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Epistemic Strategies for Solving Two-Dimensional Physics Problems

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EPISTEMIC STRATEGIES FOR SOLVING TWO-DIMENSIONAL PHYSICS PROBLEMS

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ABSTRACT

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An epistemic strategy is one in which a person takes a piece of knowledge and uses it to create new knowledge Students in algebra and calculus based physics courses use epistemic strategies to solve physics problems It is important to map how students use these epistemic strategies to solve physics problems in order to provide insight into the problem solving process

In this thesis three questions were addressed (1) What epistemic strategies do students use when solving two-dimensional physics problems that require vector algebra? (2) Do vector preconceptions in kinematics and Newtonian mechanics hinder a student's ability to apply the correct mathematical tools when solving a problem? and, (3) What patterns emerge with students of similar vector algebra skill in their problem solving abilities? Literature discussing epistemic games and frames was reviewed as well as literature discussing qualitative research, quantitative research, and think-aloud protocols

Students were given various problems in two-dimensional kinematics, statics and dynamics They were asked to solve the problems using think-aloud protocol After the student solved the problem he was asked to recall what he remembered about the solution process This procedure gave more insight into the thought process of the student during the time he solved the problems

In addition to the interviews, a vector pre-assessment survey was administered to students at the beginning of the term The vector pre-assessment survey provided data about the vector knowledge students brought into the physics course Students scoring lower than fifty percent on the vector pre-assessment survey did not solve any problems correctly These data and the results of a grounded theory study provided information about the problem solving strategies of the students interviewed in this study

Seven epistemic strategies were observed These seven epistemic strategies fell into three frames the qualitative sense making frame, the quantitative sense making

frame, and the rote problem solving frame The epistemic strategies identification of frames gave a detailed overview of how students solve physics problems involving vector algebra Incomplete pieces of epistemic strategies, called strands, were also observed Students would move between strategies without completing all the steps for a specific strategy Strands were observed for most students

Advanced problem solvers or those students with more experience solving physics problems, moved from the qualitative sense making frame into the quantitative sense making frame to solve the problems Students solving the problems correctly consistently moved into the quantitative sense making frame However, if a student had access to an example that showed the exact solution, that student could end the problem with a correct solution in the rote problem solving frame If no solutions or examples similar to the problem were available, the student was always unsuccessful solving the problem unless he/she moved into the quantitative sense making frame

Misconceptions about motion and forces were identified Vector preconceptions were difficult to identify in this project, but difficulties with vector algebra were observed

This thesis is dedicated to the memory of my mother and father,

Mary and Charles Hing

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CHAPTER I

INTRODUCTION

Vector algebra lies at the heart of many college and university level physics courses Some educators may assume that the mathematical skills necessary for college and university physics are already present through exposure in prerequisite mathematics courses Others may assume no exposure and thus devote lecture time to teaching vector algebra to their students

It seems that most students do not enter their college and university physics courses with prerequisite training in vector algebra (Knight, 1995) They do, however, gain some understanding of vector algebra through exposure in their physics coursework (Nguyen & Meltzer, 2003) Standard lectures do not seem to provide the needed vector algebra instruction to all students (Aguirre, 1988, Aguirre & Rankin, 1989, Flores, Kanim, & Kautz, 2004, Nguyen & Meltzer, 2003)

It has also been shown that even with modified instruction, such as tutorials, students show improvements but do not have significant gains in understanding and application of those vector concepts (Flores et al , 2004) Tutorials directed to address conceptual difficulties of the vector nature of velocity and acceleration show student improvement over standard instruction (Shaffer & McDermott, 2005) Tutorials and modified instruction appear to help with the conceptual aspects of vector quantities in physics, but students are still unable to formally apply vector algebra to solve physics problems (Hoellwarth, Moelter, & Knight, 2005)

Very few studies have shown how students actually solve problems that involve vector algebra What are the similarities and differences between problem solvers that can apply vector algebra to a problem and those that cannot? Is there a way to study this process and gain some insight into the difficulties students have while solving two-dimensional physics problems?

