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ABSTRACT

Over the past several years, an increasing number of educators have come to believe that teaching should acknowledge the transactional nature of knowledge and suggest that a shift be made to focus on social practice, meaning, and patterns. This style of teaching proposes that it is important to permit students to construct knowledge meaningfully in an appropriate social context. The purpose of this paper is to provide some examples of teaching practices that are compatible with this constructivist view of learning in a social and collaborative context. Discussed are basic beliefs and central metaphors of teaching, sources of case materials, teaching events, and reflections from a semiotic perspective. Heuristic diagrams are provided. (CW)

COLLABORATION AND CONSTRUCTIVISM IN THE SCIENCE CLASSROOM

by

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Ten years ago, I began to teach science just after having graduated with a M.Sc. in physics, but without a single class in educational psychology or pedagogy ("uncontaminated" so to speak). I wanted my students to learn science as I had learned physics during graduate school. I wanted my students to do, talk, and to see science. I wanted my students to experience all the excitement of science, and the excitement of finding out for yourself in a context that nurtured the emerging abilities to do science in a way scientists do it. Since then, I have taught all my courses in laboratory, non-lecture settings that emphasised science as a process of meaning-making, and knowledge as individual and negotiated construction.

Collaboration and Constructivism in the Science Classroom

Traditionally, teaching has been viewed as an event through which a "body of knowledge" is transferred from the teacher to the student. Recent philosophies of science and epistemology, however, recognise the role of personal construction of scientific knowledge; in this view, knowledge is shared through social transactions in a community of knowers, rather than being descriptive of an absolute, knower-independent reality (Feyerabend, 1980; Kuhn, 1970; Rorty, 1979). Over the past several years, a number of educators have come to believe that teaching should acknowledge the transactional nature of knowledge and suggest that we make a shift in our concerns to focus on social practice, meaning, and patterns, i.e., that we take a social and semiotic perspective of teaching (Pope & Gilbert, 1983; Blais, 1988; Hawkins & Pea, 1987; Lemke, 1988, 1989; Heine, 1989). Thus, as teachers, we have to provide for experiences which permit students to construct knowledge meaningfully in an appropriate social context. The purpose of this paper is to describe some of my own practices of teaching science which seem to me compatible with the constructivist view of learning in a social and collaborative context, i.e. with the view of learning as a social semiotic event (Halliday & Hasan, 1985; Lemke, 1989).

BASIC BELIEFS AND CENTRAL METAPHORS OF TEACHING

It has been shown that the basic beliefs and metaphors of teachers are determinants of the interactions and transactions in their classrooms (Garnett & Tobin, 1988). Knowing my basic beliefs, epistemological commitments, and central metaphors will help you construct a better understanding of the classroom strategies I use; and they will help you better appreciate the teaching-learning environment in these classrooms.

Basic Belief: *Knowledge about and meaning of our world are constructed individually and negotiated in transactions with others, i.e., all meaning is made by specific in-context human practices* (Hawkins & Pea, 1987; Heine, 1989; Lemke, 1989). In the classroom, teachers and students are involved building recognised patterns of activities and use language to build the special meaning relations of specific subjects. Thus, the students are initiated into the special ways of talking, writing, and doing within a subject, i.e., they are initiated in its specialised forms of social discourse (Lemke, 1989).

Built on this basic belief are two metaphors which effectively determine the type of classroom interactions between me and the students in my classes. The two metaphors characterising my teaching are that of *cognitive apprenticeship* and that of *enculturation*.

Metaphor 1: *Learning is a process of cognitive apprenticeship.* I try to set up learning environments that will help students develop the basic stages of the skills and attitudes of scientists. Within the context of these activities and social interactions, I take on a position that can be likened to a master in craft apprenticeship; or that of an adviser of graduate physics students, who, through a close working relationship, allows students to enter the culture of physics practice. The metaphor of cognitive apprenticeship also suggests the practices of situated modeling, coaching, and fading (Brown, Collins & Duguid, 1989) whereby teachers first model their strategies in the context and/or make their tacit knowledge explicit. Then, the teachers support the students attempts at implementing the strategies. And finally, they leave more and more room for the student to work independently. As the research by Schoenfeld (1985) and Lampert (1986) has shown, students will gain more and more self-confidence, become more autonomous in collaborative situations, and participate consciously in the culture. Through this active participation in the transactions of a culture, the students will not only develop the language and belief systems (Brown, Collins & Duguid, 1989) but, in return, will also shape these language and belief systems (Lemke, 1989; Heine, 1989).

Metaphor 2: *Learning is a process of enculturation similar to growing up in a particular society, learning its sign systems, i.e., language, behaviours, and other culturally determined patterns of communication.* Learning the language of physicists in the classroom is very similar to the learning of a language by a child. The original, very limited understanding of a concept word and its meanings is developed and extended through negotiations with teachers and fellow students. The concepts, thus, receive more and more texture as they are applied in larger number of contexts.

From these beliefs and metaphors follow some necessary implications for my teaching which are made explicit in the following corollaries. One key implication of learning as cognitive apprenticeship and enculturation in a social context is the necessity for collaboration. The other main implication is that the implementation of learning environments compatible with the above belief and metaphors will have to operate with time lines different from traditional curricula which are usually formulated in terms of low level, short term goals.

Corollary 1: *Because knowledge is a social phenomenon, negotiated and constructed through transactions, collaboration is of primary necessity to the science classroom.* It has been shown that such collaboration has positive effects on students' learning, motivation, and attitudes (Sharon, 1980; Slavin, 1980; Schoenfeld, 1985; Kroll, 1989). Provided with the appropriate environment and activities which allow for interactive exchanges, the participants will exceed that which they might achieve as individuals, thus amplifying the learning of each individual. In collaborative environments, students can "objectify" their understanding to reflect upon and evaluate it critically, and then make necessary refinements and extensions.

Corellary 2: *School learning, a process of cognitive apprenticeship and enculturation, takes a lot of time, just as its counterparts in craft apprenticeship and growing up in a culture.* Continuous feedback from peers and teachers is necessary to delimit permissible and effective diction (action) and a long term vision is necessary to provide the appropriate learning environment. Given the opportunity, the skills and practices of apprentices, whether they are high school students, crafts persons, or Ph.D. students of physics, will not only become increasingly complex but also better adapted to solve the problems and questions facing them within each respective culture. Seen myopically, this takes more time than school officials are traditionally willing to wait for "measurable outcomes." However, my successes in teaching in the past seem to indicate that long-term thinking pays off.

SOURCES OF CASE MATERIALS

Although I have taught classes using a constructivist and collaborative perspective for many years in various public schools and colleges, the following examples are all taken from my current experience of teaching five classes of junior and senior year physics at a private college preparatory school. The enrollment per class ranges from 10 to 19 boys, between 16 to 18 years of age. The scheduled classroom time consists of nine 40-minute periods per two-week cycle.

Structure of the Course: At the beginning of a tri-mester, the students receive an outline of the topics for the term which includes a schedule for all weekly assignments. These assignments usually include (1) the conceptual mapping (Novak & Gowin, 1984) of key terms in the assigned readings.; (2) "Thinking & Explain" questions which are designed to help the students attend to the key concepts of the readings; (3) Word problems where applicable; and (4) a weekly question to be answered experimentally and reported with the aid of the *Vee-heuristic* or *Epistemological Vee* (Novak & Gowin, 1984) to be described below.

Time Allotment: One day per week, usually a Monday, we use for whole class discussion, review, and laboratory preparation. Most of the other classes are spent on the investigation of experimental questions. Although the scheduled classroom time consists of nine periods, the students may use the lab and its facilities during their spare periods, after school, in the evening, or during the weekend. Attending a residential school, many students make use of this availability of the lab during "off-class" hours.

EXAMPLES FROM THE PRACTICE OF TEACHING

In the following paragraphs I will discuss two types of activities from our practice. First, in the section *Constructing Meaning by Doing and Talking Physics*, I will give examples how students construct conceptual frameworks, skills, and mathematical relationships through experimentation, data analysis, and critical reflection on these activities. Second, in *Class Discussions on the Nature of Knowledge* I will talk about our explicit reflections on the nature of knowing and knowledge.

Constructing Meaning by Talking and Doing Physics

Structure of the Investigations: Beginning with the experimental question--which is at this stage still formulated by the teacher--each group of students (2-3, rarely 4) designs its own experimental procedures and particulars of the equipment. Some typical questions to be investigated are "What is the relationship between mass and the acceleration due to gravity?" "What is the functional relationship between the composition of mixtures of para-dichlorobenzene and naphthalene and their freezing points?" and "What is the relationship between the depth of water in a trough and the velocity of the waves?" The students then execute their experiment, gather the data, and submit them to a mathematical and graphical analysis. The students make use of the analysis and graph plotting features of a variety of programs which run on Apple

II, Macintosh and MS-DOS computers. Each group discusses its results, consulting other groups and the teacher, and then prepares a report, which is typed in its final form by one of the group members. The format of the report is the "Epistemological Vee" (Figure 1), a schema that encourages the integration of the practical and the theoretical, i.e. semantic, aspects of the experiment (Novak & Gowin, 1984).

