reaction, uhm .. those two things, mainly I think probably the gel electrophoresis, and learning a little about the DNA technology type things was the most interesting, that

just these procedures and what they learn. And next time somebody talks about, in the OJ Simpson trial or something, you might know a little bit about what they were doing and things like that (P8, 2B, 63).

... It's harder, and I figure it to myself, like, "it's only one credit why am I doing all this." But, then, like, when we were doing the DNA things right now, I knew that it's a really good experience that I am interested in, and I am glad that we are doing that (P9, 1A, 568)

Other participants made their learning meaningful by perceiving a direct benefit to their learning. They considered that doing the laboratory tasks was a good way to improve their learning.

When we handed in our first lab, he gave it back with the comments and stuff, and we had to peer evaluate and stuff. And then we were given a chance to revise it. I think that's a good thing because when you revise it, then you can go back and see what mistakes that you made and fix them. So you remember the next time, you know, not to do that, and to do certain stuff (P7, 1A, 330)

... it would be a lot easier if we didn't .. if we had done it according to an outline, you know, or a lab manual. But that wouldn't have .. I don't think it would have facilitated learning at all. Uhm.. it would have been easier, but wouldn't have been better for students (P4, 2A, 42).

Some participants connected the experience in the lab with the short term and long term usefulness they can get from it. They considered the experience to be practice to improve skills they would need for other courses or for their future careers.

If I decide to go within biology and have to do more labs, this way I'll know what I am doing instead of

coming and expecting someone to tell me what to do, and I have to be able to do it by myself (P10, 2A, 235).

I feel the lab is more trying to get you into, like, prepare you, like, for later classes. Like, the library things, we went to the library just trying to get either learning how to use the library, whatever resources you are going to need for other classes. And just learning to write papers in scientific format, we are going to need (that) for other classes (P2, 1A, 334).

It's just sort of neat you have to figure it out. And I guess you are going to have to do it eventually though, so you might as well learn now. Because later, I guess, when you get the job, no one is telling you to do this and then do this. Especially when you are starting your own research, a lot of things you are going to do you have to think (about) and come up with on your own (P3, 2A, 196).

Some participants not only attempted to make sense of their learning experiences by relating them to their personal goals, but also were aware of their own characteristics as learners and how they adapted to the nature of the tasks whenever necessary. Developing a plan to meet their personal goal and the instructor's expectations on each task was one strategy they used. Their ability to plan to accomplish the big research task, the Arabidopsis, seemed to be related to their experience in doing a similar task. There were at least two students who had more experience in the processes of scientific research. They seemed to be more aware of related skills needed. For example, one student realized the importance of keeping notes on the related information and data that were collected over several weeks in that laboratory.

Uhm .. I kind of .. well, I kind of kept track of it in my lab notebook, what we were doing, So, I could kind of look back at that too and just write down what it was. Like, we mixed together and what we did with it, and stuff like that. So, I kind of kept in track of it as we went along, because I knew I wouldn't remember it all at the end (P7, 2A, 96).

Another participant developed a time schedule for finishing the written report for the Arabidopsis laboratory including having his report reviewed and corrected. He seemed to understand the importance of the processes to the improvement of his report.

Uhm .. 2 or 3 days before it's due or something. I mean, I'd gotten the research by then, I'd gotten background information. Some of these, it was .. we had to do it part by part, like Arabidopsis you made the procedure first, I mean, you had that done already at least when you were going to finish it. I mean at least the day before, a day or two before I started writing it. And I wanted it done pretty much as well as I can do it a day or a half day before it was due. I mean, it's due on Thursday, I'd want it done by Wednesday, in the middle of the day or evening. So I can have someone else read it, you know, make final corrections. I wouldn't want to have to stay up Wednesday night till 3.00 AM. finishing and just writing it up. It's better to get it most of the way done in time for someone else to make suggestions, and make some minor changes. I don't do it all at once (P8, 2B, 22).

Other students put more time and effort in finishing the task. One student said:

I, seriously, I do most of the work for my labs. I mean, I study for the lecture, and I read, and I do all that, but I do the most work for the labs, and they are only one credit each (P6, 1B, 60).

Active Learning

The laboratory required students to be active learners. Active learning in this study refers to learning strategies initiated by the students to complete the laboratory tasks and to understand the materials being learned. This theme involved four types of strategies: talking it out, connecting knowledge, following the teacher's examples, and exploring ideas and resources.

1. Talking it Out

Participants stated that they discussed ideas and problems to help them to make sense of the tasks. They discussed ideas and asked questions to other students as well as to the instructor.

We were just sitting and like, "What are you doing, man?". I sat there with J, we were like, you know, "Do you understand this?" We sat there and tried to figure it out (P5, 2A, 113)

I : Kevin didn't give you a manual, just a short explanation. Did you find it difficult?

P : Well, some of it, it is. But, then you've got to ask questions. At least, I mean, he is there if you need to ask questions. But if we can go about getting it on your own, then it kind of makes you feel like you accomplish something too, if you can work it out (P7, 1A, 323).

Even though the instructor expected that the types of learning situations provided in the laboratory would require more verbal interaction by the students with peers as well as

with the instructor, some students perceived it as producing more confusion, and as an impractical approach.

For example, several participants said:

... But, I just end up feeling dumb, because I am just like, you know, needing time to ask him how to do anything or ask everybody else. ... (P9, 2A, 12).

... If he had, like, one or two solutions to add or one or two process to do, that I would expect that, that he'd expect if we wanted to know that we'd ask him. But when we had like 20 things to add, and each little step is different, and I think it's a little bit hard to ask students, to ask twenty different like, "What he is doing?, What he is doing." I am still not used to being ... that they want us to come individually and talk (P1, 1A, 142).

These students did not seem to realize the purpose of verbal interaction in the laboratory was to help them learn from each other and from the instructor.

2. Connecting Knowledge

When describing their efforts to complete laboratory tasks and to understand the materials, the students often talked about relating them to their previous knowledge. Even though the students appeared to be aware of the importance of connecting their previous knowledge to the new knowledge, they differed in the extent to which they used previous knowledge and in the ways they organized the new knowledge. For example, in trying to find references, one student considered several concepts that were related to the Arabidopsis lab.

I : What references did you use for the Arabidopsis lab?

R: One was a journal, I think. And all had been bound into hard cover, uhm .. laboratory techniques using DNA, that was one book, and another like uhm .. I think that was a journal, and uhm .. DNA sequencing and unraveling DNA, I think that was another.

I : So, they are not specifically about Arabidopsis.

R : Oh no. I think the idea was to go beyond Arabidopsis in that report, as to how you can do this with the DNA, because there was a lot of stuff to learn using the procedures, you know. If you are doing this project and you can look using this primer and that kind of stuff. And that's important, I think, to be able to look beyond just Arabidopsis. And when you deal with something like the DNA, you have to, because it's not unique to that plant. So, therefore it wasn't hard to find references (P4, 2A, 319)

In designing an experiment and analyzing the data, participants also made connections between their knowledge and the background theory needed to solve problems.