A student's ability to add and subtract vectors graphically and analytically is paramount to their success in any college or university level physics course (Knight, 1995, Nguyen & Meltzer, 2003, Shaffer & McDermott, 2005) It ıs therefore ımportant to see how they solve these types of problems If one looks at students wıth dıfferent levels of profıcıency ın vector algebra, one may gaın some ınsıght ınto (1) how they solve the problems, whether correctly or ıncorrectly, (2) how theır problem solvıng skılls compare and contrast wıth each other, and (3) patterns ın problem solvıng related to theır vector algebra skılls Thıs can be accomplıshed by lookıng at epıstemıc *strategıes* and *frames* students use when applyıng vector algebra to solve physıcs problems

An *epıstemıc strategy* ıs a pattern of actıvıtıes that use partıcular kınds of exıstıng knowledge to create new knowledge or patterns used to solve a problem (Collıns & Ferguson, 1993, Tumınaro, 2004, Tumınaro & Redısh, 2007) A *frame* ıs a form of expectatıon that determınes how a student wıll ınterpret sıtuatıons, events or ın thıs case, solve problems (Fıllmore, 1985, Goffman, 1974, Hammer, Elby, Scherr, & Redısh, 2005, Tannen, 1993) Both the epıstemıc strategıes and framıng can help to ıdentıfy the process a student uses to solve two dımensıonal physıcs problems

I 1 PROBLEM STATEMENT

The purpose of thıs study was to ınvestıgate how students solve two-dımensıonal kınematıcs and Newtonıan mechanıcs physıcs problems through a grounded theory study

I 2 RESEARCH QUESTIONS

In thıs dıssertatıon, ınterviews were conducted to ıdentıfy how students solve two dımensıonal physıcs problems that requıre vector algebra ın the solutıon Through these ınterviews the epıstemıc strategıes students used whıle solvıng these problems were ıdentıfied and tracked In partıcular, the followıng three research questıons have been answered

- What epıstemıc strategıes do students use when solvıng two-dımensıonal physıcs problems that requıre vector algebra?
- Do vector preconceptıons ın kınematıcs and Newtonıan mechanıcs hınder a

student's ability to apply the correct mathematical tools when solving a problem?

- What patterns emerge with students of similar vector algebra skill in their problem solving abilities?

These questions were answered through a qualitative study of twenty college students enrolled at Old Dominion University The overall aim of this study was to give a detailed account of the epistemic strategies students used while solving two dimensional physics problems

I 3 BACKGROUND AND SIGNIFICANCE

Most physics courses depend on students having a working knowledge of vector algebra In introductory algebra-based courses students are expected to add and subtract vector quantities College physics textbooks, such as Cutnell & Johnson *Physics* and Sears & Zemansky *College Physics*, cover vector addition and subtraction in the first chapter In more advanced courses, such as PHYS 231N University Physics, which is a calculus-based physics course offered at Old Dominion University, scalar or dot product and cross product calculations are required to solve quantities such as work and torque Without this working knowledge of vector algebra, a student's chance of success in a college or university level physics course diminishes (Knight, 2003, Nguyen & Meltzer, 2003, Teck-Chee, 1996)

Knight (2003) has shown that the initial vector knowledge that students bring into the classroom should be a concern for all that teach physics Through his Vector Knowledge Test, he has shown that only thirty-five percent of students have a working knowledge of vector algebra when they enter the physics classroom Sixty-five percent of students in his study had some basic awareness of vector quantities or no working knowledge of vector quantities at all

Students have been shown to have difficulties with preconceptions about the vector nature of electrostatics (Kanim, 1999), forces and acceleration (Flores, 2006, Flores et al , 2004), and vector kinematics (Aguirre & Erickson, 1984, Aguirre, 1988, Aguirre et al , 1989, Shaffer & McDermott, 2005) A preconception is a preconceived idea that is difficult to extinguish and may be an underlying reason why students cannot apply vector algebra to physics problems Further discussion is given to preconceptions in Chapter II

Modifications to instruction have been moderate to very successful in helping students overcome vector preconceptions (Flores et al , 2004, Shaffer et al , 2005, Kuo & Beichner, 2006) Use of computer simulations or tutorials have shown more improvement than standard instruction (Flores et al , 2004, Kuo & Beichner, 2006) These successes appear to be limited to the students' conceptual understanding of the vector nature of physics quantities