<u>Epistemological Vee</u>: The Vee (Figure 1) was designed to help an experimenter recognise the complimentary nature of theory and experiment. In an uncharted area of research, theory will be constructed in an abductive process from the data gathered through the experiment, thus developing the left, conceptual side of the Vee starting from the right, the methodological side. On the other hand, if there is at least one existing theory, it will largely determine the hypotheses formulated and the type of events to be observed. In this case, the emphasis will lie on the left, conceptual side of the Vee, for which the right, methodological side will or will not provide confirmation. (The concept of theory is much narrower than that of a paradigm. The factors that affect perception can then be relegated to that part of the paradigm which is not covered by the theory.) Using examples from several experiments, I will illustrate the collaboration and construction of knowledge and meaning in our physics classroom.

Insert Figure 1 about here

Scientific Dialogue: <u>Mass-Acceleration Relationship of Falling Bodies</u>

When students do not receive ready-made procedures ("cookbook recipes") for an experiment that will provide the data to answer the question at hand, discussions about the meaning of the question and the ensuing experimental design will begin immediately in each group. Consequently, different groups will decide on varying designs, which may lead to the "same" or, more interestingly, to "different" results and claims. For example, while investigating the question "What is the relationship between the mass and the acceleration of falling bodies?" three types of experiments had been designed, leading to apparently different results (Figure 2). For all three experiments, the students had chosen a "picket fence" to trigger a photo gate run in conjunction with a computer resident timer and software package to determine the time needed for the object to travel the distance from one bar to the next. From these data, the software package generates distance-time, velocity-time, and acceleration-time data tables and graphs.

Insert Figure 2 about here

In design 1, the students changed the mass attached to the "picket fence" and dropped it through the photo gate. The experimenters of Design 2 made use of a frictionless airtrack, accelerating the photo gate mounted on a cart using varying masses on a string connected to the cart via a low friction pulley. In Design 3, the "picket fence" was mounted on a frictionless cart to which varying masses could be attached. The students recorded the acceleration for each mass and analyzed the data using a software package for graphical analysis (Graphical Analysis by Vernier Software). Once all reports had been submitted, I reproduced designs and results for overhead projection (Figure 2) to serve as a basis for a class discussion.

The ensuing discussion was enlightening for the students. Virtually all of them participated in the exchange, reminiscent of the discussions often found in professional journals. Recognising that the experiments yielded different relationships, the students immediately focused on the concept of "free-falling." Those who performed the experiment according to Design 1 argued that theirs was the only one in which the whole system was falling freely. The defenders of Design 3, however, argued that in their experiment the only force, and thus acceleration, was that due to gravity.

Consequently, their results also represented a free fall experiment. They interpreted the differences as stemming from the incline which "deflects acceleration." (At this point in the discussion I introduced the fact that this design was of historical relevance as it was essentially the design used by Galileo, one of the fathers of modern science.) Design 2 was the most difficult to be integrated. However, the students arrived in their discussion at the conclusion that part of the accelerated system, the cart, did not contribute to the accelerating force. For large masses, the mass of the cart is negligible, and the results approach those of the free-falling picket in Design 1. For smaller and smaller masses that provide the force for acceleration of the system, the acceleration goes to zero.

At this point, I introduced the argument based on Newton's second law that the whole system in Design 2 (cart and mass) was accelerated by the weight (force) of the hanging mass. This leads to

$$F = (m_{cart} + m_{weight}) * a = m_{weight} * g$$

from which one arrives at the relationship

$$a = \frac{1}{\frac{m_{cart}}{m_{weight}} + 1} * g$$

Using a graphing program on a Macintosh computer, the students plotted this function which permitted them to recognize the same pattern as that of their data. Using such questions as "What would happen to the acceleration if the mass of the cart was zero?" "What would happen to the acceleration if the mass of the weight was zero?" and "What would happen to the acceleration if the mass of the weight was large compared to the mass of the cart?" I provided the starting point for an exploration that would permit students to construct an understanding of the equivalence of the representations at hand (Both the equation and the graph being generalizations from the data they had collected). Then, to permit a meaningful integration of the three experiments we focus on questions such as "What would happen if the Galileo groups had raised their air tracks until they reached the vertical?" "What would happen if the Design 2 groups had increased the mass 10, 50, or 100-fold?" and "How can the differences between the designs and results be integrated into one explanatory scheme?"

The Construction of a Conceptual Framework: Relationship of Angles of Incidence and Refraction for a Beam of Light at the Interface of Two Media

In order to be able to describe the data in their raw and transformed state and to make claims from these, the students will feel the need for appropriate words (concepts). Usually, they will seek recourse in various text books available in the classroom from which they extract the concepts. During this process of generating a conceptual base, the students can be seen going back and forth from the written text to their data and back to the written text. It becomes obvious that the students use the written text and the experimental results to seek support for one in the other. In this process, the results become meaningful in terms of the written text, while the written text takes on meaning in terms of the results. Because the students work together, different interpretations of the written text or the results also arise. These differences are always resolved in lively discussions.

The report submitted for this experiment also shows how valuable the Epistemological Vee becomes as an evaluation tool. Figure 3.a shows the concepts and principles which one group of students extracted from the text book as relevant to the present experiment. Although the principles (generalizations) are "correct" from the physicists point of view, the concept map gives some interesting insights into the group's constructions.

Insert Figures 3 about here

The map (Figure 3.a) clearly shows that the students are aware of the two aspects of scientific investigation, the practical (REFRACTION is the MOVEMENT of a RAY towards NORMAL) and the theoretical (REFRACTION occurs LIGHT which DECREASES in SPEED caused by DENSITY of MEDIUM). It is interesting to note that the group decided to use the specific case, derived from the experiment, of a ray going from the less dense to the denser medium, rather than a more general TOWARD/AWAY that includes both cases. It is not clear what connection the students saw when they wrote "NORMAL bending towards SPEED"). It is also interesting that the group decided to use DENSITY in the map rather than the concept of OPTICAL DENSITY which they used in the claims section. It is important in this case to follow up because students often do not distinguish between optical density (as determined by the index of refraction) and density (as determined by the mass per unit volume) because the two are not equivalent.

To make the equivalence of different sign systems used in physics more transparent, each group has to provide a verbal description of the data, graphs, and relationships as well. Here, the student constructions also show divergences from the language of a mathematician or a physicist and appear in the descriptions of the graphs (Figures 3.c-d). The statement "As the angle of incidence increases, the refraction angle decreases" is at odds with the graph it describes. When asked, the students said that they meant "It turns like this [showing a decreasing slope with their hands]" which indicates the lack of experience in the mathematician's or physicist's language. Although, the graph of the raw data looks like a sine curve, this contention remains untested and is also incorrect. The students thought that the sine-transformation of both axes implied that the untransformed data would plot like a sine curve. The second graph shows a plot of the transformed data. The description of the plot, "This is our modified data which has been put to sin[e]" indicates that the students have not constructed, during their mathematics classes, a meaningful understanding of transformations of the form $y = f(x)$. Thus, although the students use this transformation to "correctly" identify the relationship between the angles of the incident and the reflected beams, the underlying conceptual step is meaningless.

The Construction of Equations Describing Linear Motion: The Equations Relating Acceleration, Velocity, and Time to the Distance Travelled.

One of our emphases in the physics class is to find mathematical relationships of variables and to find patterns in equivalent descriptions, such as those relating equations and their graphical counterparts. I would like students to be able to establish intuitive links between the formal knowledge presented in their textbooks and that knowledge which they construct in the interaction with equipment and their peers. An example of such a system of formal knowledge-intuitive knowledge patterns is that of our study of motion with constant acceleration.

The students work on the question "What is the functional relationship between distance travelled and the time of travel in accelerated motion?" The students' first activity is to discuss in their groups experimental arrangements and the results they expect. Because of lack of experience, hypothesis generation at this stage in their physics program often does not lead to significant experiences. However, in the present case, when asked to venture a guess as to the nature of the relationship in terms of a qualitative graph, most students (or rather groups) will indicate a linear relationship. The students gather distance-time data which they have quickly graphed by a computer including velocity-time and acceleration time graphs (Figures 4.b-d).

Insert Figures 4 about here

In the present case, the graphs are parabolas, which, as they learned previously (grade 10) could be expressed by quadratic equations. The students also look at deceleration, where they discover inverted parabolas. They have to describe the graph in words and use expressions like "the curve goes up and up" to describe the parabolic feature. I ask them to think about the answers to such questions as "What does it mean that the distance-time graph becomes steeper and steeper?" "What does it mean that the velocity-time graph has a constant slope?" and "How is the d-t graph related to the v-t graph?"

