Collaborative and Interactional Processes in an Inquiry-Based, Informal Learning Environment

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ABSTRACT

This study was conducted on informal aspects of an inquiry-based physics course and reports findings about learning interactions and discourse observed during the first three semesters the course was offered. The course offered an alternative to the large lecture instruction typical in introductory university physics and promoted learning in an informal environment. The course organization attempted to engage students in investigations with only a small fraction of time devoted to lecture/discussion. Students collaborated in groups of three to conduct investigations with the use of computer tools and laboratory apparatus. The instructor and teaching assistants interacted directly with the students with the intent to ask probing questions to guide the students through conceptually meaningful problem solving. Researchers video taped student groups as they worked through investigations. Field notes and students' investigation reports provided additional information about student performance. The study reports detailed accounts of student interaction through discourse during the class investigations and comments on the nature of the student collaborations. The study showed that during collaborative problem solving, the students engaged in informal elaborative and reflective discourse that critically examined the data the students had collected during the investigations. The author comments on possible relationships of these interactions and cognitive processes to knowledge construction in an informal setting.

INTRODUCTION

Lack of Conceptual Understanding in Conventional Courses

Research has demonstrated students enter a new science learning environment with pre-existing ideas and understandings of the concepts to be presented. Frequently, these initial conceptions fail to reflect accepted scientific understanding. Research has also proven these initial conceptions quite stable and not easily changed by traditional methods of science instruction. Many educators in the United States conduct introductory science courses in secondary schools and universities in a lecture format in which the instructor presents information and the students seldom actively participate (Wilson,1994; Roth, 1994). A pedagogical assumption underlying this form of instruction appears to be that knowledge can be transferred from expert to passive learner (Roth, 1994). Researchers' reports have pointed out that students may isolate and forget the explanations of scientific phenomena presented in the lecture and recitation mode of instruction so prevalent in introductory classes (Linn, 1995, p.5). Furthermore, researchers have indicated that the lecture and demonstration method of science teaching does not adequately promote learning for conceptual understanding (Wilson, 1994; Thorton & Sokoloff 1989; Hestenes, Wells, & Swackhamer, 1992). Blue ribbon panels of experts have published reports, including *Physics at the Crossroads* (Hilborn, 1996), that point to the need to change instructional methods to promote increased conceptual understanding.

Conceptual Gains in Activity-Based Courses incorporating Small Group Collaboration

Researchers have suggested that small group instruction in an informal, activity-centered environment may promote learners' conceptual development (Wilson, 1994; Laws, 1991; Hestenes, Wells, & Swackhamer, 1992; Johnson , Johnson & Stanne, 1985; Slavin, 1996). A few college introductory physics programs in the United States use microcomputer-based laboratory (*MBL*) tools, small group instruction, and inquiry-based curricula that allow students to take an active role in their learning (Laws, 1991; Thornton & Sokoloff, 1989). Educators have designed these programs to help students construct conceptual understanding, often using data collected by direct observation while working in a collaborative group. One of the most notable of these programs, *Workshop Physics*, is in use and development at Dickinson College in Pennsylvania. This program is also linked to the *Tools for Scientific Thinking Project*, based at Tufts University in Massachusetts. A third program called *Studio Physics*, based at Rensselaer Polytechnic Institute in Troy, New York, has developed a similar *MBL* Physics course that calls for students to actively participate in their own learning, with less lecture and more activity-based problem solving.

All three of these programs have carefully designed curricula that claim to be based on educational research. These programs also incorporate the intensive use of *MBL* sensors, computers, and software (Laws, 1991; Thornton & Sokoloff, 1989). Research on these programs has demonstrated substantial conceptual gains with error rates on pre- and post-test questions improving by as much as 50% when using assessment questions designed to show conceptual understanding and not just the memorization of facts (Thornton & Sokoloff, 1989). Students enrolled in a lecture-recitation course used for comparison showed "no improvement" on these conceptual questions (Thornton & Sokoloff, 1989). This observation is similar to what was reported by Roth and Roychoudhury (1993) when they discussed the development of science process skills within an inquiry centered classroom environment.

Limited Research on the Nature of Informal Instruction that may Promote Conceptual Understanding

While studies in the literature have reported pre- and post-test scores indicative of changes in students' knowledge and skills, very little information exists about the nature of the instructional treatments that may lead to enhanced conceptual understanding. Prevalent research on physics course effectiveness has not examined specific aspects of the classroom environment that may promote conceptual understanding. Research by a group from Bremen, Germany, has most recently attempted to assess conceptual development within the natural classroom setting using continual data collection techniques. The group studied high school students and used interviews as a principal source of data collection (Neidderrer, 1997).

Neidderrer pointed out that there were only 16 studies that attempted to look at conceptual understanding in physics within the natural classroom setting. All of these studies are based on high school or middle school students, and all took place outside of the United States. Most of these studies are doctoral dissertations and have not been published in journals.

The existing studies on conceptual understanding of college-level students are usually based on pre- and post-testing of the subjects and normally do not attempt to discover how the students develop this understanding. The field lacks research that clarifies the specific events within the natural classroom setting that may promote improvement in conceptual understanding of the students involved in the study. This study is one of the first in the United States to use continuous data collection in an informal, university physics classroom setting in the effort to identify the nature of the group interactions that may promote understanding of introductory concepts.