Although studies have been conducted to study preconceptions of vector algebra concepts, the vector nature of kinematics, forces, and electrostatics, it is still unclear how students solve these types of problems What mechanisms are in place to allow a successful solution to be obtained by some students but not others? Are the preconceptions that students bring into the classroom the only reason they are unsuccessful in the problem solving aspect of physics problems involving vector algebra? A cognitive theoretical framework can be used to analyze and describe how students use vector algebra to solve physics problems In this study, this framework will be used to identify the "epistemic games" (Tuminaro & Redish, 2007) students use when solving vector problems correctly and incorrectly, thus giving an insight into how students think through their problem solving process

The results from this study may lead to the development of instructional materials that could help students solve two-dimensional physics problems correctly This work could also lead to the development of individual interventions to help students become more successful problem solvers Identifying epistemic strategies would give insight into a different facet of student difficulties with solving two dimensional physics problems in kinematics and mechanics

I 4 LIMITATIONS

There are several limitations in this research Only twenty students volunteered to be interviewed for this study The students were enrolled in either an algebra (PHYS 111N) or calculus-based (PHYS 231N) physics course at Old Dominion University Specific emphasis was placed on two-dimensional problems in kinematics and mechanical forces In order to facilitate comparisons, students of both algebra and calculus-based physics courses had to have common knowledge to solve the problems, therefore, problems with dot products and cross products were not studied

I 5 ASSUMPTIONS

As in any research study there are several assumptions made by the researcher In this dissertation there are four assumptions made by the researcher The first assumption is that students are not given the same vector algebra instruction before entering a physics class Because of this assumption, it was important to identify the level of vector knowledge each student had at the beginning of the course

A vector pre-assessment, designed by Nguyen and Meltzer (2003), was administered to students at the beginning of the semester

The second assumption is that calculus is a prerequisite or a co-requisite for the calculus based physics course Students taking the university calculus-based physics course are most likely science or engineering majors

The third assumption is that students taking the college algebra-based physics course are usually health sciences majors, education majors, pre-med students, or engineering technology students This course has mathematics pre-requisites which do not include vector algebra in the course description

Fourth, kinematics and forces were covered early enough in the course to allow enough interviews to be conducted for this study

I 6 PROCEDURE

Students from Old Dominion University college (algebra-based) and university (calculus-based) physics were given a survey to determine pre-existing vector algebra knowledge All students enrolled in PHYS 111N, College Physics, PHYS 231N, University Physics, and PHYS 226N Honors University Physics were given the pre-assessment during their first laboratory session (See Definition of Terms, p 8) The results of the pre-assessment survey were not known by the interviewer until after interviews were conducted The interviews were conducted with students in an individual setting so that group dynamics were not a factor Students participating in this study were trained in think-aloud protocol (Ericsson & Simon, 1993) They were given instructions to tell the interviewer what they were thinking as they answered basic questions The training questions were multiplying two numbers, how many windows are in their home, and naming twenty animals Once the student was comfortable with "thinking aloud," they were asked to solve several problems on topics such as two-dimensional kinematics and application of forces Students were asked to verbalize (Ericsson & Simon, 1993) what they were thinking as they solved the problems They were asked to recall what they were thinking while they were solving the problem once the problem was completed If time was a consideration, students were not given all problems selected The interviews were video-taped and audio-taped The audiotapes were transcribed and notes were added to the transcription based on actions in the videotape This gave an overall record of both the written and verbal interview The work from the student was collected and used for analysis

After the data from the interviews were transcribed, a grounded theory analysis of the transcripts was conducted (Strauss & Corbin, 1998) Grounded theory analysis is discussed in more detail in Chapter II Key words and phrases were recorded, coded, and then epistemic strategies were identified In this dissertation, an epistemic strategy is a series of "moves" that allows a student to connect mathematical and conceptual knowledge together to form new information, i e , the solution to the problem The moves are the steps a student must take to solve the problem For instance, a student may read a problem and decide he needs a free body diagram He would draw the free body diagram based on his understanding of forces and vector algebra If he draws the free body diagram to scale, he might also apply his knowledge of equilibrium He could label each force and then determine if he has completed his task based on his own personal expectations Once he is satisfied with his diagram he may move into another epistemic strategy or this task alone may be the solution to the problem He has created a free body diagram, new knowledge, from knowledge he already possessed More details about the various epistemic games is presented in Chapters II and V