Using software packages, one by devised by this author and another, commercial one for the Macintosh (Graphical Analysis by Vernier software does not allow for functions of the type $y = a*x^2 + b*x + c$) the students analyse the curve with respect to the mathematical function that describes it. Figure 4 b-d shows an example of such an analysis. The students found the relationship $d = .0002 + 6.89*t - 6.85*t^2$ where d = distance and t = time; the constants 6.89 and -6.85 do not yet have any meaning. In their Vee diagrams students then "claim" that accelerated motion leads to a parabolic distance-time graph the functional relationship of which is expressed by a quadratic equation. The next step in their analyses is the preparation of velocity-time graphs from their original results and the interpretation of the parameters +6.89 and -6.85.

Here, the graphs show linear relationships of the form $v = -13.6*t + 6.89$, v = velocity, 6.89 and -13.6 still unknown parameters. The constant 6.89 is then interpreted as the velocity when t = 0, thus $v_0 = 6.89$ cm/s. In the third step, the student find an average acceleration of -12.5. The students then compare--often they have to be prompted--the different parameters from the three steps. They find that -6.85 is approximately $^{13.6}/_2$. In summary, the students found for the airtrack on a constant slope, the equation $d = {}^a/_2 * t^2 + v_0 t$, $v = a*t + v_0$. After the students completed their experiments, data analysis, and the report in the form of a Vee map, we come together for a class discussion. We compare the results reported by each group, which, until that point are still tentative and at the stage of hypotheses (i.e. abductions). The next step is inductive. From the fact that 15, inter-class groups come to similar results, we conclude that the description of accelerated motion is of the following form:

a. the distance-time relationship takes the form $d = {}^{a}/_{2}*t^2+v_0*t$ or, equivalently it is described by a parabola;

b. the velocity increases linearly (steadily, in students own words), forming a straight line as velocity-time graph and is of the form $v = a*t + v_0$;

c. the acceleration is constant, i.e. its acceleration-time graph is a straight line of slope 0 described by the function a = constant.

At this point I have the students go and look up the equations of motion in an advanced textbook. The significance of the event is that the students arrived at equations, coached by the teacher, that they will use at a later point in time to calculate problems when they have to manipulate these equations.

The Complementary Nature of Theory and Experiment: <u>The Two-dimensional Collision of Hard Spheres</u>

An interesting problem for physics students is that of two hard spheres of unequal mass which collide non-centrally and are scattered as a consequence. The practical situation to which the students can immediately associate are the games of pool and billiards. More removed from the students' direct experience but also of relevance here is the problem's application to the scattering of neutrons at protons. This scattering problem is never dealt with in high school physics books, and seldom in college text books which precludes students going to the books for the "right results." In our case, the question "What is the relationship between initial velocities, impact parameter, masses, and scattering angles in a two-dimensional collision" gave rise to an important learning experience about the complementary and interactive nature of theory and experiment.

Two mathematically better students took on the task to derive a mathematical relationship that would link the variables involved (Figure 5). While I discussed with them some of the possible approaches to the problem, other students, in groups of 2-3, began to explore the experimental issues by trying out some of the materials I had

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Insert Figure 5 about here

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prepared, and gathered some initial data. After both the student theorists and experimentalists had concluded the first stage of their work, we came together to (1) compare the theoretical and the experimental results and (2) to decide upon further steps in the experiment. A very interesting dialogue began between the two groups during which the students found out that

1. some of the angles which the experimentalists measured where very small so that the disagreement between theory and experiment was very large, at the order of 50%.
2. some experimental groups did not have enough data to compare their results with the theory.
3. the experimental groups had measured data (velocities) which were irrelevant for the scattering angles.

During their discussions, the theorists found that they could easily express the angle between the two scattered spheres in terms of the masses, radii, and impact parameters. The experimentalists, on the other hand, indicated that they could measure the same angle with a larger precision than individual angles. The groups then decided to continue on this path with the result that on the final reports the experimental results were in good agreement with the theoretical calculations.

<u>**Some observations**</u>:

Over a period of several months I was able to observe a number of important developments in student understanding.

1. Through the continuous use of data analysis, students develop an intuitive understanding of mathematical equations, graphs, correlation coefficiants, standard deviations, and how they can be used as indicators of the quality of data. The students

now are able to make decisions on whether or not to eliminate data points, whether they have to transform their data to achieve a better fit. Through the link with the physical experience, mathematics becomes concrete and something students construct on their own. Many students have come to me saying "Now I understand what we did last [this] year in mathematics."

2. The students in the 2nd year physics course, who take calculus and/or advanced algebra concurrently, construct an intuitive understanding (meaning) for such concepts as derivative, integral, linear transformations of vectors, rotations, etc.
3. The experiments give rise to many fruitful discussions about the nature of physical laws and develop an intuitive understanding that most "laws" are mere approximations and idealizations of actual situations as for example the force-distance relationship between two magnets. The students found it extremely puzzling that the relationship was not of the type

$$F \sim \frac{1}{r^2}$$

but closer to

$$F \sim \frac{1}{r^{1.5}} \text{ and } F \sim \frac{1}{r^{2.5}}$$

for small and for large distances, respectively).

Class Discussions: The Nature of Knowledge

Other activities in which we engage treat the question of the nature of knowledge explicitly. To get us started, we read such articles as "The Invisible Civilization" from Inventing the Future (Suzuki, 1989), "Beyond Language" and "Physics: A Path with Heart" from the Tao of Physics (Capra, 1978), and "What Every School Boy Should Know" from Mind and Nature (Bateson, 1980). Stimulated by these essays, the students become involved in very lively discussions about *facts* about *objectivity* and *subjectivity*, about *perception*, about the effect of language on perception, knowledge, etc.

The students usually write a short reflection before we come together to discuss an issue. This assures (1) that students have read the assignment and (2) that they have already thought about the pertinent issues which usually leads to more productive discussions. We open these discussions by talking about the meaning of the text, or by reading paragraphs together to establish its significance together.

A recurrent theme in our discussions--during which I am mostly a moderator and do not give authoritative answers and advice--is the nature of knowledge. Some of the questions that come up are, if "Knowledge is there before man who comes along and discovers it?" Whether "equations of physics, or mathematics in general, describe/conform with an absolute reality (Greek-Platonic idealism) or whether they are constructions of the human mind, only reflecting what we can perceive, the structure of our perceptions-mind)?" "Is there an ultimate truth?" (Platonic idealism) "How do we know something as being true?" "What distinguishes physics from metaphysics, religion, or philosophy if, for example, Eastern mystics arrive at similar perception of the structure of the universe-nature as modern particle physicists?"

Some Observations:

Initially, many students were troubled by the open-endedness of the discussions. They thought that there must exist definite answers, known to the teacher, which they then could appropriate for themselves. In one case, we discussed human conventions and knowledge as social phenomena which are subject to change and thus are historical phenomena. In another case, a troubled student asked "If we know that accepted knowledge will change, why do we waste teaching and learning what will be irrelevant after 10 or 20 years?" This question became a key experience for all students involved, as it led to the recognition on the part of the students that learning the processes of constructing knowledge and the skills associated is more important than learning specific "facts."

Usually, many of the discussants seem to agree that "knowledge" is negotiated, a social phenomenon rather than an absolute. Yet their statements are not always consistent with it. Some still believe that knowledge can be transmitted, that teachers have to be there to transmit it. Students are still authority oriented believing that their own constructions are not valuable or valid. Others take a purely utilitarian approach to knowledge: all knowledge is worthwhile if it can serve mankind, improve our way of life (A higher than normal percentage of the students go into engineering programs).

Reflections from A Semiotic Perspective

In physics (really in all of science teaching) we often get into situations where the students do not possess the means of isolating a pertinent feature of the environment that plays a key role as a physical concept. The task of the teacher, then, has to be to encourage the "discovery" of the feature and then to provide the "sign vehicle" that the culture has developed during its history. This seems to me an issue that addresses the distinction between environment and Umwelt. Although a natural phenomenon has been part of the environment of the student, it has not been part of his Umwelt (to the students these phenomena are still part of the undivided whole, they have not yet the tools, i.e., the sign vehicles to isolate the phenomena). In semiotic terms, the issue for teaching is that of developing the correct sememes, i.e., correct semantic markers for the new concept (sign vehicle). It seems to be a task of teaching science to set up teaching-learning contexts that permit an efficient enculturation of novices into the subculture of scientific discourse. One of the key problems of science teaching is that the concepts used have a very restricted set of semantic markers, the restrictions being set by the mainstream research community, i.e., the mainstream paradigm. The semantic markers used by the general public, are more liberal but in their nature unuseable for the kind of research by traditional scientists. One of the issues in my teaching, then, has to be empowerment, i.e., the learning-how-to-learn, construction of knowledge within the framework of the current paradigm.