Well, sort of. Because I knew somehow you had to use the bubbling from the carbon dioxide to measure it, but I wasn't sure how you could achieve that using the stuff that we had on the table. So, (I was) confused a little bit, but then things get easier after we got passed that point. It got a lot easier to do the experiment once you figured it out how to set it up. And Kevin did give us a clue on that, because I've never used the tubes stuck inside to another tubes like that before. It made sense, but I just didn't think about it. So, it got easier after we got started (P4, 2A, 94).

Other students also described how they related the lab material to the theory presented in their other classes.

I don't feel, like, lost, you know, or anything. I mean, I am learning everything two or three times because biology class seems to parallel my biochemistry introductory class. So, I learn things twice, and I

get in chemistry. There is kind of interrelated. So, everything kind of gets related (P5, 1A, 497).

That's really interesting, because I am taking an introductory of biochemistry now, and like each week, also one credit class like one hour a week, he talks about general aspects of biochemistry. And last week we talked about what we were doing in lab, like electrophoresis and DNA. So, right after I've done the lab, we learned everything that we just have done, I was like, "Oh we were doing that." That's interesting. It gives you more, you know, practical knowledge. And anytime you do something hands-on you are going to learn more than just learning about it in class (P9, 1B, 6).

Participants who had more background knowledge appeared to have less problems in completing the tasks. One student explained he had done a similar type of fermentation laboratory in his freshman year in high school. For him, the fermentation lab was not a problem solving task, but it was more about remembering what he already had learned.

R: We did that in freshman year in high school. The yeast-beast lab is what my bio teacher called it. It was basically the same idea. He didn't make us design it, but it was his first lab to give us experience in writing it up. ... We didn't change the ratio on ethanol, we just put in different mixture of water, and Karo syrup, and salt, and see how much CO₂ was produced. We had the same idea and the same apparatus.

I : So, you figured it out fast because you learned it before.

R: Yeah, it's more of what we did in freshman year than actually having to figure it out.

The participants made connections between their new learning and their previous knowledge not only by themselves, but also with the help of their friends and the instructor.

Discussion with friends and the teacher seemed to help them to see the relationships among concepts.

I mean, every once in a while, when you tried a certain number of things and none of them worked, then you were like, "Well, Ok, what's the answer? What should we do?" But with some of them, it's not that bad. Once you got guidance in a certain direction, it's just kind of a little bit easier to figure out what to do (P7, 2A, 208).

3. Following Teacher's Example

The lab tasks were new to a certain degree for each participant. In the Arabidopsis lab, the participants did the experiment after the instructor demonstrated how to do it. In completing the written reports, all participants followed the guidelines given by the instructor. When asked whether he had difficulty in writing the reports, one student explained:

I've always found writing difficult. But, I guess, it takes me a lot of time, like, to figure out what I want to say, and get it down the way I want to say it. And I guess, sort of a good part about this lab that we had, like, a definite structure, like, the way the abstract and the introduction, and see if you can separate it and stuff like that. See, that helps a lot (P3, 2A, 159).

Participants also learned about writing the lab report in a scientific format by revising their reports following the instructor's suggestions on the first report for the fish laboratory which was the first investigation that required a format report. For the first report, the instructor didn't give elaborate explanations on how to write a scientific

report. He only gave a brief introduction to the writing guidelines and assigned students to read chapters in a textbook on writing biology reports. Therefore, as expected, all participants noted they needed to make a revision for the fish lab report. One student, for example, said she had to make overall revisions in her first report:

Just the whole thing, and also for my results. For my results I had, like, a table that said, you know, there is no response and the whole bunch of things. And he said, "Well, this can be summarized in just one sentence." So I did that. And also my results, I didn't do, like, written, like in paragraph form. I did, you know, all kinds of observations and stuff. So, I went back and changed that. And also in my discussion I had something that I said, like, in the introduction or something or I guess maybe the procedures. So, he said I don't need that in my discussion. I went back and fixed that stuff (P6, 2A, 149).

4. Exploring Ideas and Resources

When faced with a situation in which the instructor didn't give specific information to complete the tasks, the participants explored possibilities to solve the problems. They used a trial and error method that often made them frustrating at first. For example, this student stated that she and her group tried several ways to devise and test hypotheses in the fermentation experiment.

We just, I guess, a little bit at first. But once you started, you just started trying different things and seeing what works and what doesn't work. And, I mean, once you figured it out, like something that works, you can find out other things that might work too, because you kind of know what's going to, kind of get an idea

what will be happening then. See if you can try things, see if they work or not. So, sometimes it's all confusing trying to figure it out, like, with the fermentation one, we were first really, how we were supposed to know how much junk was all in it. But once we figured it out, like the general, like concepts behind it, then we started, we were able I guess, better to put something together to figure out what was going on (P7, 2A, 183).

An exploration strategy was also used to find references. Besides researching relevant references using library facilities introduced in the library orientation, some students used other library facilities they learned by themselves. For example, one participant explained she used microfilm which she never had used before to find additional references for the Arabidopsis report.

I : Did you have difficulty finding references for ... I think for Arabidopsis he requires you to have 3 references, right, at least?

R: Uh huh.

I : Did you have difficulty?

R: That took me a long time. Well, first I just got some books. But I figured books wouldn't help, and actually they would have (helped), and I should have stopped there. But, when I was in the library doing that, I also looked on the uhm infotrack, at the magazines and papers and stuff. And I ended up going through, like, microfilms. So, I really like doing that, because I've never really used microfilms before. So it was pretty fun, and I know how it works now (P9, 2A, 66).

Another student found additional references for his Arabidopsis report from a computer network:

I did have all three resources, but one of them, I was, like, on my roommate's computer and accidentally I found the Arabidopsis server on, like, a network. ... I down loaded it. It was like uhm .. it was just like another server, uhm .. you just ran .. I just, like, did gopher, like a program, and you went in. And I had, like, back issues of the journal articles about the Arabidopsis and other research that scientists have been doing about the Arabidopsis. So, I took something from that. I downloaded, like, two articles (P3, 2A, 118).

Lack of specific guidance in reporting the experiment made the students work it out by themselves. For example, one student noted that she learned how to make bar graphs from a computer program when she wrote her report to fulfill what was expected in the report.

Well, I had a little problem when, you know, he wanted us to do bar graphs and tables and stuff, because I hadn't used bar graphs before. Luckily, I found program that could do that. ... It took me forever, but I got it (P9, 2A, 104).

Interactive Learning

This strategy is characterized by direct involvement between the participants with other people that could help them with the lab tasks. All participants mentioned that they had assistance from their peers and the laboratory instructor. Only one participant talked about trying to get help from another instructor when writing a report.

1. Cooperative learning with peers

Participants seemed to look to peers as their main resources to help them with the problems they encountered to complete the lab tasks. They described cooperative work in class while working with the experiment as well as outside the class while working with reports. In class, they worked together by discussing their knowledge and ideas. Several students talked about the importance of discussion in developing their understanding. For example, in the fermentation lab where the students were given a task to design an experiment to see the relationship of the rate of fermentation to alcohol concentration using materials provided by the instructor, one participant thought that group work helped her to understand the process.