Next, frames were identified A frame is the expectation the student has while solving the problem For instance, when students are taking a test, they may have a different expectation of how they should solve a problem than if they were doing the same problem for homework On a test, they would activate or recall prior knowledge to arrive at a solution For homework, they may check their notes or a textbook for a similar example or to find a necessary equation This expectation effects how they apply their own knowledge to solve the problem

The interviews conducted in the spring 2008 semester were used to develop the codes for the epistemic strategies The first five interviews were used to develop the codes and then the remaining three interviews were used to refine and adjust the coding for epistemic strategies After the coding of the data from the first semester was complete, the second semester interviews were coded No new variations in codes appeared in the second semester interviews The coded data were compared with epistemic strategies defined by Tuminaro (2004) in his doctoral dissertation The steps for each of Tuminaro's epistemic games is compared to the steps obtained in this research A discussion of the similarities and differences is given

I 7 DEFINITION OF TERMS

The following is a list of terms used in this study

Epistemic strategies "coherent activities that use particular kinds of knowledge and processes associated with that knowledge to create knowledge or solve a problem"

(Tuminaro, 2004, p 4)

Frame an expectation that determines how a student will interpret a physics problem and how they will solve it

Framing clusters Frames that emerge from the different mathematical resources activated by students while problem solving The mathematical resources appear as clusters or groups within the data set

Head-to-tail a graphical method of adding vectors by placing the tail of the second vector to the head of the first vector The resultant is then drawn from the tail of the first to the head of the last The vectors are drawn as a line segment with an arrowhead where the length indicates magnitude and the direction the arrow points is the direction of the vector quantity

Grounded Theory A method of using empirical data to construct a theory or theoretical framework

Mapping Meaning to Mathematics an epistemic game in which students start with a formula and try to give it conceptual meaning in terms of the problem they are solving (Tuminaro, 2004)

Mapping Mathematics to Meaning an epistemic game in which students start with a concept and develop a mathematical formulation from that concept (Tuminaro, 2004)

Mathematical resources cognitive tools involved in problem solving and mathematical thinking (Tuminaro, 2004)

Parallelogram Method a graphical method of adding vectors The two vectors are translated to a common origin and a parallelogram is constructed The resulting vector is drawn from the origin along the diagonal of the parallelogram as shown in Figure 1

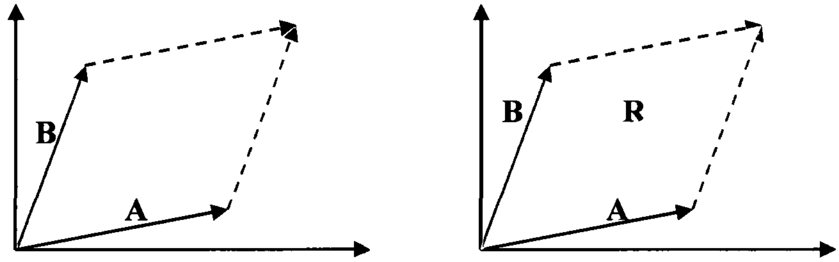

Figure 1 Parallelogram Method

PHYS 111N Algebra-based physics course with a traditional lecture offered at Old Dominion University This course is taken by pre-med, physical therapy, sports medicine, physical fitness, and engineering technology majors

PHYS 226N Calculus-based physics with a traditional lecture course offered through the Honors College at Old Dominion University This course is taken by engineering and science majors enrolled in the Honors College

PHYS 231N Calculus-based physics course with a traditional lecture offered at Old Dominion University This course is taken by engineering and science majors

Physical mechanism game an epistemic game in which a student attempts to construct a physically coherent and descriptive story based on his/her intuition about a problem (Tuminaro, 2004)

Pictorial Analysis an epistemic game in which a student uses a picture to solve a problem (Tuminaro, 2004)