Another issue is that of the existence of multiple forms of representation. There are verbal descriptions, mathematical descriptions, and graphical descriptions for the student's experience. For example, the students treat as discrete forms of knowledge (i) a sentence such as "acceleration is the rate of change of velocity", (ii) slope of the velocity-time graph is equal to the acceleration, (iii) given a v-t graph, calculate slope as rise over run and (iv) the equation a = dv/dt although they all represent the same concept. For most students it is a very difficult task, to recognise the equivalence of these descriptions. Most of their school experience treats knowledge in the form of isolated packages that students "unload" after major examinations and never use it again. This sort of conception leads students to want to learn three distinct "pieces of knowledge" rather than trying to integrate them into a meaningful whole. My task is to help them to develop the connections between the representations.

CONCLUSION

In school, whether teachers recognize it or not, children are active interpretative learners who bring their prior understandings and frames of interpretation to making sense of pedagogical presentations and interchanges, and other events occurring in this learning setting (re.: the discussion of the planned, implemented, and actually achieved curriculum). As active learners, understanding develops by motivated engagement with issues that the learner feels genuinely problematic. Deep understanding does not simply arise from acquiring new information, but from relinquishing or reconfiguring some other way of conceiving phenomena.

In order for students to become engaged and critical, classroom environments have to be changed so that critical thinking can be fostered as being as purposeful and meaningful in, as it is out of school. Classroom contexts that are meaningful and purposeful encourage risk-taking and reflective criticism. These contexts will function as "abductive environments" where students are involved and practise the logic of discovery and where students are encouraged to use anomalies as starting points for learning. The advantage to learners is that they experience hypothesis generation, that crucial but often missing component in critical thinking. Such a nonlinear view of critical thinking suggests that reflection is a search for meaning and that that search as such is as much an exploration of where an idea might go as it is a look at where it came from.

REFERENCES

Bateson, G. (1988). Mind and nature: A necessary unity. Toronto: Bantam Books.

Blais, D. (1988). Constructivism--A theoretical revolution for algebra. Mathematics Teacher, November 1988, 624-631.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. Educational researcher, 18(1) 1989, 32-42.

Capra, F. (1975). The tao of physics. Boulder, CO: Shambala.

Feyerabend (1978). Science in a free society. London: New Left Books.

Garnett, P. J. & Tobin, K. (1988). Teaching for understanding: Exemplary practice in high school chemistry. Journal for Research in Science Teaching, 26(1), 1-14.

Halliday, M. A. K. & Hasan, R. (1985). Language, context, and text: Aspects of language in a social-semiotic perspective. Victoria, AUS: Deakin University Press.

Hawkins, J. & Pea, R. D. (1987). Tools for bridging the cultures of everyday and scientific thinking. Journal of Research in Science Teaching, 24(4), 291-307.

Heine, D. (1989). Learning as a social/semiotic process. ERIC document ED307304.

Kroll, D. L. (1988/89). Cooperative problem solving and metacognition: A case study of three pairs of women. Doctoral Dissertation, Indiana University, 1988. Dissertation Abstracts International, 49, 2958A.

Kuhn, T. S. (1970). The structure of scientific revolutions. Chicago: University of Chicago Press.

Lampert, M. (1986). Knowing, doing, and teaching multiplication. Cognition and Instruction, 3, 305-342.

Lemke, J. L. (1988). Genres, semantics, and classroom education. Linguistics and Education, 1, 81-99.

Lemke, J. L. (1989). Using language in the classroom. Oxford, UK: Oxford University Press.

Novak, J. D. & Gowin, D. B. (1984). Learning how to learn. Cambridge, MA: Cambridge University Press

Pope, M. & Gilbert, J. (1983). Personal experience and the construction of knowledge in science. Science Education, 67(2), 193-203.

Rorty, R. (1979). Philosophy and the mirror of nature. Princeton: Princeton University Press.

Schoenfeld, A. H. (1985). Mathematical problem solving. Orlando, FL: Academic.

Sharan, S. (1980). Cooperative learning in small groups: Recent methods and effects on achievement, attitudes, and ethnic relations. Review of Educational Research, 50, 241-271.

Slavin, R. E. (1980). Cooperative learning in teams: State of the art. Educational Psychologist, 15, 93-111.

Suzuki, D. (1989). Inventing the future: Reflections on science, technology and nature. Toronto: Stoddart.

Figure 1: VEE HEURISTIC

(from Novak & Gowin, 1984)

CONCEPTUAL

METHODOLOGICAL

Focus Question: (Initiate activity between the two domains and are embedded in or generated by theory; FQ's focus attention on event and objects.)

Hypotheses:

Theory:

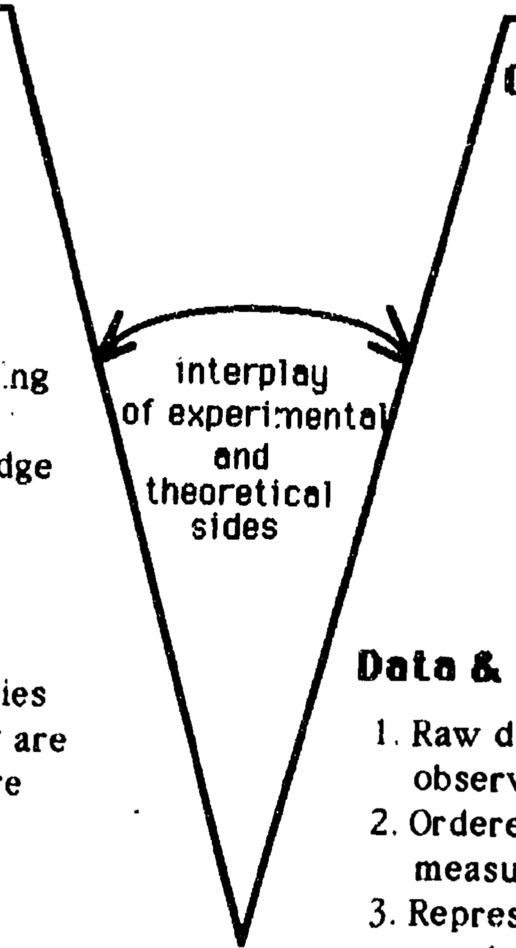
Logically related sets of concepts permitting patterns of reasoning leading to explanations.

Principles:

Conceptual rules governing the linking of patterns in events; propositional in form; derived from prior knowledge claims.

Concept Map:

Sign or symbols signifying regularities in events and shared socially. They are combined into a conceptual structure



Claims:

1. The worth, either in field or out of field of the claims produced in an inquiry.
2. New generalizations, in answer to the telling questions, produced in the context of inquiry according to appropriate and explicit criteria of excellence.

Data & Transformations:

1. Raw data and records of the objects & events observed.
2. Ordered data, goverend by theory of measurement and classification
3. Representation of the data in tables, charts and graphs.

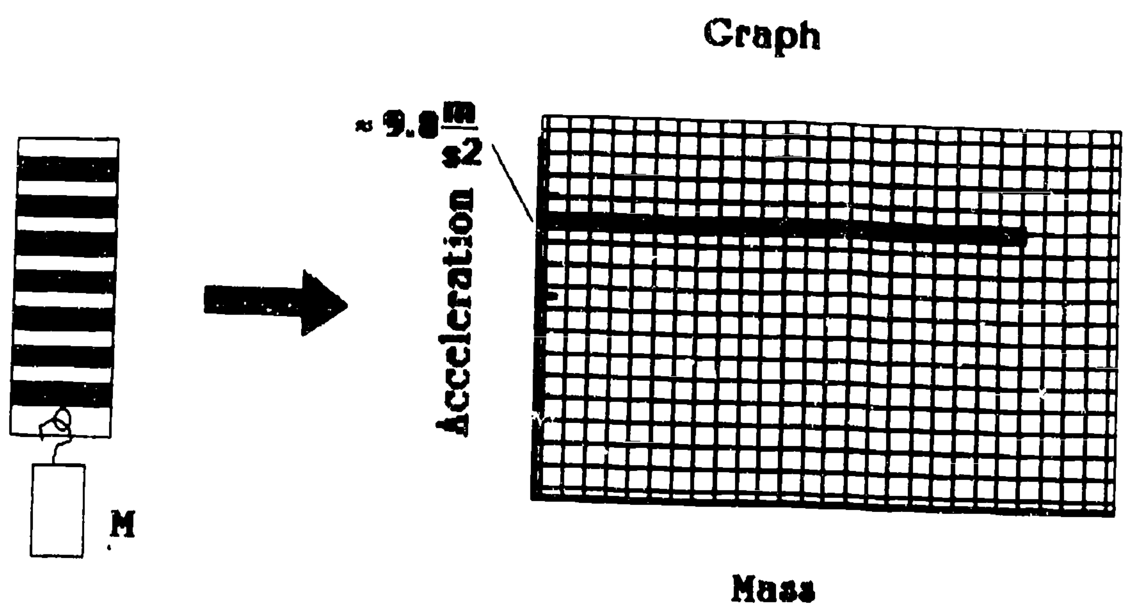
Events:

Phenomena of interest apprehended through concepts and record-making: occurences, objects

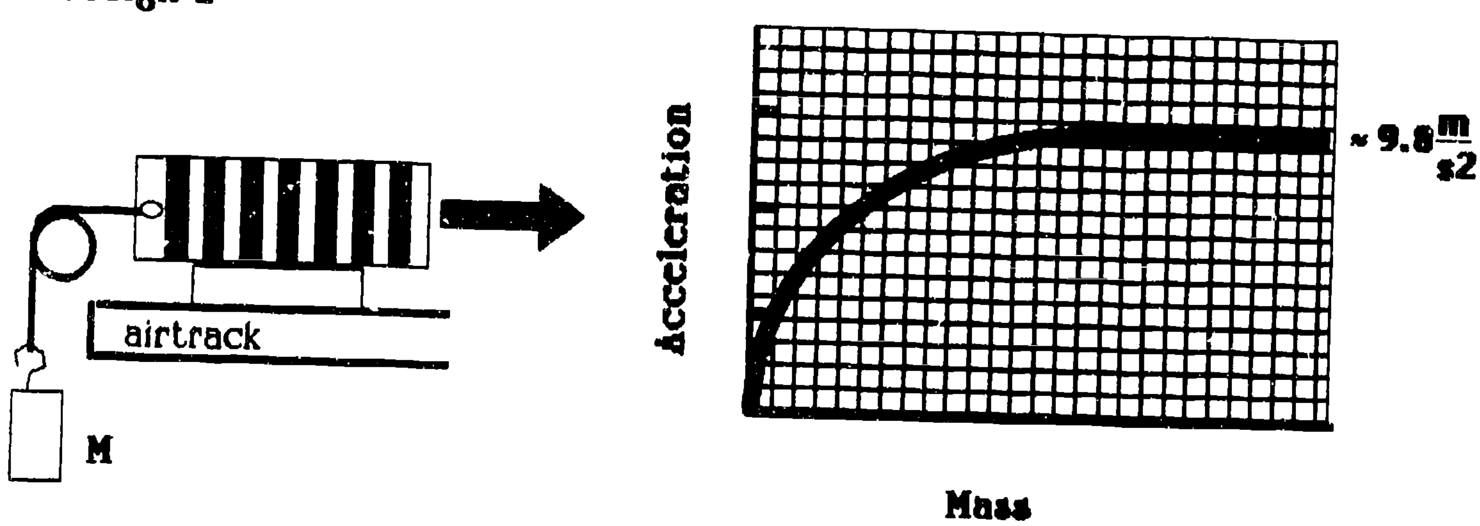
Figure 2

What is the relationship between mass and acceleration?

Design 1:



Design 2



Design 3

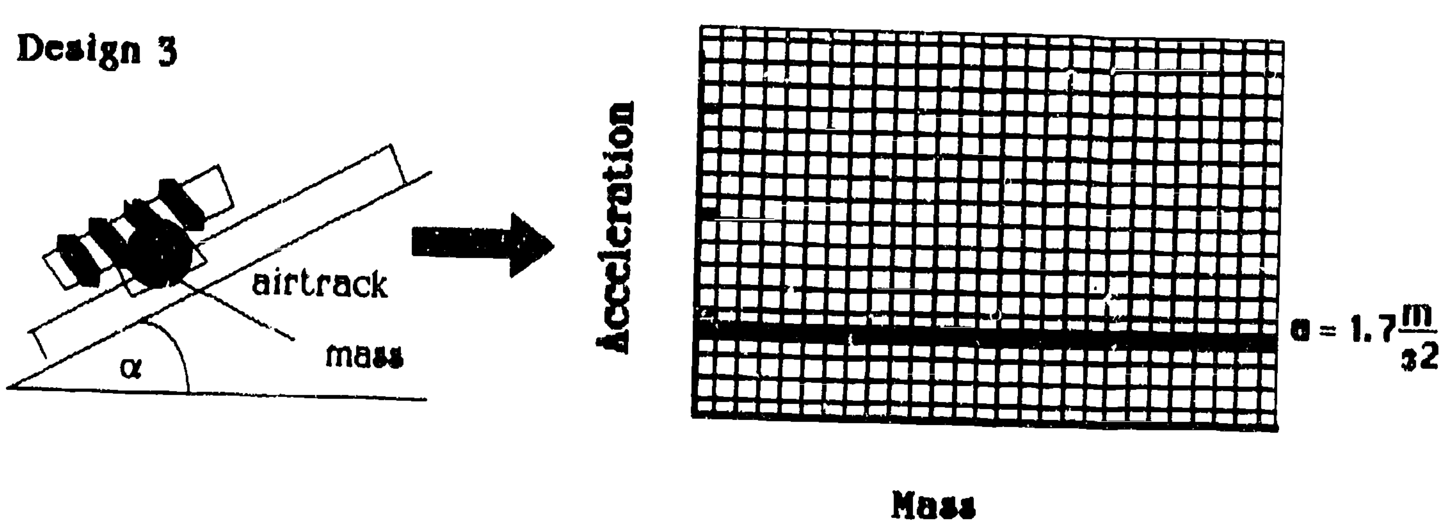


Figure 3 a

Focus Question: What is the relationship between the refracted and the incident angle of a light ray travelling from air to some denser medium, such as glass or plastic? What is the relationship between the sin of these angles?

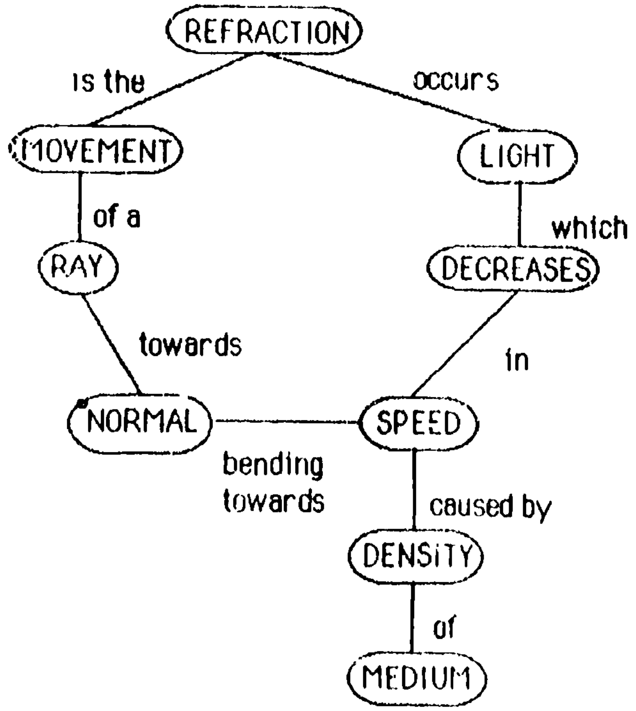
Hypotheses: We believe that the reflected angle will change by five degrees after reflection through plastic. We feel the change will be proportional each time it is reflected.

Theory: Optics

Principles:

1. Snell's Law: n sin θ = n' sin θ'
2. Refraction is caused by a change in the speed of light.
3. Speed of light is reduced by optically denser medium

Concept Map:



interplay of experimental and theoretical sides

Claims: Upon viewing the results of both the qualititative aspects of the experiment and the subsequent apearance of both raw and modified data, it becomes evident that our hypothesis lacks accuracy. The effect of the bending of the light is due to refraction. This involves the bending of light towards the normal as a result of the light decreasing in speed. This decrease in speed is the result of the light moving through an optically denser medium. Although partial reflection can take place the refraction remains more evident. In determining the mathematical relationship of the angle of incidence to the angle of refraction Snell's Law becomes the basis. He put foward that:

$$n \sin \theta = n' \sin \theta'$$

n and n' are the indices of refraction and θ and θ' are the angles of incidence and refraction.

Data & Transformations: cont. next page

See following tables and graphs.

Events:

1. Using a ray box and polar graph transparency, the light is reflected through a plastic medium(lens).
2. The angle of incidence is varied and the angle of reflection is subsequently measured.
3. A graph of "Angle of Incidence vs. Angle of Reflection" is plotted and put to sin using Graphical Analysis.