Learning Science: Recommendations from the Literature

Some of the most well-known learning theorists and psychologists of modern times have discussed the understanding of the basic learning mechanisms and the examination of ways to promote learning. As there are no widely accepted theories to guide instructors on how to promote complex human learning and understanding in physics, the education literature reviewed below suggests a few relevant strategies.

Cooperative Grouping

A cooperative group exists when the goals of the individuals within the group are so linked together that the individual cannot attain his/her goals unless every other member of the group can also attain his/her goals (Johnson, Johnson & Stanne, 1985). One may summarize the structure of cooperative learning groups in the following manner:

- Positive interdependence among group members is promoted.
- Individual accountability is clear.
- The membership is typically heterogeneous in ability and personal characteristics.
- All members share responsibility for performing leadership actions.
- The goals maximize and maintain good working relationships among members.
- The instructor observes and gives feedback related to the task attainment (Adapted from Johnson, et. al., 1984).

Group Size

Johnson, et. al. (1984) recommend that beginning instructors and students start with groups of two or three. As the learners and instructors become more experienced and skillful in working with the cooperative group structure, they may better handle larger groups. In the school setting, Johnson, et. al. (1984) suggest six as the upper limit for a cooperative learning group.

Heller and Hollabaugh (1992) reiterated the suggested groups of three for students who have no real cooperative group experience. They believed the three-member group to be large enough for the production of varied ideas, yet small enough so that all members could contribute to the solution of the problem. Proceeding on the basis of these and other research recommendations, the researchers in this study arranged the students in groups of three and assigned them a computer station.

Group Composition

Heller and Hollabaugh (1992) described the optimum cooperative group composition in the physics classroom as one of mixed ability. Their research suggested that mixed ability groups performed as well as groups consisting of only high-ability students. They stated the groups that were most successful in improving their problem solving skills were made up of "a high-ability, medium-ability, and lower-ability student" (p.644). Their research further suggested that homogeneous gender groups and mixed gender groups of two females and one male performed better than groups with two males and one female.

The above observations of group composition may be difficult to achieve in a completely informal learning environment. With this as its premise, the rest of this paper will report on the results of forming informal learning groups of three heterogeneous students within a formal educational setting.

Implications for Teaching and Learning with Cooperative Groups

Research has demonstrated that cooperative grouping and student collaboration may be an appropriate means of promoting student understanding of science (Heller, Keith, & Anderson, 1992; Heller & Hollabaugh, 1992). Heller, Keith, and Anderson, (1992) deemed problem solutions produced by group effort preferable those produced by the best individual problem solvers. Other researchers have reported on the benefits of cooperative group learning and are summarized in the bulleted items below.

Cooperative/collaborative learning promotes:

- Higher Quality and Quantity of Daily Work
- Greater Mastery of Factual Information
- Increased Ability to use Factual Knowledge
- Increased Success in Problem Solving
- Increased Motivation to Reach Goals

(Adapted from: Johnson, R., Johnson, D., & Stanne, M., 1985).

Theories and current research into the social aspects of learning and cognition build a strong argument for the use of collaborative group work in the classroom. Here, one must distinguish between the terms *collaborative* group and *cooperative* group. In a cooperative group, the members work collectively to arrive at the solution to a provided or perceived task. This may take the form of "divide and conquer" in which each member of the group takes a specific task and then the group assembles the pieces at the end. In this way, not every member of the group needs to engage in the cognitive interactions that promote conceptual understanding. Collaborative interactions necessitate the participation of all group members in the negotiation of all aspects of the task solution. Collaborative work requires all members of the group to engage in cognitive interactions that help to promote conceptual understanding (See below and also, Dillenbourg, 1999). Kelly and Green (1998) explained that the beliefs, actions, concepts, and shared knowledge can be viewed as a *conceptual ecology* that is constructed by the interaction of the members within the group.

Collaborative Interactions in a Group Setting

Linn and Burbules (1993), Tao (1997), and Roth (1995) have all reported on the conceptual development observed as students engage in the social interactions promoted by appropriate group collaboration in the science classroom. Appropriate group learner collaboration would include such things as: (a) working jointly on the problem; (b) critically re-examining assumptions; (c) elaborating material for each other; (d) engaging in mutual feedback and debate (Slavin, 1996). Appropriate social collaboration promotes deep conceptual insights and shifts in perspective (Damon & Phelps, 1989), aspects of learning that have been closely linked with conceptual understanding. A model of collaborative grouping devised by Lumpe and Staver (1995), reported to be an effective way of enhancing understanding, included assigning specific cognitive roles to the students. In this model, students within a group take on a different cognitive role each week: e.g., an executive makes problem-solving suggestions, a skeptic questions the plans or ideas, an educator explains and summarizes the solution ideas for other members of the group, a record keeper writes down the process, and a conciliator resolves any conflicts (Lumpe & Staver 1995). The different roles help to instigate high-quality cognitive interactions among students and, thereby, promote higher-level thinking and learning of difficult concepts. Peer collaborative group interactions include higher-level cognitive questioning, problem solving, and active student engagement, which Lederman and Druger (1985) report significantly facilitate gains in student understanding. These interactions allow learners to achieve a level of academic ability they would not reach on their own. This aspect of collaborative learning relates to Vygotsky's (1978) theory and students' "ZPD". Student interactions and collaborative talk while working on meaningful group activities cultivate a deeper understanding of concepts and knowledge construction. "*Intersubjectivity*," defined by Roth (1995, p. 182) as a condition of "knowing that others know and refer to the same things" develops through these intense collaborative interactions among the students. Roth goes on to further describe this type of "*intersubjectivity*" as "the understanding which the collaborating individuals have of each other and their joint task" or "the existence of a common situation definition and the knowledge that it is shared" (p.183). Academic ability might include scientific reasoning skills such as: defining the problem; stating hypotheses; collecting, interpreting and analyzing data; and making predictions (Friedler, Nachimas, & Linn, 1990). As the students involved in productive social interactions gain ability, they may also engage in collaborative social interactions, negotiate conceptual understanding, and reconstruct their conceptions leading to increased conceptual understanding (Slavin, 1996). Collaborative informal learning, guided by appropriate research in learning and instruction, should become a more integral part of current teaching methodology.