Because I didn't know anything about fermentation, I, like, I didn't know ... But, I mean, since we were, like, working in groups, it was neat because everybody, like, contributed, things were falling in place. It worked pretty good. And I think it was a real neat idea. I, like, actually enjoyed that more than the Arabidopsis, because, like, I understood what was going on (P2, 2A, 501).

Similarly, when one participant was asked about how he coped with the fact that the instructor didn't provide specific and detailed information to do the fish lab and the taxonomy lab, explained:

Especially, like, in your lab groups, you just sit together and try to figure it out. You have to come out with your hypothesis and, like, think of ways in order to test that. So, basically just draw out ideas,

and I and everyone else, like, debate about them and then see which one is the best (P3, 2A, 42).

Besides sharing their ideas during the lab, participants also mentioned that they worked cooperatively to collect data by dividing the lab tasks. This student described what she did with her friends in the Arabidopsis lab:

For that we just kind of divided, like, I am, like, I just made the buffer, and one person just measured the leaves, and one person. And for that you didn't really need people to back you up that much, because it's like you pretty much know what you were looking for. So, with that we did more divided stuff, and then when we got back to our group, we said, "Ok. This is what I did. This is what I did." Then we, like, shared our information (P7, 2A, 238).

Outside the class, participants described that they got help from their friends in completing their written reports. For example, P1 explained that he and his friends shared information about the procedures in the Arabidopsis lab.

I called my team mates, our group, and also a girlfriend. We talked about it, kind of got together what all we did. One person remembered this, another person remembered that. I mean, it gave the way to discuss it as a group, read it, copied this paper. So, we discussed it, we realized what we did (P1, 2A, 71).

Talking with friends also helped some participants to analyze the data in Arabidopsis lab.

Like, the whole time I was writing my discussion in the Arabidopsis lab, I was, like, I had no idea what he wanted. But, I would have a paragraph about something, and I tried to analyze it, explain it, but I wasn't sure what exactly I was doing. Yeah, I guess I did call about that. I figured that was supposed to be done individually. But, yeah, I mean, I was still confused

about what we were supposed to be writing. I mean, we were just confused ... (P9, 2A, 432-450).

The instructor suggested that students critique each other's paper and this was considered by all participants to be beneficial to improving their reports. However, most participants stated that their review of their friends' reports was mostly for correcting technical writing.

It helps catch some of the mistakes that you missed. Like, a lot of the time I'll read it and if it sounds Ok I'll give to someone else, and they'll catch some mistakes. So, I think that's good because if I didn't have it then I'd get a lot more taken off because I missed a lot of the mistakes (P10, 2A, 348).

Some participants spent considerable time in addition to getting the written critique by discussing their reports directly with their friends.

We spent, like, 5 hours just talking about each other report. It was really a good experience. ... We had a lot of dialog. It helped, I mean, reading each others, I reread hers, telling her what I thought about this thing and her explanation on each part and how she expanded it. It was very helpful for me (when I was) writing my report too, and the same for her. It's a very good experience (P1, 2A, 599 & 2B, 2).

Besides discussion with friends from the same lab, some participants mentioned having a discussion with friends who were not in the same laboratory.

Like, my roommate has a lot of different ideas on things. He is taking Principle of Biology too. It's not an honors course, so they do things differently. And I, like, "Hey Doug, what do you think about these?" So, that helps. Again you find somebody who is looking in things in one perspective, one direction,

or he maybe looking at totally different angle, and that helps a lot to point thing out (P4, 2B, 228).

I mean, I have my own, I mean, it's informal. You can ask someone just to read it for you. They don't have to be the one in science. I did a couple of times before I turned it in anyway. I would have had someone to read it anyway, even it's not assigned (P8, 2A, 159).

2. Seeking help from instructor.

To finish the lab tasks in which the criteria was set up by the instructor, the participants described how they often requested clarification and assistance from the instructor. Typically during the lab, however, knowing that the instructor often would not give a thorough explanation, the participants asked the instructor questions after they had discussed ideas among their friends.

Yeah. We tried, if we couldn't figure it out, like, within our group, we'll ask other groups, like, some of other groups around they know what's going on and what we are supposed to be doing next, or how something is supposed to be working. If they don't know or they are all giving us different answers about what should be going on, then we usually just ask Kevin. And because they don't know what's going on either, Kevin is pretty much the only one who does (P7, 2A, 249).

Yeah, probably just discussed with students first, and see what else, what they were thinking about, and if not you can always call or talk to Kevin after class, during class. You can always bounce your ideas for interpretation off him, and see what he thinks of them. And he usually would give enough hints of what he is thinking just for that reason. I mean, usually most teachers will give enough hints about what they want, what they think is the answer, if you are if you are kind of clueless and don't know where to start. I mean, with him giving us the klitogramphs and things already,

you can always compare those, and see if there is differences (P1, 2A, 535).

Even though the participants mentioned that getting direct assistance from the instructor in a conversational way helped them with the tasks, asking questions of the instructor may have created another problem for some students. It seemed that the instructor's effort to try to help the students to connect what they knew about background theory with the new task by using probing questions may have been interpreted differently by the students. For example, one student said,

... Like I just have all the questions in the last week, and, like, I couldn't go and see Kevin or anything. I don't feel comfortable asking him questions anyway.... Because I still don't like how he treats you, and he asks questions when you ask him questions, instead of helping you or whatever, he just .. even when he said it again he doesn't explain it well. And he just treats you like, "Oh, you should know this," and everything, you know (P9, 2A, 469,482).

Feeling safe to ask questions appeared to be a factor that encouraged students to interact verbally with their instructor. For example, one student stated that he felt his questioning of the instructor was not something that had a negative affect on the assessment of his ability.

He is quite helpful. You always have the ones, like, you're kind of scared the teacher would judge you for asking questions, like, "Shoot, how I asked a dumb question. So, now he thinks I am an idiot!" But, Kevin is pretty good about that. I called him a couple of times, and also in class I asked him questions. I always do (P1, 2A, 85).

Getting help from the instructor was done in several ways. Participants used written feedback on their report to improve their report. They described how they tried to understand and follow the instructor's suggestions.

Yeah, I got a lot though. I took pretty much all of his suggestions, I think all of them. And it came out really, like, a much nicer paper. I can see how it works, like, it's nicer to read in that format (P2, 2A, 109).

I usually let the fish lab open just to see how does he want it. How he wants references done, how to do things that I didn't look through it, and see if I put label table on the top, figures at the bottom, things like that (P8, 2A, 360).

Characteristics of the Learning Processes in the Program

Analysis of the transcripts of interviews with the instructor and the students, the field notes from observation, and written documents from the laboratory work led to the conclusion that students' learning in the laboratory can be categorized into: understanding science skills, collaborative learning, learning science as a scientist, and making science learning enjoyable.

Understanding science skills

The laboratory was designed in which students first learned science techniques and skills, and then applied them to a bigger investigation project. When asked the way the laboratory was structured, the instructor described,

I am trying to take to start of with the basics, the skills they need, and then trying to push them further and further in the situation where we gave them a research problem and say, "Ok, you are going to have to solve it. Here are the tools that you can use, here is the problem, now go ahead. You've got all the basics, can you do it on your own?" Essentially, that's kind of the last lab was, hoping to push them (A6).