Figure 3 b

Claims:

This equation can be rearanged in order to compare our results with that of this principle:

$$\frac{\sin\theta i}{\sin\theta r} = \frac{ni}{nr}$$

$$\sin\theta' r = \frac{ni}{nr} * \sin\theta i$$

this provides the basis for the equation. $y = mx + b$

Determining the slope becomes the first step in theoretical comparison:

$$\text{slope} = \frac{ni}{nr}$$

$$= \frac{1}{0.654}$$

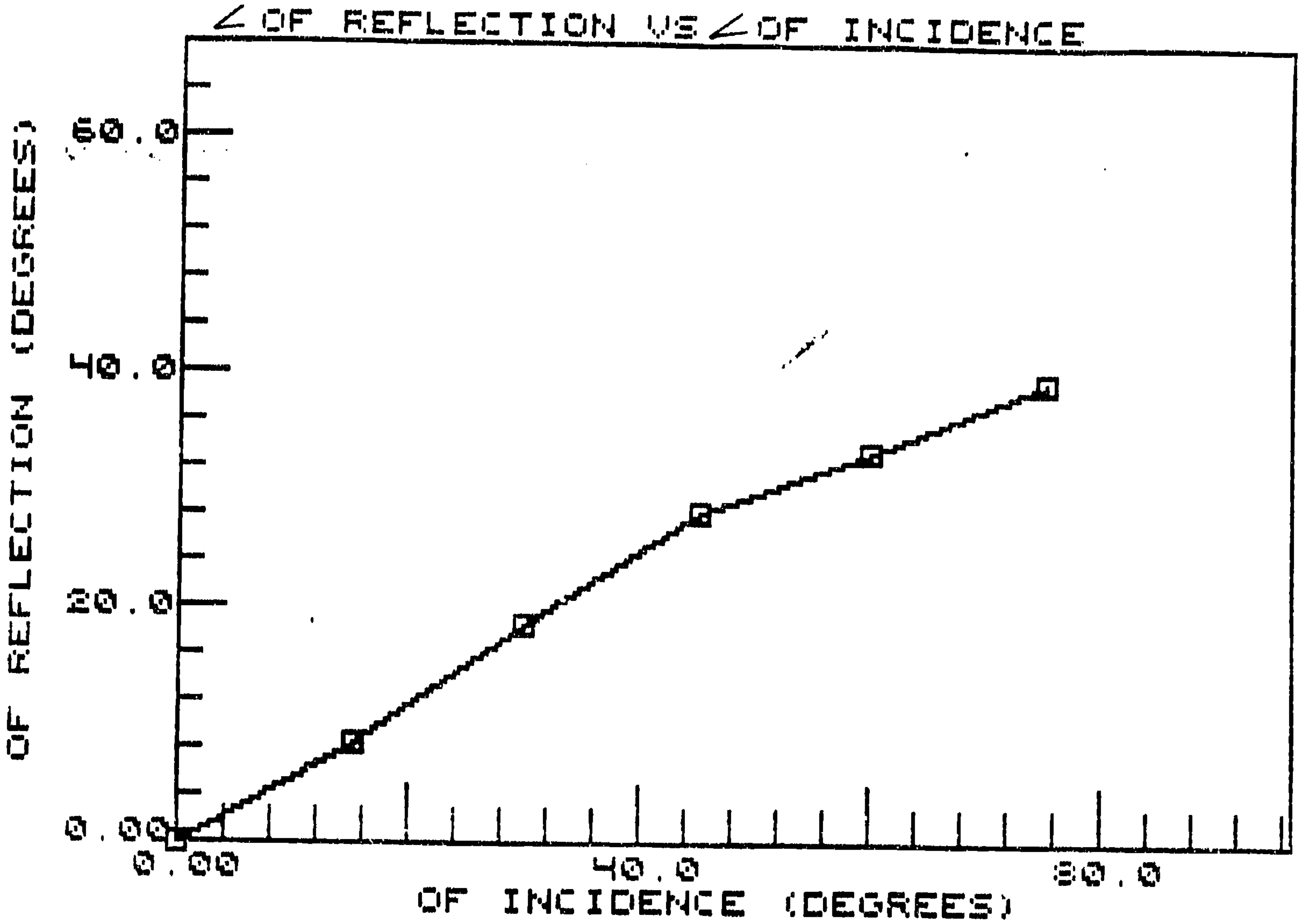
$$= 1.529$$

Thus, the equation becomes defined as : $\boxed{\sin\theta' r = 1.529 * \sin\theta' i}$

Although the result of this equation is fairly accurate it is not perfect, which provides for experimental error. This could be found within inaccurate readings from the polar graph as estimation was the basis of our findings. Nonetheless, while the actual figure is unavailable for plastic, air glass interface which is similiar to air plastic is 1.5, while our figure is 1.529.

In the world around us, certain applications can be determined making this investigation usefull. The location of satellites, stars and other distant things can be more accurately determined recognizing the refraction, especially atmospheric refraction.

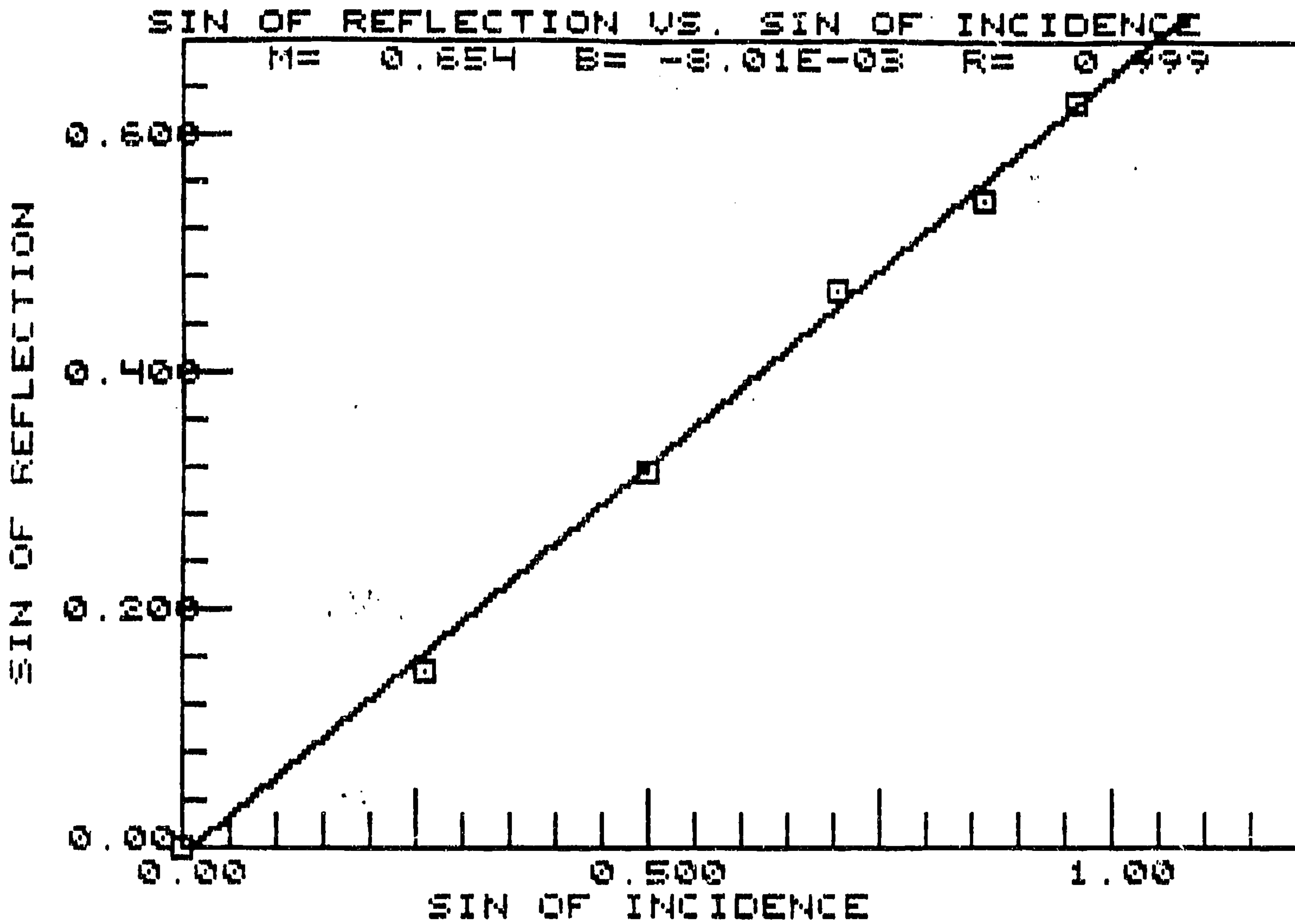
Figure 3 c



LINE #	OF INCIDENCE (DEGREES)	OF REFLECTION (DEGREES)
****	***********	***********
SERIES 1 :		
1	0.00	0.00
2	15.0	8.50
3	30.0	18.5
4	45.0	28.0
5	60.0	33.0
6	75.0	39.0

From our 'raw data' results, it is evident that this graph has the shape of a portion of a sin graph. As the incident angle becomes greater, the refraction angle slowly decreases and thus, if the graph were to be extended it would be clearly seen as a sin wave. This explains the slight dropoff at the end of our graph.