METHODOLOGY

Informal Aspects of the Course

Development

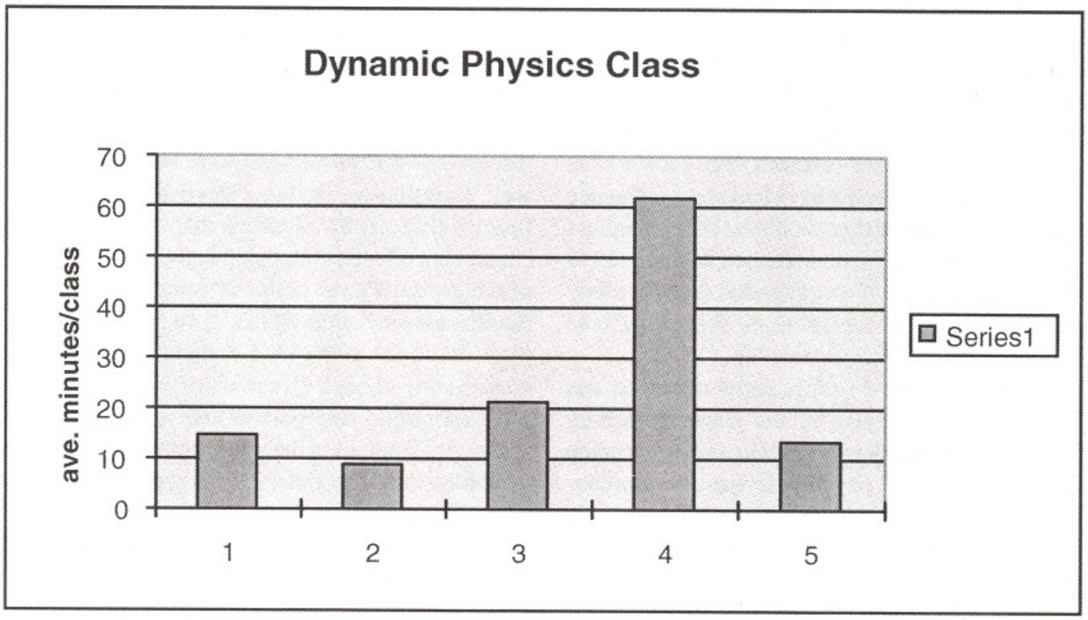
In response to the concerns that the standard lecture-recitation style of delivery did not provide students with a deep conceptual understanding of physics, the lead professor worked with colleagues and staff to design a physics course responsive to problems described in the literature. Guided by that literature and by reflection on many years of experience in university physics education, he and his team developed a course containing many aspects of an informal learning environment. The course was first offered in the fall of 1996 as an introductory calculus-based honors class. In its inaugural semester, two sections with up to 42 students in each were offered in a classroom renovated to contain fourteen computer/laboratory stations that would accommodate teams of three students each. Each student team was intended to be a collaborative laboratory group that would work together informally to solve the inquiry-based activity problems that formed the core of the curriculum. With easy access to *MBL* tools, specially prepared authentic problems, and informal collaborative learning techniques, it was intended that students would develop enhanced understanding of physics concepts and that there would be equity in learning in the course for participating women and minority students.

Group Assignment

The student laboratory groups in the course were organized according to work done by Heller, Keith, and Anderson (1992). Their research indicated three is the optimum group size for physics problem-solving work, composed of either two females and one male, or single gender. The groups of three were composed of one high, one medium, and one low ability student, parallel to the work reported by Heller and Hollabaugh (1992) and others (e.g. Slavin, 1996; Johnson, Johnson & Stanne, 1985; Webb, 1989) whose work has indicated that heterogeneous grouping produces increased collaborative dynamics. These collaborative dynamics include increased questioning, explaining, elaborating, discussing, exchanging of ideas and information, etc. All of these dynamics are linked to the benefits of collaborative group learning described earlier. The measure of ability for the group assignment was the score on the first day test adapted from the Hestenes force concept inventory test (Kuech, 1999). This test was also given as a post-test as one measure of student concept development during the semester (see Mackin, 1998).