Ponderables "These are problems that are often not-well defined Students have to conduct web searches for relevant information, or more commonly, make estimates of quantities" (NCSU Physics Education Research and Development Group, 2007, pg 1)

Recursive Plug-and-Chug an epistemic game in which students plug numbers into a physics formula without any conceptual understanding of the problem (Tuminaro, 2004)

Rote Problem Solving Frame an expectation such that all a student needs to do to solve a problem is find a formula and substitute numbers into the formula

Transliteration to Mathematics Transliteration is the process of mapping from one system of writing into another word by word They do so without developing a conceptual understanding of the worked example Students simply map the quantities from their target problem into the solution pattern of a solved example problem (Tuminaro, 2004)

Tangibles "These are problems that require some kind of observation Students must decide what can be determined from a measurement and what has to be estimated or located in other resources" (NCSU Physics Education R & D Group, 2007, pg 1)

I 8 SUMMARY AND OVERVIEW

Chapter II offers a review of previous and current research on student difficulties with vector algebra and the preconceptions students have about vector concepts in physics Previous research on mathematical problem solving with an emphasis on two-dimensional mechanics and kinematics is also discussed Research into epistemic strategies and frames is then summarized

In Chapter III, a discussion of the methodologies and procedures for this work is presented An overview of participant selection, vector pre-assessments and interviews is given In Chapter IV the transcription of the interviews and the grounded theory study that was conducted to identify epistemic strategies for each interview is presented A comparison of the epistemic strategies identified from the data in this study is made with the results presented by Tuminaro (2004) Chapter V covers the results from the vector assessment survey and the results from the twenty interviews conducted for this study A comparison between high and low vector pre-assessment students and their solutions is made Different problem solutions for each student is also discussed In Chapter VI conclusions are drawn with recommendations for future studies

CHAPTER II

REVIEW OF LITERATURE

This chapter provides a review of literature concerning student difficulties with vector algebra Students' difficulties may range from no knowledge of vector algebra at all, to an inability mainly in solving problems using vector algebra Students may show misconceptions in physics concepts that use vectors, such as acceleration and velocity in two dimensions Epistemic games, warrants, and framing will also be discussed in this chapter Finally, an overview of grounded theory will be presented

II 1 PHYSICS EDUCATION RESEARCH (PER) INSTRUCTIONAL METHODS

As society moved into the 21st century, there were great strides in incorporating the results of Physics Education Research (PER) into our high school and university curricular materials For example, modeling workshops developed at Arizona State University (Hestenes, 1989) are available every summer to train high school and college or university level instructors Universities continue to adopt an inquiry-based curriculum through use of Socratic Dialogue Labs (Hake, 1992) and Teaching Physics through the Physics Suite CD (Redish, 2003), which is a collection of curricular materials that incorporate PER Matter and Interactions, another curriculum developed from the results of PER (Chabay & Sherwood, 2010), has been developed and is available for use in university physics classes

Furthermore, more than 100 colleges and universities have adopted SCALE-UP (Student-Centered Active Learning Environment for Undergraduate Programs), which uses a studio environment for large lecture classes SCALE-UP incorporates "tangibles" and "ponderables" (see Chapter I 7) to give students an inquiry based learning environment On-line homework systems such as Pearson's MasteringPhysics and North Carolina State University's WebAssign® incorporate physics education research in the software design WebAssign® allows customers to assign quizzes and tests as well as homework problems MasterıngPhysıcs uses ınteractıve sımulatıons from the PhET Interactıve Sımulatıons Project at the Unıversıty of Colorado (PhET) (http //phet colorado edu/) ın ıts tutorıal problems

II 2 VECTOR ALGEBRA

However, despıte all of the research and currıcular materıals avaılable, some students contınue to struggle wıth problem-solvıng and understandıng of physıcs concepts (Hoellwarth, Moelter, & Knıght, 2005, Valıotıs, 2008) Thıs ıs especıally true when one looks at the use of vector algebra to solve two dımensıonal physıcs problems (Hoellwarth et al , 2005) One problem may be that students do not necessarıly arrıve to theır physıcs courses wıth the prerequısıte vector algebra skılls (Knıght, 1995, Nguyen & Meltzer, 2003)