Figure 3 d



LINE #	SIN OF INCIDEN CE	SIN OF REFLECT ION
****	**********	**********
SERIES 1:		
1	0.00	0.00
2	0.259	0.148
3	0.500	0.317
4	0.707	0.469
5	0.866	0.545
6	0.966	0.629

This is our modified data which has been put to sin. It is now nearly a perfectly straight line as our raw data was a portion of a sin curve. As can be seen, the points are not all completely accurate. This is due to estimation errors during the experiment (estimation was the method of attaining data).

Focus Question: What is the relationship between (1) distance, (2) time, and (3) acceleration & time in decelerated, frictionless motion?

Hypotheses: Deceleration decreases velocity and distance traveled of an object

Theory:

Classical Mechanical Theories

Principles:

Friction is absent
Deceleration because of gravity
Air track is inclined

Concept Map:

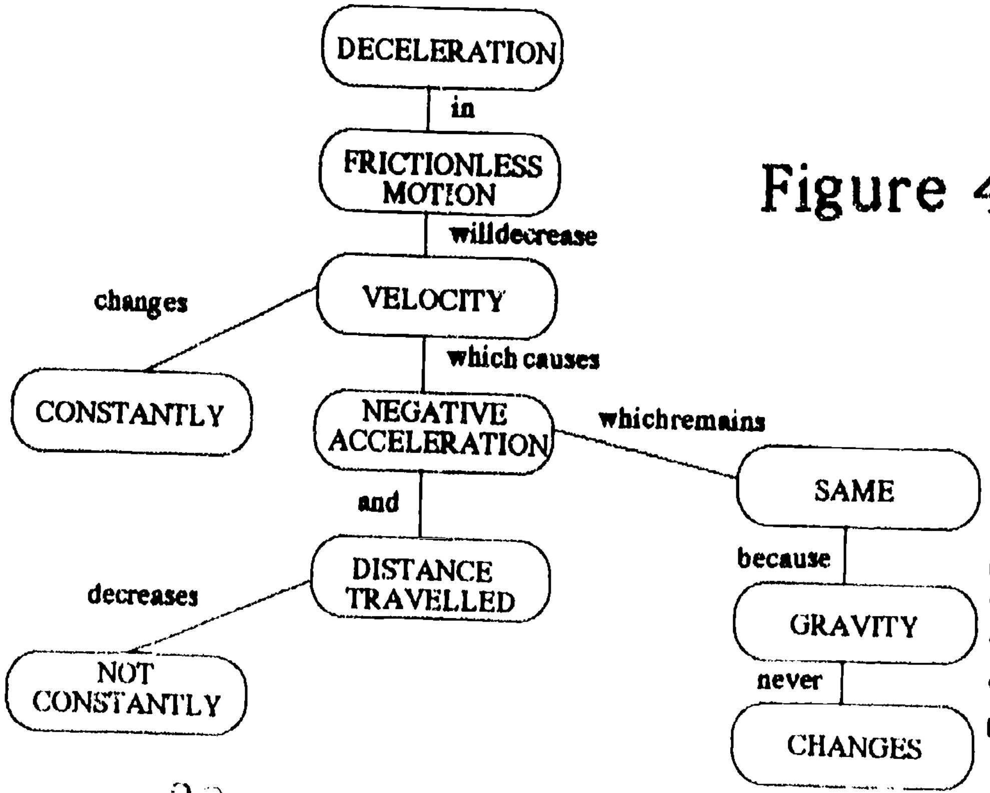


Figure 4 a

interplay of experimental and theoretical sides

Claims:

If there is deceleration (going down-slope, cause of friction), the velocity and the distance traveled per unit of time will decrease constantly and non-constantly respectively. The deceleration is caused by the earth's gravitational force which pulls the cart with the picket fences to slow down in our experiment.

Data & Transformations:

See on other pages

Events:

Prepare an air track, Apple IIe computer with photogate system and a cart with 25 picket fences to improve results. Push the cart upward through the photogate's beam on the inclined track. When the picket fences pass through the light beam of the photogate, the information will be calculated, and we plot the graphs to observe the experiments results.

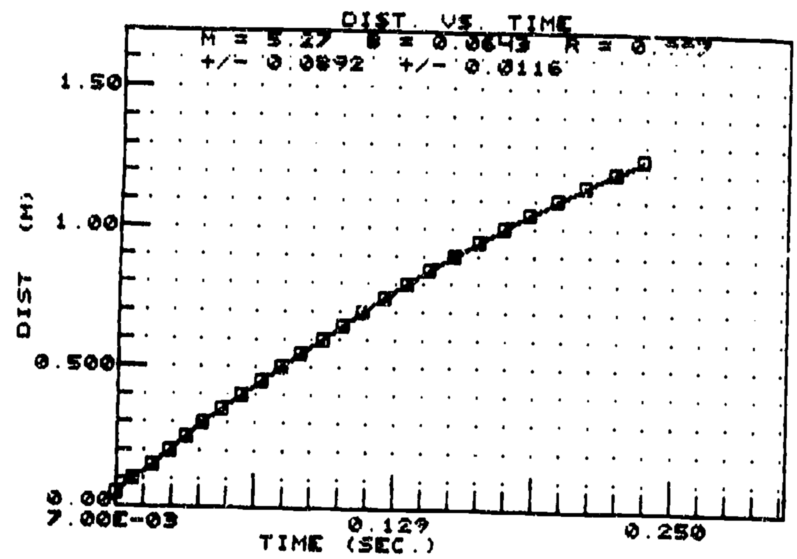


TABLE OF CALCULATED VALUES
MOTION TIMER

LINE #	TIME (SEC.)	DIST. (M)
1	7.41E-03	0.0500
2	0.0148	0.100
3	0.0223	0.150
4	0.0297	0.200
5	0.0376	0.250
6	0.0452	0.300
7	0.0535	0.350
8	0.0619	0.400
9	0.0702	0.450
10	0.0788	0.500
11	0.0877	0.550
12	0.0964	0.600
13	0.105	0.650
14	0.114	0.700
15	0.124	0.750
16	0.134	0.800
17	0.144	0.850
18	0.154	0.900
19	0.165	0.950
20	0.176	1.00
21	0.187	1.05
22	0.199	1.10
23	0.211	1.15
24	0.224	1.20
25	0.237	1.25
N		25
MEAN		0.650
S.D.		0.368
MIN.		0.0500
MAX.		1.25

[illegible]

The distance vs. time is gradually decreasing. Notice that there is a curve because the cart is travelling up the slope and has a decrease in velocity constantly. This is taking place because gravity is pulling it down which causes the distance to decrease with time. Interesting to note is that the distance traveled by the object is decreasing slowly and will reach zero per unit of time.

$$d = .0002 + 6.89 * t - 6.85 * t^2$$

Figure 4 b

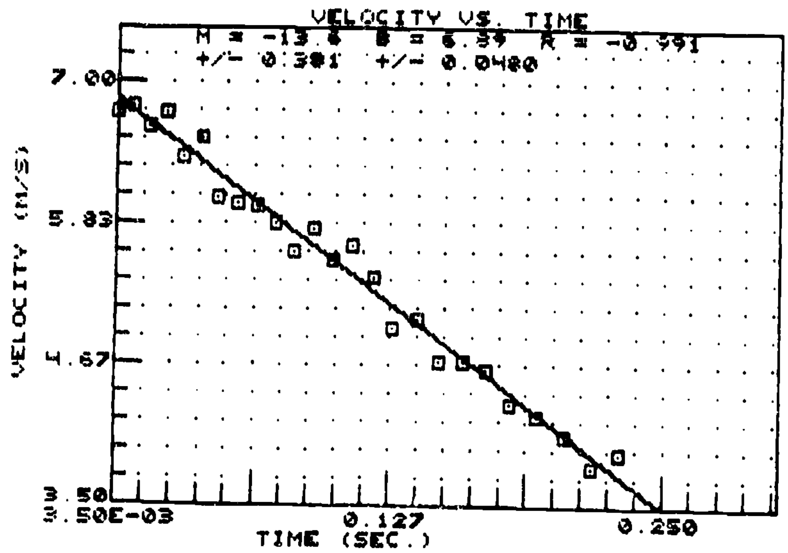


TABLE OF CALCULATED VALUES
MOTION TIMER

LINE #	TIME (SEC.)	VELOCITY (M/S)
1	3.70E-03	6.75
2	0.0111	6.78
3	0.0185	6.64
4	0.0260	6.75
5	0.0336	6.36
6	0.0414	6.52
7	0.0494	6.04
8	0.0577	5.99
9	0.0661	5.97
10	0.0745	5.83
11	0.0833	5.60
12	0.0921	5.79
13	0.101	5.52
14	0.110	5.64
15	0.119	5.39
16	0.129	4.97
17	0.139	5.04
18	0.149	4.70
19	0.160	4.70
20	0.170	4.62
21	0.181	4.34
22	0.193	4.24
23	0.205	4.09
24	0.218	3.84
25	0.231	3.94
N		25
MEAN		5.44
S.D.		0.945
MIN.		3.84
MAX.		6.78