The students were first introduced to library facilities to access references. The students together with the instructor visited the Newman library. After the students received an orientation from a librarian on resources in the library, especially the science literature retrieval facilities to find references, the students worked on the library assignment. They worked individually in finding literature and information that related to the next lab topics.

The students learned basic statistical analysis and computer usage in the second week of the laboratory. After the instructor gave a brief explanation about the role of statistics in research and showed an example of analyzing a set of data, the students were given an opportunity to learn how to develop hypothesis, how to collect data, and how to analyze their data using a computer. The instructor assigned students to work in groups to develop hypothesis on their measurable physical characteristics, and then to collect the data from all students in the lab. Each group shared their

hypothesis and data on the board, and analyzed the data using a statistical software in a notebook computer.

The students also learned observation skills such as how to reduce subjective prejudices during observation. The topic covered in learning observation skills was the behavior of male Siamese fighting fish (*Betta splendens*). In this session, the students started to learn to report the experiment in scientific format. To guide students with their writing, the students were suggested to read several chapters from a text, "A Short Guide to Writing About Biology" by J. A. Pechenik. In addition to the reading assignment, the instructor gave a brief handout on how to write a scientific report.

Improving verbal and written communication skills as a way to clarify students' thinking were encouraged in this laboratory. The instructor expected students to be actively talking about the laboratory problems with each other and to the instructor. He often asked probing questions to the students that gave students an opportunity to talk and ask more. He stated,

We get them talking more, and that usually, that communication gives them thinking more. When you look at the fermentation lab, the groups that didn't do the best were the ones that all were just sitting there, or talking. The groups that did best were sitting there saying, "how about this, how about this, how about this," talking. And the more you can get them talking and stuff, talking about project, ... the more you can draw them out, usually the better they do (B126).

The instructor also the students aware of the importance of writing skills in reporting the projects. To improve students' writing skills, peer critique on the reports was required before the students submitted them to the instructor. The instructor also reviewed the reports and provided written feedback in terms of writing technicalities and content. The instructor's critics and suggestions were a way to show the students his thinking process in order that the students could learn from it. As the instructor described it,

I'll occasionally throw, like, I'll write the sentence for them occasionally, just to give them kind of a model of the type of the stuff that might, you know, if they have a sentence that is three lines long, I might scratch it out and write, you know, a short sentence that can say the same things, just to give them an idea of how they can write it better (A423).

In his effort to encourage the students to revise their reports, he gave an opportunity to rewrite the fish laboratory report for better grades.

Collaborative learning

The laboratory program which did not use a manual to guide laboratory work. Instead, limited explanations were given in handout(s) and brief lecture at the beginning of the work to encourage students to actively work together in completing the laboratory tasks. By encouraging

collaborative learning among the students, the instructor hoped to expand their knowledge. He stated,

Everybody has a different idea of how they do stuff. They can learn from each other as much as they can learn from me (B154).

In this laboratory, two kinds of collaboration learning were readily apparent. Informal, unstructured collaboration began spontaneously among students in the groups and outside the groups. In groups that were established by the students, three to four students worked together on laboratory tasks. The students also discussed the problems they encountered. Ideas and knowledge generated by the students were shared not only within the groups but also outside the groups when they appeared to be helpful to overcome difficulties such as designing an experiment, collecting data, and using instruments. The instructor constantly monitored group work by moving among groups, listening to discussions, and guiding students' work.

The formal, structured collaborative element in the laboratory was provided in peer critiques. During the peer critique students used each other as resources for help in improving their reports. The students also received critiques from the instructor.

Learning science as a scientist

In this laboratory program, the students were given an opportunity to learn the processes of scientific work. Exercising scientific skills that the students already had learned from the previous laboratory activities was apparent in the last laboratory, the Arabidopsis. The Arabidopsis laboratory was the main project during the semester that took six weeks for the whole work. In this laboratory, although all students worked on the same project, they were expected to make their own hypotheses about the project. The instructor intentionally did not provide clear and thorough instructions for this laboratory work. In the interview he described his reason:

The regular labs are more "here is a recipe, and go ahead and make this cake," rather than "OK, here is some flour, here is some sugar, here is a mixing bowl. What can you make from these? How do you make it?" We tried to push them as much as possible through the process of research(A26).

The students were also introduced to practices done by scientists in doing research. The practices required in the laboratory were keeping a laboratory notebook and reviewing each other's reports. The students were expected to get a habit of recording their laboratory work in their laboratory notebooks. As the instructor described:

If they are going to do research at the university or company or whatever, they got to keep a lab notebook.

So, I figured out, trying to get them used to keeping descent notes (A340).

The importance of laboratory note-taking was not always realized immediately by the students, especially when it came to the big project, the Arabidopsis laboratory. This aspect was revealed in an interview with one participant:

I : Kevin expected you to have a notebook and then he signed it after each laboratory. What did you usually write down in your notebook?

R : It's just my data. And, like, one day I didn't write anything down, so I just had the date, and he signed it (laugh). And I didn't write anything in there. But probably, now looking back, I wish I had taken better notes, because I don't understand exactly what we did and some of the stuff. That's why I have holes in my methods, because I didn't take enough notes of what we were doing (P2, 2A, 377).

Introducing students to the practice of reviewing each other's reports was the instructor's goal to help the students improve their writing skill for reporting the result of research. The instructor tried to show them that the practice is common in scientific writing. He noted,

That's how scientific writing works. You just keep modifying it until it reaches the form that is acceptable. So, it's definitely also a process (A133).

The students wrote up their report in a standard scientific report format as a requirement for the fish and Arabidopsis laboratory which included an abstract, introduction, materials, methods, results, discussion, and references sections.

Besides learning scientific knowledge and process skills, the students also learned attitudes that scientists usually have. The instructor encouraged students to work on their own and solve their own problems. He often stressed verbally to students to "try to figure it out" by themselves. The instructor often seemed to refuse to give direct answers to students' questions when he knew the students were capable of finding the answers. His practice is related to his belief,

Just because someone is a professor or a graduate student, it doesn't mean that everything they say is right, or that they know everything. They are just plain people, just like students, it's just that they have more experiences. So, I am trying to help get them of that experience and, you know, get them started (B94).

Although the instructor encouraged independent thinking, at the same time he also emphasized cooperative learning among the students.

Another attitude that was instilled in the laboratory was persistence in doing and reporting scientific research. Especially for the Arabidopsis laboratory, the students experienced long-awaited data gathering and accidental technical failures. Frustration that may emerge from these processes is one aspect that the instructors tried to show to the students.

... We're trying also to have at least some of the labs, at least portions of the labs not work on purpose, because that's the way real research is. So, if they are willing to learn there is going to be some frustration, about what you do in that case. If

something doesn't work you can try it again; do it again; you change things and do it again; you get more information; or you talk to someone (A40).

For the students, this experience may have provided a better understanding and appreciation of the nature of science work. For example, one participant described her understanding of the work when experiencing a long period of data gathering:

The DNA stuff, that stuff, looking back at it, I found it very interesting that we were doing it. But then it was, like, very monotonous and boring, because a lot of time just sitting around waiting. Actually, I guess, maybe I learn that, like a lot of scientists just sitting there and waiting (P2. 2B, 283).