Instructional Treatment

Inquiry-based investigation-problems formed the core of the curriculum around which all the lectures and collaborative laboratory activities centered. In class, the student groups functioned in an activity-based, laboratory environment withcomputer technology tools available to each group. The investigation-problems parallel a category of learning tasks that Slavin (1996) described as "controversial tasks without single answers" (p.59). This type of task contains a high level of "cognitive complexity" with no immediately apparent path to a solution or to one correct answer. These tasks or activities are likely to promote differences of opinion leading to increased discussion (Slavin, 1996). The investigations were



designed to be academically challenging and to require basic assumptions or approximations of needed data so the groups of learners would find it beneficial to work together to find an appropriate solution. Lectures were intended to occupy less than one-fourth of the class time so the students could dedicate the majority of their time to activities associated with solving the investigation-problems (see Chart 1). The student groups collaborated informally to solve the mechanics investigation-problems that had been organized by the instructors. (I use the term informal to describe the collaboration of the students in the groups because no guidance or instruction was provided to aid in the roles that students would take within the group. The students were assigned to a group and told to work together to solve the investigations.)

Research Questions

This research study examined the ways a group of students interacted to solve problems within the context of a high technology, activity-based physics course that intended to promote small group collaboration. The specific research questions that guided this study were:

1. What is the nature of the interactions between the students within the group?
2. In what ways do the interactions potentially influence student conceptual understanding?

These research questions were chosen in an attempt to characterize the specific nature of the environment that made it different from a more typical college course. Specifically, limited student interactions or discussions are allowed during most courses, in fact students talking during a typical course would be asked to leave because they were disturbing the other students around them. In contrast, student interactions were encouraged in the small group environment. The classroom and course organization intended that the students collaborate informally in order to find appropriate solutions to the investigation activities. The research team decided that these interactions/discussions must have had some influence on the student learning process that produced the conceptual gains observed on the pre and posts-tests (see Mackin, 1998 for pre/post-test information). It was intended that this study would identify the types of interactions that may have promoted the increased conceptual learning.

The research study reported in this paper observed and identified interactions employed by the learners as they attempted to solve investigation-problems and to develop conceptual understanding of physics. It was the student-student interactions in the presence of high technology tools that produced a relatively unique learning environment, setting it apart from typical introductory level university courses. The role of group interactions and problem solving processes in the construction of understanding was examined carefully in the study as the students worked within the informal classroom environment of the course.

Research Methodology

The research study was conducted using qualitative case study methodology. Merriam (1988) wrote that case study research is an excellent technique for studying peer interaction and that it can enable an in depth study of an issue. Case study methods were selected to organize the research since the study was to examine carefully the social interactions occurring within a student group that might promote conceptual understanding. *Purposeful sampling* was thought to be an appropriate method of data gathering for this study. Merriam (1988) indicated that purposeful sampling "is based on the assumption that one wants to discover, understand, gain insight; therefore one needs to select a sample from which one can learn the most" (p.48). It was important therefore to select the sample for the study carefully. Patton (1990) discussed several kinds of purposeful sampling including cases that represent extremes, the norm, or convenience. For this study, it was decided that the positive extreme of a well functioning group would provide the richest data source for the researcher.

This study was to focus on the interactions of a group of learners as they attempted to develop conceptual understanding while solving assigned investigation-problems. The particular group was selected for special attention on the basis of two significant factors:

1. An especially well functioning collaborative group.
2. A location in the room that allowed easy access without researcher interference.

1. The group demonstrated positive interaction skills and collaboration from the beginning of the course. All members of the group contributed to the discussions and other activities. Earlier pilot studies indicated that the willingness and ability of all group members to participate in activity related discussions and procedures were important precursors for a well functioning collaborative group. Studying a well functioning group allowed information to be gathered concerning effective interaction and learning. No one member of the group of three males selected seemed to dominate all the discussions, although in retrospect, they did appear to play different roles. All three of the learners seemed comfortable enough to ask clarifying questions if they did not understand any part of the material or topics being discussed. Students in the group would take the time to answer questions raised by others in the group and to explain to the best of their abilities.

2. The group selected was situated in a classroom location away from the projection screen where the lectures were presented. The laboratory station to which they were assigned by the instructor was at the end of a table next to the center

aisle and adjacent to the back wall of the classroom. In this location the researcher could look over the shoulders of the students in the group and onto the computer station at which they were working. The researcher could view all the work in which the students were engaged as well as clearly hear their discussions and see their computer screen. At the same time the observer was located at the back wall, and he did not interfere with the normal flow of classroom activity.

Data Collection

This study involved *continuous data collection* (Neidderrer, 1997) in a natural field setting. It attempted to identify the group interactions and problem-solving processes employed by the learners and to examine aspects of those interactions that seemed to promote the construction of conceptual understanding. The continuous data collection method required that the collection of data occur without interrupting normal group interactions or classroom flow. Using this methodology, the researcher did not ask any clarifying questions of the students or conduct any interviews. However, in field notes he did attempt to capture as much of the contextual information as possible so as to facilitate an accurate interpretation of the data collected. The transcripts and other data sources permitted the researcher to make inferences about what might be promoting development of conceptual understanding. The inferences derived from this methodology may offer insights with practical implications for teaching since they were made from discussions and interactions that occurred in a normal classroom setting.