[redacted]

The velocity vs. is on a decrease. The slope is -1.36 with a very small error showing that the regression line is correct. The reason the velocity is decreasing is because gravity is pulling it back at a constant deceleration causing the cart to slow down. Since the deceleration is constant that means the decrease in velocity will be a straight line.

$$v = 6.89 - 13.6 * t$$

Figure 4 c

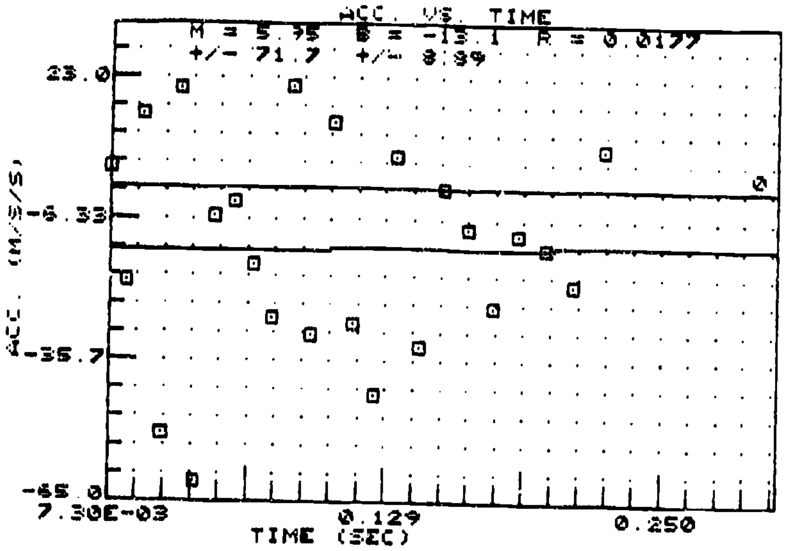


TABLE OF CALCULATED VALUES
MOTION TIMER

LINE #	TIME (SEC)	ACC. (M/S/S)
1	7.40E-03	4.01
2	0.0148	-19.5
3	0.0223	15.5
4	0.0298	-51.0
5	0.0375	20.8
6	0.0454	-60.7
7	0.0535	-5.63
8	0.0619	-2.77
9	0.0703	-16.0
10	0.0789	-26.6
11	0.0877	21.5
12	0.0965	-30.4
13	0.105	13.5
14	0.114	-28.2
15	0.124	-43.0
16	0.134	6.48
17	0.144	-32.7
18	0.154	0.00
19	0.165	-7.84
20	0.176	-24.4
21	0.187	-9.19
22	0.199	-12.1
23	0.211	-20.1
24	0.224	8.37
N		24
MEAN		-12.5
S.D.		22.2
MIN.		-60.7
MAX.		21.5

CONCLUSION

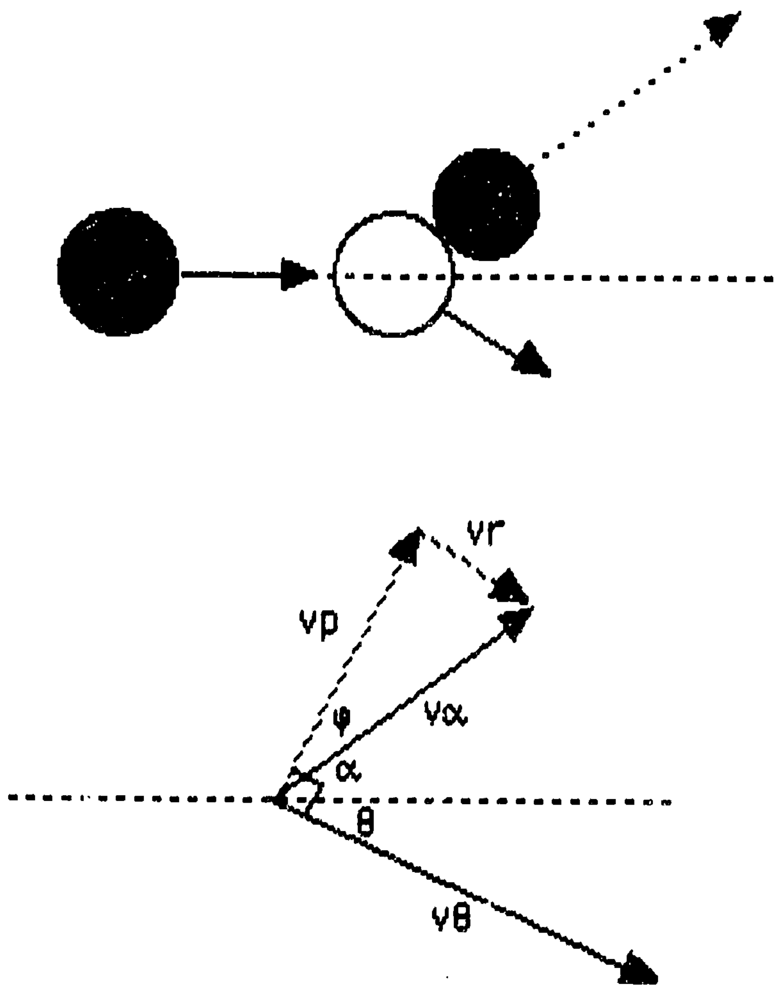
There is a large variation in points for the acceleration vs. time graph. However, the regression line showed what we were looking for. We already know from previous experiments that gravity is constant, so a negative acceleration should show up on the graph. The reason for the variation in the points could be that the picket fences was'nt spread apart correctly or there was a small degree of slowness from the motion timer related to the computer.

$a_{avg} = -12.5 \pm 4.4$

Figure 4 d

<u>The Derivation of a Two Ball Collision Angle Formula</u>

In the accompanying diagram, one ball with an initial velocity strikes another with a different mass, and radius. What is the angle that the ball with the intial velocity will deviate from its original path?
Express $\alpha = f(r1, r2, m1, m2, d, v)$, where d is the distance that the radii are separated on a perpendicular to v



From the diagram, the following relationships are observable:

$v_\theta = v\cos\theta$	Where v_θ is the component of v striking ball two.
$v_p = v\sin\theta$	Where v_p is the remaining component of v.
$v_r = \left(\dfrac{m_1 - m_2}{m_1 + m_2}\right) v_\theta$	Where v_p is the resultant velocity of ball one due to striking ball two, along v_θ.

Figure 5

Therefore:

$$v_\alpha = v_r + v_p$$ Where v_α is the resultant velocity of ball one.

Also:

$$v_r = \left(\frac{m_1 - m_2}{m_1 + m_2}\right) v\cos\theta$$

By trigonometrically adding v_r and v_p :

$$\varphi = \tan^{-1}\left(\frac{v_r}{v_p}\right)$$ Where φ is the resultant angle that the final velocity of ball two deviates from the original.

Substituting from other relationships:

$$\varphi = \tan^{-1}\left(\left(\frac{m_1 - m_2}{m_1 + m_2}\right)\frac{1}{\tan\theta}\right)$$

By simplifying:

$$\varphi = \tan^{-1}\left(\frac{\left(\frac{m_1 - m_2}{m_1 + m_2}\right) v\cos\theta}{v\sin\theta}\right)$$

$$\varphi = \tan^{-1}\left(\left(\frac{m_1 - m_2}{m_1 + m_2}\right)\sqrt{\frac{\cos^2\theta}{\sin^2\theta}}\right)$$

$$\varphi = \tan^{-1}\left(\left(\frac{m_1 - m_2}{m_1 + m_2}\right)\sqrt{\frac{1 - \sin^2\theta}{\sin^2\theta}}\right)$$

Figure 5 cont'd

But, from a trigonometric relationship:

$$\theta = \sin^{-1}\left(\frac{d}{r_1 + r_2}\right)$$

Therefore:

$$\varphi = \tan^{-1}\left(\left(\frac{m_1 - m_2}{m_1 + m_2}\right)\sqrt{\frac{1 - \frac{d^2}{(r_1 + r_2)^2}}{\frac{d^2}{(r_1 + r_2)^2}}}\right)$$

Simplifying this:

$$\varphi = \tan^{-1}\left(\left(\frac{m_1 - m_2}{m_1 + m_2}\right)\sqrt{\frac{(r_1 + r_2)^2}{d^2} - 1}\right)$$

Also, from the diagram:

$$\varphi + \alpha = 90 - \theta$$

$$\alpha = 90 - \theta - \varphi$$

Substituting from other relationships:

$$\alpha = 90 - \sin^{-1}\left(\frac{d}{r_1 + r_2}\right) - \tan^{-1}\left(\left(\frac{m_1 - m_2}{m_1 + m_2}\right)\sqrt{\frac{(r_1 + r_2)^2}{d^2} - 1}\right)$$

Tasso Karkanis
C.B. Smith
March 1, 1990.

Figure 5 cont'd