Making science learning enjoyable

The concept of science as something fun to learn was trying to be conveyed by instructor constantly. In the interview he described,

I am trying to keep it as easy going as possible. And science is fun, and that's why I am doing it. So, I want them to have fun with it too. I am trying to keep the atmosphere light, you know, not like there is some hammer on them that they have to work and get stuff (done), but you can have fun doing it too (B159).

The instructor also tried to create a caring and supportive learning situation for the students by depicting his role as their guide in the process of learning scientific research. He views himself as a "big brother" for them.

In the lab I am trying not to be so much the teacher dictating things, but just trying to guide them through stuff, or like a big brother kind of thing, you know,

someone that hasn't been so long since I've been out of college that I've forgotten (B77).

CHAPTER 5

CONCLUSIONS AND IMPLICATIONS

Conclusions

The findings of this study suggest two conclusions. First, there was a similar pattern of learning strategies used by student participants in the investigative biology laboratory program that seemed to be related to the instructional method. Second, there was also diversity in the degree of application of the strategies that was apparently related to characteristics of individual students. These findings support the theory proposed by McKeachie et al. (1986) that a student's learning strategy is a result of interaction of the context of the learning and characteristics of the student.

The instructional design for the investigative biology program appeared to influence the use of similar patterns of learning strategies by the students. This investigative program that emphasized teaching the processes of scientific work seemed to implicitly encourage students to use the kinds of strategies that were identified by this research. This result supports Klauer's (1988) concept of systematic training in which the structure of course tasks can actually suggest the application or introduction of certain learning strategies. In this study, it was not only the structure of

the course tasks that seemed to influence students' use of strategies, but also the interaction of other instructional variables of the program including the teaching practices and assessment procedures.

Previous studies about learning strategies have demonstrated that learning situations including teaching practices (Decarlo and Rubba, 1991; Sheppard and Gilbert, 1991) and assessment procedures (Thomas, 1986) have impact on students' applications of learning strategies. In this investigative program, teaching practices that provided less directions for students appeared to encourage students to apply more active learning strategies in completing laboratory tasks. For example, in the fermentation laboratory in which the students were asked to design an experiment with little guidance from the instructor, the students appeared to adopt similar active learning strategies including connecting knowledge, exploration, and cooperation with peers. One student stated:

He was, like, "Come up, develop an experiment for it." And I was really, like, "Ok." But then, like, we started remember, like, I remember with, like, we used gas displacement and stuff. So, yeah, you do the displacement thing, but I don't quite remember how. So we kind of .., working in a group made it easier too because everybody remembered different stuff, and when you combined it all together then it worked better.

The assessment procedures in the program, primarily based on written reports, also appeared to provide a reward for practicing certain learning strategies. It should be

considered that students in school may not only want to learn, but usually also want to earn satisfactory grades. To earn satisfactory grades means students must complete the tasks that satisfy the demands of assessment. Therefore, students' application of learning strategies might be influenced by assessment procedures. The assessment procedures together with the tasks and teaching practices appeared to induce the application of similar general learning strategies in the investigative program. However, the degree of applying appropriate learning strategies varied from one student to another. With regard to differences in the application of learning strategies, students' characteristics such as gender, age, major, academic level, experience, learning style, and motivation probably all interact to influence the applications of strategies.

According to Entwistle (1987), students' characteristics play a greater role in determining how students learn than does the context of learning. It is considered that students' perceptions of the learning situation have the greatest impact on the application of learning strategies. In this study, students' characteristics seemed to influence the degree of application and elaboration of the general learning strategies imposed by the instructional method. There are three students' characteristics that appeared to have primary influence on the students' learning strategies: experience; motivation; and learning style.

In relation to experiences, it was found that students who had experiences both in learning the subject matter presented in the program and in similar learning situations appeared to apply strategies that were appropriate for their intentions to learn and for the demands of the program. This result supports Jakoubek's and Swenson's (1993) findings that students who have more knowledge of both the subject matter and appropriate strategies apply more elaborate learning strategies.

Even though experience seemed to have an important role in students' selection and application of learning strategies, other characteristics such as students' motivation also may have had an impact on it. All of the students interviewed seemed to have intrinsic motivation to learn. This intrinsic motivation was apparent in how they perceived the value of a learning situation in the program in relation to their personal goals. Pintrich and Garcia (1991) found that students' use learning strategies that reflect their perceived values of the task. In the current research, considering the differences of students' experiences in science learning, some students might not use appropriate strategies but they simply were so involved with the tasks that they applied or acknowledged certain learning strategies.

Involvement with the tasks also seemed to relate to other characteristics of the participants. Students'

attitudes such as willingness to change their learning habits to adapt to the demands of the laboratory tasks helped students' feel more comfortable eventually in working with the tasks. However, this attitude of willingness to change may not have been so easy for some students because they had learning preferences that contradicted the learning style intended by the program. It was found in this research that students who reported the greatest uneasiness with the approach were students who had concrete sequential learning styles. This feeling of uneasiness may have hindered them in the expansion of their learning strategies (Claxton and Murrell, 1987).

Implications

The information gathered from this study has several implications for instructors of investigative biology laboratory programs in colleges. The use of appropriate learning strategies was found to be important for students' academic success. This suggests that instructors need to be aware of this when they assess students' learning. How the students handled laboratory tasks perhaps was more related to the experiences they had in similar learning situations rather than to their cognitive abilities. Students may understand the strategies, but not know when and why they should use the strategies. To address this problem, teachers

should try to provide students with information about the nature and processes of science learning. A discussion with students stressing the importance of certain learning strategies needed in the program could be helpful in raising students' awareness about the processes of science learning.

The concept that students' learning styles may relate to their experiences as well as to their developmental stages suggests that the instructors need to be aware of and respect students' learning preferences. Support and help from instructors for students who have different learning styles could help students because students will more readily accept change if they believe they are supported by the instructor.

Recommendations for Future Research

This exploratory study revealed several learning strategies used by students in the investigative biology laboratory program. Additional studies need to be done to investigate the use of learning strategies in similar programs with different groups of students including nonmajors and majors who are not in an honors program. Similar studies in other cultures would be beneficial to provide more insight into learning strategies.

The findings of this study suggest the need for additional research on the relationships between effects of students' characteristics and the learning strategies they

use. Further research to determine effective learning strategies and ineffective strategies in relation to learning outcomes in an investigative biology laboratory program would provide useful information.

Longitudinal research on the impact of the program on students who have experiences in an investigative biology laboratory program on their learning in future academic work would be helpful for gathering information about learning strategies developed by students in the program.

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APPENDIX A
INTERVIEW GUIDE

INTERVIEW GUIDE

Introduction

Thank you very much for your time and willingness to participate in this study. The study I am doing is about learning strategies used by college students in an investigative type of introductory biology laboratory. I would like to interview you because you are a student who is taking this type of biology laboratory.