Data Sources

Video Tapes. Video tapes of the students in the group as they attempted to solve the investigation-problems within the normal classroom setting was the primary data source for the development of the case study. These video recordings were transcribed to prepare hard copies for analysis of all the discussions that occurred during the class activities involving members of the group. The actions of the students and their use of technology during their work on the investigation-problems were recorded in detail. Video recording and subsequent transcription allowed the researcher to isolate individual parts of the student problem-solving processes and to observe carefully what was transpiring. These data were analyzed to examine the problem-solving processes employed by the students and the role of social interaction and the technology tools.

Field Notes. Extensive field notes were collected by the researcher to supplement the data recorded on the video tapes. Activities such as use of personal calculators, computer-probes, spreadsheets, VideoPoint activities, interactive physics simulations, printers, etc. were all carefully noted. The researcher's field notes also commented on the processes that occurred within the group. The field notes included comments on the participation of students, the level of group collaboration, who was using the keyboard or mouse and any other activities the group members were involved in that might influence their participation in the learning process. The researcher also noted when discussions related to the specific activity occurred, who led the discussions (if anyone), or if the group skipped certain parts of the lab activity. Field notes recorded whether the group read the activity description from the computer or from a hard copy printout. The individual who went to get a print out or needed equipment and the individual or individuals who did certain readings and related activities were identified. The researcher also noted peripheral circumstances such as if the class was unusually quiet on a particular day, if the class occurred on the day before a vacation, if it was a stormy day or other intangibles that might influence the nature of the discussions.

Investigation Reports. Investigation reports were reviewed to expand the classroom observations made with the video and to enable triangulation of different sources of data. The investigation reports were evaluated as another indicator of the nature of the conceptual understanding the group was exhibiting during an investigation. The investigation reports were compared to the video tapes and their transcripts to corroborate discussion patterns and ideas or concepts were inferred in the data.

Data Analysis Framework

The framework for the data analysis was built around the assumption that learning, understanding, and conceptual growth are promoted through the social discourse of the learners involved (Lave & Wenger, 1991). The most substantial difference between the observed course and a more typical lecture/recitation course was the informal interactions among the students in the laboratory group. For these reasons the analysis was organized around the assumption that "learning is observable as a change in agents' interactions with their social worlds (through language) and their material worlds (through practical actions)" (Roth, et. al., 1997). By examining the activity related discourse that occurred within the problem-solving interactions, the collaborative dynamics that might lead to understanding of physics concepts were described. The annotated transcripts of the video tapes, including the contextual references, were the principal sources for reconstructing the students' discussions and actions as they developed an understanding of the investigation in which they were involved.

As discourse between learners in the group evolved within the transcribed data, it was categorized and coded. Drawing upon the observations made during the two earlier pilot studies and considering the specific collaborative dynamics that produced increased achievement (Slavin, 1996; Webb, 1989) assertions were made that seemed to summarize the main points of the study.

RESULTS

The researchers interpreted the data using a two level interpretation process similar to work reported by Kesidou & Duit (1993). For the first level, the group discussions for each activity were classified into three categories: reflection and recall, intersubjectivity, and elaboration. These categories were constructed on the basis of initial ideas about student interactions that were formed during the first two pilot studies on the course and linked to the collaborative learning literature that identified interactions that promoted increased achievement (Slavin 1996, Webb 1989). The second level of analysis then established how the three categories could be interpreted to have affected learning for understanding within the observed group members.

Student Achievement in the Selected Group

It was not the goal of this paper to build a convincing argument about the significance of the Dynamic Physics student achievement gains in the understanding of mechanics concepts. This had already been done by Mackin (1998). This study sought to explain the student interactions of a particular group and how these interactions could have facilitated the conceptual gains that were observed in the learning environment. It is important for the purposes of this study to point out the achievements of the students within the group selected for study.

Table 5.1 below lists the final course grade and the scores on the pre- and post-test. A limitation of these scores is that student S2 dropped the course for personal reasons and did not receive a grade on the final investigation or take the post-test. So the study was left to comment on achievement based on the scores of 2 students. This would certainly not be a large enough sample to convince anyone of the student achievement promoted by the course. As stated above, the achievement gains made by the students in the course in conceptual understanding were evaluated by Mackin (1998), who wrote, "students made above average gains in understanding of mechanics concepts after instruction in this learning environment"(p. 100). The normalized gain on the FCI has a range from 20 to 50 percent nationwide and the two students in the group came within and above that range leading the researcher to argue that the students in the selected group also made above average gains in conceptual understanding.

S3 earned a course grade of 94, well above the class average of 87 and he made the greatest conceptual gains of the group on the pre-test to post-test gain scores. [Gain Scores: raw (23) and normalized (92%)]. The group also performed quite well on the investigation reports receiving scores as follows:

Atomic Bomb	7.5
Demon Drop	8.5
Tractor Pull	9.2
Bungee Jump	9.9
Rotational Kinematics	9.8

All of the scores were on basis of 10 total points. It should be noted here as mentioned previously that the reason for the lower than average score on the first report was due to the group receiving only partial credit for the conceptual explanations they gave. As the group became better at collaborating and improved on their conceptual explanations in the investigation report their scores improved. On the last two investigation reports, the group received two nearly perfect scores indicating a high level of conceptual understanding.