Knıght (1995) developed the *Vector Knowledge Test* whıch provıded a look at the vector knowledge calculus-based students brıng ınto the classroom He found that for the 286 students enrolled ın calculus-based physıcs at Cal Poly, the class average for correct answers was only thırty-five percent Sıxty-five percent of students ın hıs study had some basıc awareness of vector quantıtıes or no workıng knowledge of vector quantıtıes at all Students repeatıng the course due to faılure or wıthdrawal performed slıghtly better than students takıng the course for the first tıme It was found that one lecture coverıng vector quantıtıes and one homework assıgnment were not adequate for most students

Nguyen and Meltzer (2003) at Iowa State Unıversıty developed a seven ıtem quız that ıncluded free response problems pertaınıng to vector algebra ın one and two dımensıons They admınıstered thıs quız durıng the first week of classes to 2031 students The students were enrolled ın a two semester course sequence ın calculus-based physıcs or algebra-based physıcs The quız was admınıstered ın both the fall and sprıng semesters

They found that twenty-five percent of students enterıng the second course ın calculus-based physıcs were unable to carry out two dımensıonal vector addıtıon Fıfty percent of students entering the second course in algebra-based physics were unable to carry out the same two dimensional vector problems These data show that not all students learn the necessary vector algebra skills during their first semester of physics and reinforces the results found by Knight

The results from Nguyen and Meltzer prompted Van Deventer (2007) to developed two, ten question multiple choice tests One test included vector algebra mathematics problems and the other test was an isomorphic physics test A mathematics problem may ask for the cross product between vectors $\vec{A}$ and $\vec{B}$ such that, $\vec{A} \times \vec{B} = \vec{C}$ An isomorphic physics problem would ask for the torque when given the force and the lever arm, such that, $\vec{\tau} = \vec{r} \times \vec{F}$ Both problems use the same mathematical tool the cross product

Both tests were administered in the fall semester before a lecture on vector algebra, post lecture, and at the end of the semester Before the lecture, there was no significant difference between the mathematics and physics tests Van Deventer observed a significant difference after the lecture and at the end of the semester

He observed a statistically significant difference ($t_{two\text{-}tailed}$ = 3 317, df = 64, p = 0 002)[1] between the math and physics vector quizzes for the post-lecture sample This difference was on the order of two questions, with the mean of the math vector quiz being higher than the mean on the physics vector quiz

At the end of the semester, he observed a statistical significant difference ($t_{two\text{-}tailed}$ = 2 027, df = 208, p = 0 044) between each quiz version There appeared to be a slight difference in performance on the math and physics isomorphic vector quizzes at the end of the semester with scores on the mathematics test slightly higher than those on the physics test

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[1] A two tailed t- test was performed The degrees of freedom, df are given A small p value means the null hypothesis is false and a significant difference is present between the two group means

II 3 VECTOR MECHANICS

Aguirre (1988) looked into student preconceptions about vector kinematics Research has shown these preconceptions are quite tenacious and difficult to extinguish (Ausubel, 1968, Vokos, Shaffer, Ambrose, & McDermott, 2000) Aguirre identifies several implicit vector characteristics to explore for student vector preconceptions These characteristics are called implicit because they may not be discussed explicitly during instruction

One vector characteristic involves frame of reference and speed Students were asked to identify the speed of a boat moving across the water by (a) the people in the boat and (b) a person on the shore watching the boat cross the river Aguirre identified that students believed the speed was an intrinsic property of the boat and was independent of the reference frame For instance, one student said "it looks like it's moving slower or faster but if you actually measure it it's the same for both observers "

Another vector characteristic is *simultaneity of components* Students were asked to sketch the paths of the moving bodies in various tasks, one being the boat problem These drawings seemed to indicate that students believe one component of the velocity acts after the other without an interaction between the two In other words, they act sequentially One explanation used to support this preconception was that the motion in one dimension has to "wear off" before the other motion can start influencing the object

Three preconceptions were identified from the third vector characteristic, independence of the magnitude of the components The first preconception is that the magnitude of a component velocity decreases due to an interaction with the other component The second preconception is that the magnitude of a component velocity increases due to the interaction with the other component and the third preconception is that the magnitude of the component velocity changes due to the interaction with the other component The first and second preconceptions are contrary to each other and show the various preconceptions students possess about the interaction of the magnitudes of vector components