To obtain a more complete picture of your learning experience in the laboratory, I will be asking you questions about your background experience in science learning, the learning strategies that you use in this course, and your reflection on learning in this course. I will be taking notes and taping during the interview. Please respond in your own way and take as much time as you would like. If you need clarification of the questions, please ask me for further explanation.

I. Background Experience in Science Learning

1. Would you please describe your high school?
 - a. Where is it located?
 - b. What type of the school is it?
 - c. Does it offer different programs?
(e.g. vocational, general, college bound)
2. Would you please describe each of science courses you took in high school and in college until this semester?
 - a. What courses were they?
 - b. How many hours for each course?
 - c. When did you take it?
 - d. Why did you take it?
 - e. How was each course taught?
(e.g. laboratory, lecture, demonstration, discussion)
3. Have you ever participated in science-related activities, such as science fair and field trips offered by the school?
 - a. What kinds of activities were they?
 - b. When did you participate?
 - c. What did you do?
4. How do you feel about science?

5. Is there any person(s) who has(have) influenced your attitude toward science?
 - a. Who are they?
 - b. How did they influence you?
6. As a student, what do you identify as your personal strengths? and weaknesses?
 - a. In what specific areas?
 - b. How do you handle your weaknesses?
7. How do think you learn best?
8. How do you define successful learning?

II. Current Experience in Biology Laboratory

1. Why are you taking this laboratory?
2. At the beginning of the semester, what did you think about the laboratory?
3. What do you think about the lab right now?
4. What do you expect from this lab?
5. Could you describe step by step how you handled the laboratory project from the moment you receive the task to the time you handed it in and made corrections on it.
6. What problems did you face in the laboratory?
7. How did you solve each problem?

III. Reflection on Learning

1. Given what you have described about your experience in this lab, has the experience changed the way you learn things?
 - a. What specific areas or skills you have changed?
 - b. How do you think you have changed?
2. Did any previous learning experiences help you in the course?
 - a. What kinds of skills and experiences helped you?
 - b. In what laboratory tasks did they help you?
 - c. How did they help you?

3. What do you think about the laboratory in relation to your expectations?
4. If you were a teacher of this lab, what would you do to maximize learning benefits for your students?

APPENDIX B

CONSENT FORMS

INFORMED CONSENT FOR PARTICIPANTS

Title of Research: Learning strategies used by honors students in an investigative introductory biology laboratory program.

Investigator: Diah Aryulina

Department: Education, Curriculum and Instruction

I. Purpose

Open-ended investigative laboratory programs in science are considered to be more useful in developing students' higher level thinking. One aspect that can promote better academic achievement in such programs is the application of appropriate learning strategies. As a student who is taking an investigative type of introductory biology laboratory you are invited to participate in a study that will examine learning strategies you use in this program.

II. Procedures

This study mainly involves your participation in a three-phase interview during the Fall, 1994 semester. The interview consists of your description about your past experience in science learning and other learning situations, your current experience including your learning strategies in the biology laboratory you are taking, and your reflection on your learning. The first- and third-phases interview should take about one hour, whereas for the second one and a half hour probably will be needed. The interview will be scheduled at your convenience. The first interview will be held in the first month of the semester. The second and third interviews will be held at about the end of the semester. The interviews will be audio taped and notes will be taken. During the study you have the right to review the transcripts of the interviews.

Additional forms of information on laboratory activities and your performance in the course such as the laboratory syllabus and handouts, your papers or reports, and discussion with the instructors will be needed. Except for laboratory syllabus and handouts, examination of your laboratory papers or reports and discussion with your instructors regarding your performance in the course will be done only with your permission. Please note that by agreeing to participate in this study you are giving permission for

the researcher to make copies of your works and to discuss your performance with the instructors. Your participation in this study will not have any effect on your grade.

III. Benefits

From this study we hope to learn more about how students use learning strategies to solve problems they face in an open-ended investigative introductory biology laboratory. Greater knowledge and understanding of students' learning strategies can help teachers as well as other students to improve science learning. When this research is completed, you may receive a research summary.

IV. Anonymity and Confidentiality

The result of this study will be kept confidential. To maintain your confidentiality in participating in this study, the tapes and transcripts of the interviews and copies of your works will be stored and locked up in a safe place that only the researcher can have access on them. Your name will not be identified during analyses. All identifying markers from the transcripts will be removed to provide anonymity. The researcher will not release the results of the study to anyone without your written consent.

V. Freedom to Withdraw

You have the right to withdraw from this study at any time without penalty or any effect on your grade, by contacting Diah Aryulina, investigator of the study (951-7732), or Dr. Thomas G. Teates, Faculty Advisor, Division of Curriculum & Instruction, War Memorial Hall, Virginia Tech (231-5537), or Dr. Ernest R. Stout, Chair of the Institutional Review Board (231-9359).

VI. Approval of Research

This study has been approved by the Human Subjects Committee and the Institutional Review Board. You will receive a copy of this consent form. If you have any further questions about this research you may contact:

Diah Aryulina (951-7732) or
Dr. Thomas G. Teates (231-5537) or

I have read and understand the informed consent and conditions of this study. My signature below indicates that I agree to voluntarily participate in this study.

Student

Date

Investigator

Date

Addendum for the informed consent form.

The interviews for this study *Learning strategies used by honors students in an investigative introductory biology program* have attempted to explore your learning strategies. Some of the factors that determine the use of learning strategies are prior knowledge and learning style. Therefore, additional information about learning style would be beneficial for generating richer information about your learning strategies.

One method to assess your learning style is by using an instrument that you already have completed in the Honors Biology class at the beginning of Fall semester 1994. However, the use of the information from the instrument which characterized your learning preferences can be done only with your permission. If you agree to permit our use of your learning style information in this study, we will provide you with a copy of the instrument and an explanation of the analysis of your learning style.

I agree to permit the use of information about my learning style for this study.

Signature

Date

APPROVAL TO PARTICIPATE IN STUDY

I, _____, have read and understand the informed consent form of Diah Aryulina's dissertation study on learning strategies related to Honors Biology Laboratory program at Virginia Tech.

My signature below indicates that I give my consent to _____, to participate in the study under the conditions described in the consent form.

Signature of parent

Date

APPENDIX C

**DESCRIPTION OF
ANTHONY F. GREGORC' LEARNING STYLE**

Style Comparison

The following brief synopses are condensed from the *Mind Styles™* research of Anthony F. Gregorc. Twelve of eighteen frames of reference are listed. They represent dominant style characteristics of the four mediation channels*.