The brief discussion of student achievement in the above section demonstrates a higher than average gain in conceptual understanding for the group selected for study, consistent with the findings of Mackin (1998) in the broader study of the Dynamic Physics learning environment.

Interpretation of Selected Data

The following transcripts were selected as representative examples of the student-student interactions that occurred throughout the semester of study whenever the students found it necessary to collect and interpret investigation data in order to arrive at an appropriate solution to the activity they were studying.

A brief description of the instructor's stated purpose of

Table 1

Student	Course Score	Pre-test	Post-test	Raw Gain	Normalized
S1	73	33	50	17	25.4%
S2	69	48	N/A [missed final investigation & post-test]		
S3	94	75	98	23	92.0%

(Mackin 1998)

the investigation-activity is provided for each investigation followed by some contextual information to help the reader understand what the students had been doing and what they were trying to accomplish in the ensuing transcript excerpt. The excerpt is then presented followed by an interpretation of what the researcher aided by his field notes thought was taking place through the students' discourse.

The purpose of this activity was to engage the students in the investigation of acceleration of objects by measuring position versus time and then interpreting the data to determine speed and acceleration. The students used VideoPoint (Lenox Softworks) software to collect position versus time data from videos of an amusement park ride called the Demon Drop (Hershey Park). The students also collected and analyzed similar position and time data from 2 rocket launches, 1 of a Mercury Rocket liftoff, and the second of the Space Shuttle liftoff. Both of these videos were made available by NASA films.

The students were instructed to use the VideoPoint software and start with the Demon Drop video clip making the video display window as large as possible to produce more accurate viewing of the motion of the car in the film. Within this window the students were instructed to carefully select a point on the car and to follow this point as closely as possible. The students were further instructed to use the ruler utility within the software to set the scale of their measurements so that they were collecting data in meters. Once this data had been collected it was then transferred into Excel (Microsoft) for further analysis using the "copy" and "paste" functions of the software. At this point the students were instructed to delete the X coordinate data (which the program automatically collects) because it is a constant and not needed and may add to confusion (for a more complete discussion of this activity, see Kuech, 1999).

Assertion 1: *Reflection* and *Recall* promoted student learning that developed familiarity with the Mechanics Concepts.

The students attempted to gain a better understanding of the acceleration versus time data for the Mercury Rocket they were looking at, (as an instructor was not immediately available) by relating this acceleration to something they were more familiar with, the acceleration of a car. This *recall* of previous knowledge with which they were more familiar was seen in the following transcript excerpt about the acceleration of a car.

S1 A car goes 35 miles per hour. . . . a car goes 35 miles per is? it probably just goes . . . [inaud]

S3 Tell me those ?

S1 50 miles per hour, that's 65 miles per hour. What will that be? [as S2 brings up the video of the rocket used to gather the data]

S3 In how many seconds?

S1 Just velocity. You don't have to have seconds.

S3 You will for acceleration.

S2 Well. Well.

S3 How much time do you have for the average acceleration?

S1 For a fast car 0 to 60 in around 4 seconds. [S2 shakes his head not]

S2 0 to 60 in 6 point 3, and that's one of the fast cars.

S1 Well a Porsche will go 0 to 60 in ahh.

S2 6 point 2, 6 point 3, I don't know.

S1 this isn't a Porsche, this is a rocket ship. The closest thing to a rocket ship would be like a...

(lines 79 – 107)

The students critically reflected on the acceleration data they produced for the liftoff of the Mercury Rocket. They attempted to negotiate an understanding of why the acceleration they had calculated seemed so slow. Minstrell (1991) pointed out that:

> "students search novel situations for features or results that are familiar to them and consistent with what they already believe. In this way their knowledge systems appear conservative and resist change" (p.121).

The findings of the acceleration of the rocket were inconsistent with what the students already believed and so the students resisted accepting these data to be correct. The students in the observed group did not report these suspect findings and feel that this would be good enough. They attempted to gain a better understanding of the acceleration versus time data they had generated and if this could be correct, by relating their calculated acceleration to something they understood better. The students had to *recall* and build on previous knowledge with which they were more familiar. Niedderer & Schecker (1991) report that "one mechanism in this process of meaning construction could be to find relations between earlier experiences and a given new situation"(p. 86). For example, in the Demon Drop Investigation (lines 79-111), the students discussed the acceleration of a sportscar (an earlier experience) and how this related to the acceleration of a rocket during liftoff (a new experience). Recall of the previous experience may have been a preliminary step in the understanding of the meaning of the new situation. This supports the conclusions of Nuthall (2000) and how new information gets tied into previous knowledge to produce increased learning and long term memory. The observation of the acceleration of a rocket during liftoff using video data, allowed the students to view acceleration from a new perspective. The student-student discussion of their understanding of the acceleration of a rocket, a sportscar, the car of an amusement ride, the space shuttle and the acceleration of gravity, enabled the students to become more familiar with the concept of acceleration and how it applies to different types of vehicles. The students were able to *recall* related experiences to look at the concept (acceleration) from numerous perspectives and increase the opportunities to learn. Roth (1995) reported a similar observation:

> "...that understanding becomes deeper and more complex when students have available an increased number of practices to interact with the phenomena they study . . . . This construction of a deeper understanding through an increasing familiarity with a phenomenon is very much like getting to know a city that one explores by walking, riding a bike, taking a car, looking at a map, or observing it from a bird's eye perspective. It is in this multitude of experiences and the familiarity which it affords, that we learn about our physical and conceptual environments, and that we increase out understanding of learning phenomena" (p.266).