Frames of Reference	Mediation Channels			
	CS Concrete Sequential	AS Abstract Sequential	AR Abstract Random	CR Concrete Random
KEY WORDS	Practical	Probable	Potential	Possible
WORLD OF REALITY	Concrete world of the physical senses	Abstract world of the intellect based upon concrete world	Abstract world of feeling and emotion	Concrete world of activity and abstract world of intuition
ORDERING ABILITY	Sequential step-by-step linear progression	Sequential and two-dimensional; tree-like	Random web-like and multi-dimensional	Random three-dimensional patterns
VIEW OF TIME	Discrete units of past, present, future	The present, historical past, and projected future	The moment: artificial and restrictive	Now: total of the past, interactive present, and seed for the future
THINKING PROCESSES	Instinctive, methodical, deliberate	Intellectual, logical, analytical, correlative	Emotional, psychic, perceptive, critical	Intuitive, instinctive, impulsive, independent
VALIDATION PROCESS	Personal proof via the senses; accredited experts	Personal intellectual formulae; conventionally accredited experts	Inner guidance system	Practical demonstration; personal proof; rarely accepting of outside authority
FOCUS OF ATTENTION	Material reality; physical objects	Knowledge, facts, documentation, concepts, ideas	Emotional attachments, relationships, and memories	Applications, methods, processes and ideals
CREATIVITY	Product, prototype, refinement, duplication	Synthesis, theories, models and matrices	Imagination, the arts, refinement, relationships	Intuition, originality, inventive, and futuristic
ENVIRONMENTAL PREFERENCE	Ordered, practical, quiet, stable	Mentally stimulating, ordered and quiet, non-authoritative	Emotional and physical freedom; rich; active and colorful	Stimulus-rich, competitive, free from restriction
USE OF LANGUAGE	Literal meaning and labels, succinct, logical	Polysyllabic words, precise, rational; highly verbal	Metaphoric, uses gestures and body language; colorful	Informative, lively, colorful; "words do not convey true meaning"
PRIMARY EVALUATIVE WORD(S)	Good, Not Bad	Excellent	Super, Fantastic, Marvelous	Great, Superior
NEGATIVE CHARACTERISTICS	Excessive conformity; unfeeling, possessive	Opinionated, sarcastic, aloof	Spacey, overly sensual, smothering	Deceitful, unscrupulous, ego-centric

*Source: Anthony F. Gregorc, *An Adult's Guide to Style*. Columbia, CT: Gregorc Associates, Inc., 1982. For additional information, see also: Anthony F. Gregorc, *Inside Styles, Beyond the Basics*; Columbia, CT: Gregorc Associates, Inc., 1985.

Gregorc Associates, Inc., 15 Doubleday Road, Box 351, Columbia, CT 06237-0351
Voice and Fax (203) 228-0093

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APPENDIX D
PROGRAM SYLLABUS AND HANDOUTS

HONORS BIOLOGY LABORATORY

FALL 1994

COURSE #: H1115 INDEX #: 4767 AND 4768

Teaching Assistant: Kevin Simon

Office: 1014-C Derring

Office Hours: by appointment

Phone: 231-6679

Text: Pechenik J.A. 1993. A Short Guide to Writing About Biology. 2nd edition. Harper Collins College Publishers. NY, NY.

Attendance Policy: Students are required to attend every lab.

Purpose: to educate students in research methodology by providing opportunities for:

- 1) using library services
- 2) using standard laboratory and field techniques
- 3) data collection, processing, and interpretation
- 4) scientific writing

THIS LABORATORY OPERATES UNDER THE VIRGINIA TECH HONOR SYSTEM

LAB #	DATE	TOPIC
✓ 1	8/25	Using library resources: MEET IN FRONT OF LIBRARY READINGS IN PECHENIK: p. 3-12 Keys to Success p. 24-25 Plagiarism p. 46-109 Laboratory Reports p. 177-207 Revising
2	9/1	Hypothesis testing: data collection/processing LIBRARY REPORT DUE
3	9/8	Roles of observation and prejudice in research
4	9/15	Introduction to taxonomy
5	9/22	Taxonomy continued: <u>no formal lab meeting</u> FISH LAB DUE
6	9/29	Plant ecology/molecular biology/biotechnology TAXONOMIC KEY OF PLANTS DUE
7	10/6	Arabidopsis lab cont.

8	10/13	Arabidopsis lab cont. ARABIDOPSIS INTRODUCTION AND METHODS DUE
9	10/20	Arabidopsis lab cont.
10	10/27	Arabidopsis lab cont.
11	11/3	Arabidopsis lab cont.
12	11/10	TBA ARABIDOPSIS FULL REPORT DUE
13	11/17	TBA ARABIDOPSIS PEER REVIEW DUE
14	11/24	THANKSGIVING BREAK
15	12/1	Wrap-up: student evaluations and comments ARABIDOPSIS FINAL DRAFT DUE

Laboratory Notebooks: Students are required to keep a laboratory notebook to contain information on methods and results from the labs. The notebook will be signed by the TA at the end of each lab. It is the student's responsibility to get the signature!

Written Reports: All written reports must be typed, double spaced, and on time. Papers not meeting these requirements will not be accepted. You will have at least one chance to rewrite each paper after I have reviewed it. You may accept the first grade given or rewrite the paper to try for a better grade. You will also review other students' papers in a peer review process.

Grading:

Library Report	10	A: ≥90%
Fish lab	20	B: 80-89%
Taxonomic Key	20	C: 70-79%
Arabidopsis Report	40	D: 60-69%
<u>Lab notebooks</u>	<u>10</u>	F: <60%
Total	100	

HONORS BIOLOGY LAB
LIBRARY REPORT

25 AUGUST 1994

NAME:

- 1) FIND THE PAPER PUBLISHED BY A. KONIECZNY AND F.M. AUSUBEL IN 1993 TITLED: A PROCEDURE FOR MAPPING *ARABIDOPSIS* MUTATIONS USING CO-DOMINANT ECOTYPE-SPECIFIC PCR-BASED MARKERS. MAKE A PHOTOCOPY AND ATTACH IT TO THIS SHEET.
- 2) HOW MANY TIMES WAS DR. BRENDA W. SHIRLEY CITED IN 1994?
- 3) FIND THE CBE STYLE MANUAL AND COPY THE PAGES WITH EXAMPLES ON CITING SOURCES (E.G. JOURNALS, BOOKS, ETC.). YOU WILL NEED THIS INFORMATION THROUGHOUT THE TERM!
- 4) WHAT IS *Arabidopsis*?
- 5) WRITE A 2 PAGE PAPER ABOUT THE FOLLOWING:

WHAT IS A SPECIES? IN YOUR OPINION, WHAT REQUIREMENTS MUST TWO ORGANISMS MEET TO BE CONSIDERED TWO SPECIES? WHAT TECHNIQUES CAN WE USE TO DISTINGUISH SPECIES? CONSIDER, FOR EXAMPLE, LIONS AND TIGERS. THESE ANIMALS CAN INTERBREED, YET THEY ARE REFERRED TO AS DISTINCT SPECIES. WHAT ABOUT PLANTS THAT CAN HYBRIDIZE?

PLEASE INCLUDE AT LEAST TWO REFERENCES IN YOUR PAPER AND CITE THEM ACCORDING TO PECHENIK AND THE CBE STYLE MANUAL.

FISH LAB

8 SEPTEMBER 1994

PURPOSE

The purpose of this lab is to test the student's ability to observe the complex sequence of aggressive behavior in male Siamese fighting fish (*Betta splendens*)

OBJECTIVES

Students will work in groups and design their own experiment. Using the supplies provided:

- 1) Identify the aggressive and submissive displays
- 2) Determine the sequence of displays
- 3) Rank the displays from most to least important. How did you quantify them?
- 4) Which stimuli are most important in initiating aggressive behavior? Defend your answer.