This type of interaction and construction of meaning is closely related to what Uno (2002) calls multidimensional literacy. This type of literacy is described as "a broad, detailed, and interconnected understanding of a subject" (Uno, p.46). We can see that the members of the group are interconnecting many ideas and information. The students in this study used *reflection* and *recall* to provide several perspectives from which to view the concept of acceleration. Viewing the concept through multiple perspectives gave the students an opportunity to develop a better understanding of acceleration. Through Multiple perspectives, the students became familiar with the concept of acceleration, one of the stated goals of this investigation.

The group received eight point five out of a possible ten points for their efforts on their lab report, demonstrating that the instructor also felt that they had developed a better understanding of the concepts. The development of familiarity with a concept through multiple perspectives provided by *reflection* and *recall* during informal student discussions, may have been an important factor in promoting deeper and broader understanding (Kuech, 1999).

Assertion 2: Group collaboration promoted *intersubjectivity* among the students as they worked together to understand the investigations.

The student-student discussion of the acceleration of a sportscar (reported above), helped the members of the group to develop *intersubjectivity* demonstrated by collaboratively constructed sentences (Roth, 1995; Lehtinen & Repo, 1996).

S1 starts by saying "well a Porsche will go 0 to 60 in ahhh" S2 finishes by saying "6 point 2, 6 point 3, I don't know."

The co-construction of sentences indicated a common situation definition existing between S1 and S2 allowing for a joint discussion of the problem at hand. S3 was the student who suggested that a time was needed to determine acceleration and so it can be assumed that he also had a common understanding of the conversation, even though he does not personally take part in this specific segment. Lumpe and Staver (1995) report on the group co-construction interactions that aide in the ability to learn concepts in the following:

> "Sullivan's co-construction theory of peer interaction (Damon & Phelps, 1989) explains these types of interactions and their effectiveness. The key component of Sullivan's theory is that ideas are formed jointly by peers working as equals, yet without copying one another. Damon & Phelps (1989) interpret Sullivan's theory as the joint formation of ideas as peers 'share ideas, seek consensus, compromise willingly with each other, and remain open to new insights' (p. 334). The case study group appeared to form ideas jointly throughout the study with becoming explicitly dissonant. Agreement was quite common, and explicit group conflict was rare. For example, group members often finished each other's sentences, and each member added something positive to the dialogue" (p. 92).

The *intersubjectivity* displayed by the students during this and many other conversations during the course of the semester of study, was a starting point for the construction of knowledge about the concepts undertaken in the concurrent investigations. Roth (1995, p. 183) contends "from a Vygotskian perspective, *intersubjectivity* allows for joint thinking, problem solving and decision making from which learners appropriate (that is, intraindividually construct) new knowledge". The appropriation of new knowledge and development of a deeper understanding of the associated concepts was a desired outcome of the informal learning environment.

Assertion 3: The students engaged in *elaboration* and concurrent questioning as they negotiated the meaning and understanding of Mechanics Concepts relevant to the investigations.

Although the students had negotiated a shared understanding of the concept of acceleration, there was a need for some *elaboration* of the relationship between velocity and time as it pertained to acceleration. It appeared that student S2 did not clearly understand that you not only needed to know the change in speed of the car, but also the time necessary to make this change of speed in order to accurately discuss acceleration. In this same transcript excerpt from the Demon Drop Investigation, student to student elaboration was observed as the students negotiated an understanding of the acceleration of the car.

In the following lines, S1 recalled the speed of various automobiles and how fast they can go:

S1 A car goes 35 miles per hour. . . . a car goes 35 miles per is? it probably just goes . . . [inaud] (lines 79-80)

[S3 interrupted S1's train of thought to get some further clarification from him on what he meant by saying that the car goes 35 miles per hour.]

S3 Tell me those ? (line 82)

[S1 then continued the discussion of the change of speed of various automobiles that he recalled from previous experience. He recalled this information as support that the data they had produced about the acceleration of the rocket was not accurate. But during this discussion it seemed that he did not have all of the information that he needed to explain the acceleration of the car he was thinking about.]

S1 50 miles per hour, that's 65 miles per hour. What will that be? (line 84)

[S3 was not satisfied with this explanation and interrupted again with a clarifying question for S1. S3 seemed to have a firm understanding that it requires both the change in speed and the change in time to determine the acceleration of the automobile. So he questioned S1 as to how long it takes for the car to get to the speed he was referring to.]

S3 In how many seconds? (line 88)

[At this point S3 had pinpointed the problem with S1's discussion of the acceleration of the automobiles and S1 seemed to understand what S3 was getting at. S1 however, was not fully cognizant of the full concept until after the next brief exchange.]