Once you are satisfied that you can answer these questions and defend your answers gently suspend a second fish (inside a ziplock bag) in the aquarium. Observe and record the responses of the fish. Use this information to compare to your previous data and to help answer the questions above. What is the adaptive value of these displays?

REPORT

Each student must submit a written report. The report must be in a scientific style (see Pechenik and the handout provided). You must cite at least 1 source in your paper.

CAUTIONARY NOTES

Bright clothing, loud noises, and movement may excite or frighten the fish! Do not overstimulate the fish. Allow the fish to rest at least 2 minutes between your tests. Keep your testing periods short.

GUIDELINES FOR WRITTEN REPORTS

All written reports must be **typed, double spaced, and on time**. Page numbering is groovy, but not necessary. Don't use bizarre margin sizes. Papers not meeting these requirements will not be accepted.

Please write your reports in the following format:

TITLE PAGE: Title of your paper, your name, date submitted

ABSTRACT: A brief summary of your research. Keep background information and methods very brief. Give the most important results and your conclusions.

INTRODUCTION: What is the question you are investigating. Give any pertinent background information. Explicitly state your hypothesis.

METHODS: Give the methods you used in enough detail for someone else to conduct the experiment again. Keep this section short and clear.

RESULTS: This section contains only your results. Do not interpret the results. Use tables and figures for your data. The text should briefly cover the results, referring the reader to the appropriate tables or figures, and point out the major trends in your data.

DISCUSSION: Interpret your data. What are your conclusions? Make sure you address the hypothesis you stated in the introduction.

LITERATURE CITED: References for the authors you cited in you paper. If you didn't cite a book don't put it in the lit. cited section. Follow the CBE Style Manual. All citations in the text should be in this form: (author date).

Each section (except title page) should begin with the words in bold above. Title page, abstract, and literature cited are on separate pages.

If you aren't sure what goes in a given section read Pechenik or see me!

TAXONOMY LAB

14 AND 21 SEPTEMBER 1994

Taxonomic keys use morphological features to identify organisms (remember your species definitions?). Morphological keys are fast, cheap, and easy compared to other techniques for distinguishing between taxonomic groups. Most biological keys use the same format: dichotomous branching. Once you learn how to use a taxonomic key, you can identify nearly any other organism (from aardvarks to zooplankton) you desire by finding the appropriate key.

WEEK 1 - 14 SEPTEMBER

Students will work in pairs identifying samples of stream macroinvertebrates using standard taxonomic keys.

Students are required to identify at least:

- 2 phyla
- 2 classes of Arthropoda
- 3 orders of Insecta
- 2 families of Ephemeroptera
- 1 genus of Ephemeroptera

WEEK 2 - 21 SEPTEMBER

Students will again work in pairs (different ones from last week!) to identify trees on campus. After identifying the trees, each pair must construct a dichotomous key (using morphological features) for those trees you have identified.

TAXONOMIC KEYS ARE DUE 29 SEPTEMBER 1994

PLEASE TYPE YOUR KEY AND USE THE FORMAT PRESENTED IN CLASS

Arabidopsis Lab

HANDOUT #1

Arabidopsis thaliana is globally distributed and used as a model for studying molecular pathways in plants. You will be given plants from populations found in 7 distinct locations in the world. Using the materials and techniques provided you must achieve the following goals:

- 1) Given the geographical locations of the plants, tell me which populations should be most similar. Defend your answer.
- 2) Use morphological characteristics to distinguish and group the plants.
- 3) Directly examine the DNA of the plants and group the plants based on your results.
- 4) Using the methods in #'s 2 and 3 above, tell me where the Landsberg population is from.
- 5) Compare your results from each method you used. Why or why aren't the results the same?

LAB 1

IN THE LAB: Divide into 7 groups. Once you understand the techniques you will use, decide how to achieve goal #3. What are your hypotheses? (You should reformulate these using information from #1).

Practice the techniques for extracting DNA from the plants.

ON YOUR OWN: Complete #1 above. This will require some work in the library. Document any sources you use.

Arabidopsis Lab

LAB 2

DNA EXTRACTION CONTINUED: SEE ATTACHED SHEET

Finish extracting DNA from the plants. Use PCR to amplify sections of the DNA.

GROUPING PLANTS USING MORPHOLOGY:

- select 8 morphological characters to be used to distinguish the plants
(e.g. serrated or smooth leaf margins)
- try to select most of the characters before examining the plants
- if, after examining the plants, you see characteristics that seem to distinguish plants, include these characteristics in your data

**** STOP BY MY OFFICE BEFORE NEXT WEEK AND SEE THE NOTICES I HAVE
POSTED OUTSIDE MY DOOR ****

Arabidopsis Data and Report

The report for these data should be in the format used for the Fish lab. **The report is due on 1 December 1994 at 5:00 PM. Late papers will not be accepted.** The report must be typed and double spaced.

Report Contents:

- 1) See Arabidopsis Lab Handout #1. Address each of the 5 points on the first page of the handout.
- 2) Your paper should include at least 3 cladograms.
 - a) geography
 - b) morphology
 - c) DNAI suggest putting all of these drawings on one page for easy comparison.
- 3) You are required to have at least 3 citations. You may not use the following: your textbook, encyclopedias, or comic books.
- 4) Tell me where each plant is from using the data you have collected (geography, morphology, Table 1, Figure 1) and the following information: CS901 is from Argentat, France; the Landsberg and Columbia plants used in Konieczny and Ausubel (1993) are the same plants used in your experiment.
- 5) Don't forget the other primers you used with Landsberg and Columbia!

Good luck!!!!

Literature Cited

Konieczny, A. and F.M. Ausubel. 1993. A procedure for mapping Arabidopsis mutations using co-dominant ecotype-specific PCR-based markers. *The Plant Journal* 4(2): 403-410.

FERMENTATION LAB

17 November 1994

Beverage	% Alcohol
Beer	4
Wine	12-14
Tang	0
Fortified Wine	20
Yoo-Hoo	99
Distilled Spirits	40-75

Beer and wine are made by allowing yeast to metabolize sugars (malt or fruit juice) present in the ingredients used to make these drinks. Fortified wine requires addition of alcohol and distilled spirits require distillation to achieve the levels of alcohol shown in the table above.

Using your knowledge of the process of fermentation and the equipment address the following:

Why is the maximum alcohol content in wine 12-14%? Prove or disprove that this is the maximum alcohol content that can be achieved by yeast fermentation only. How is the rate of fermentation related to alcohol concentration?

Your experiment must include the following:

- 1) an explicit, testable hypothesis(es)
- 2) controls

VITA

Diah Aryulina was born in Jakarta, Indonesia in 1962. She completed her undergraduate degree in Biology Education at IKIP Jakarta in 1986. She earned her Master of Art degree in Biology from State University of New York (SUNY) at New Paltz in 1988. Since 1988 she has been teaching biology at the Department of Science and Mathematics Education at the University of Bengkulu, Indonesia. In 1992 she had an opportunity to come back to America for a doctoral program in curriculum and instruction at Virginia Polytechnic Institute and State University. During her study at the University, she was primarily interested in science education.