S1 Just velocity. You don't have to have seconds.
S3 You will for acceleration. (lines 90-92)

At this point the conversation took a turn and there seemed to have been a change in the conceptual understanding of the topic of acceleration that they were discussing. S1 now began to express (accurately at this juncture) the acceleration of the automobiles in terms of how fast they can get from 0 to 60 miles per hour in terms of the number of seconds it takes. S2 also added his thoughts on how fast an automobile can accelerate observed in the following few lines of the Demon Drop transcript excerpt.

S1 For a fast car 0 to 60 in around 4 seconds. [S2 shakes his head not]
S2 0 to 60 in 6 point 3, and that's one of the fast cars.
S1 Well a Porsche will go 0 to 60 in ahh .
S2 6 point 2, 6 point 3, I don't know.
lines 98-104

This excerpt showed a shift in the discussion from simply talking about velocity of automobiles without a mention of how long it takes to make the change in the velocity, to a clear discussion of change in velocity also requiring a discussion of change in the time for this to take place. The student-student discourse had moved the language of the students from the everyday colloquial terms toward more scientific language. The correct units for acceleration of meters per second squared were used throughout the group's investigation report demonstrating that the students were aware of the appropriate scientific terminology for linear acceleration.

Questioning for understanding was also observed during the Demon Drop Investigation (lines 79-111) when S3 asked about the time it took for the change in velocity needed to determine acceleration. The student-student questioning demonstrated one of the advantages of collaboration among the students in a well functioning group. Lumpe and Staver (1995) summarize this positive student-student interaction in the following manner as they speak of Piaget: "[Piaget] contended that peer interaction is more desirable than adult-child interaction because peers are not as threatened with each other and are more willing to share ideas more readily" (p. 92). The questioning reported here is supports the work of Marbach-Ad and Sokolove (2000), who demonstrated the importance of questioning to students' understanding of biology concepts. In the informal group environment, the students were able to ask questions about concepts they did not fully understand and receive immediate non-threatening feedback. Student-student questioning segments demonstrated what Roth (1998) referred to as a "repair sequence" (p. 5) in which participants in a community of discourse engage in to reach a common understanding. In his text, *Designing Communities*, Roth described what it means for students to reach or construct a common understanding or shared meaning.

> "Initially, two or more individuals talking to each other do so based on the default assumption that understanding is shared. If, during the unfolding conversation doubts about this assumption emerge in one or the other participant, they will engage in a repair sequence intended to re-establish the default state" (Roth, 1998, p.5-6).

When one student in the group had doubts about another's understanding of the concept under investigation, the first student engaged a questioning discussion that repaired or re-established the common understanding of the group. This was observed during the Demon Drop Investigation when S3 questioned S1 about the time it tool for the sports car to change its velocity from 0 to 60 miles per hour (line88). S1 stated that "you did not need time, just speed" (line 90), and S3 corrected him by stating "you would need a time if you wanted to discuss an acceleration" (line 92).

These brief *elaborations* are consistent with what Slavin (1996) described as "the classic Vygotskian paradigm; students in collaborating groups make overt their private speech, giving peers operating at a slightly lower cognitive level on a given task a stepping stone to understanding" (p. 59). The *elaborations* elicited by student-student questioning may have been the "stepping stone to understanding" that allowed the students to make the reported significant gains in conceptual understanding as measured by the pre- and post-test results (Mackin, 1998).

DISCUSSION

Informal learning environments promote student interactions that include reflection and recall, intersubjectivity, and elaboration and questioning. These interactions have been shown in the cognitive literature to be important in promoting conceptual understanding and retention of concepts (Slavin, 1996; Webb, 1989; Damon & Phelps, 1989; Johnson, Johnson, & Stanne, 1985). The study reported above also found their learner-to-learner interactions to be important factors that may have contributed to greater understanding of physics concepts as measured on pre- and post-tests. The interactions as presented above required the students to restate, explain, or defend their interpretations of the concepts to other members of the group. The restatement of their interpretations of the concepts caused the learners to critically evaluate and reflect on their existing knowledge of the situation. When students have to evaluate, integrate or elaborate upon their existing knowledge, they are likely to construct a deeper understanding of the concepts involved (Roth & Roychoudhury, 1993).

Informal learning environments provide increased chances for learners to interact with the concepts they are observing. In his book "Authentic School Science" Roth (1995) argues that "understanding becomes deeper and more complex when students have more chance to interact with the concepts they study" (p. 266). Roth contends that as the students interact with the phenomena under study they become more familiar with the phenomena and related concepts. It is through this increased familiarity that learners increase their conceptual understanding (Roth, 1995).

Informal learning environments were shown to promote opportunities for learners to engage in interactions including reflection and recall, development of intersubjectivity, and elaboration and questioning (Kuech, 1999). These interactions were associated with improved conceptual understanding of concepts as measured with pre- and post-test assessments, and provide reasons why informal learning environments may promote deeper conceptual understanding in learners. As we look at increased conceptual understanding, we also need a way to observe and assess conceptual change in an informal learning environment, without going to the pre- and post-test model, but what model will provide the most precise and reliable information. How can we assess conceptual understanding and conceptual change in even more informal learning contexts? Most of our post-school learning, which makes up the majority of our lives, occurs in informal environments and we need to continue to pursue research that will provide insight into the best methods of developing productive forums for learning.

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