Aguirre also identified a preconception with the vector characteristic, independence of direction of the components Students were asked to draw a moving block at three separate positions The block was put into motion by a spring on an inclined air table The initial orientation of the block was indicated by a mark on the block The spring kick was applied to the square block's center of mass No rotation of the block was present Students were instructed that the spring kick would cause no rotation and the block was on a frictionless plane

When students were asked to draw this block at three different positions during its motion, he found that students believed that the orientation of a moving body is always tangential to the path at any point They consistently drew the line on the block rotating as the block fell He also found that students believed that the orientation of the moving body was always changing or spinning and that the moving body gradually changed from a horizontal to a vertical heading

The preconceptions identified by Aguirre affect how students perceive vector characteristics of velocity in physics problems If these preconceptions are not explicitly addressed through instruction, students may not be able to solve problems correctly

Shaffer and McDermott (2005) investigated the vector nature of kinematical concepts They examined the ability of students to determine qualitatively the magnitude and direction of the instantaneous velocity and acceleration of an object from knowledge of its trajectory Three groups were given the pendulum problem as shown in Figure 2 a The three groups consisted of 125 University of Washington undergraduates enrolled in the calculus-based physics course, 22 pre-service high school teachers enrolled in a program at the University of Washington, most of whom had studied kinematics in previous coursework, and 22 University of Washington teaching assistants A fourth group of students taking the Ph D qualifying exam were given the girl on a swing problem shown in Figure 2 b

With these results, the major goal was to develop tutorials in one and two-dimensional kinematics During this study, pretest results identified eleven student preconceptions The first four pertain to incorrect reasoning about kinematics at arbitrary points along a trajectory They are (1) students do not recognize that instantaneous velocity is tangent to the trajectory, (2) students do not distinguish between velocity and acceleration and sometimes use identical vectors for both, (3) students believe the acceleration is zero when the speed is zero and, (4) students assume that the acceleration is directed toward special points

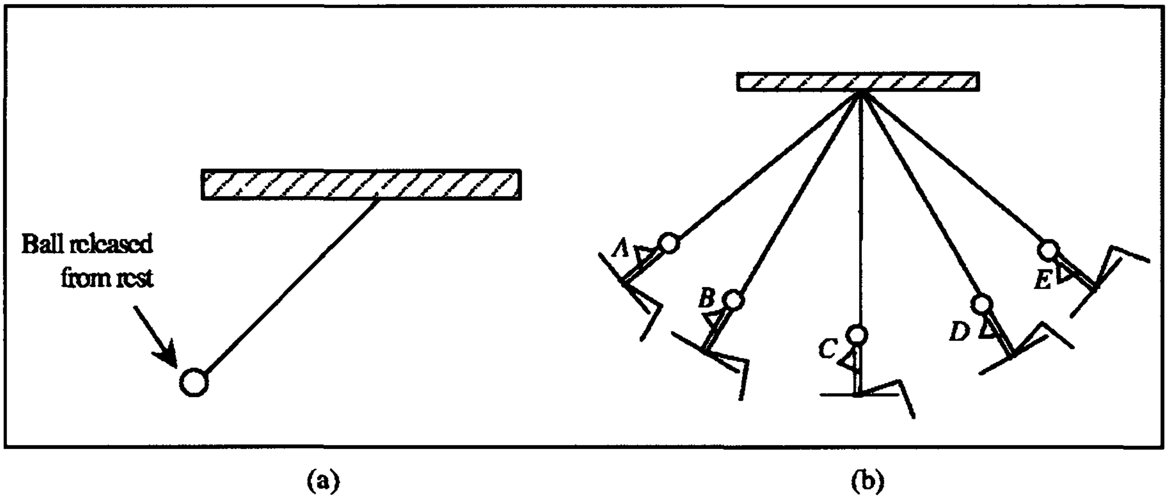


Figure 2 (a) Problem given to students and teaching assistants (b) Problem given on the graduate qualifying examination (Shaffer & McDermott, 2005)

The next set of preconceptions related to incorrect reasoning for turnaround points Students mistakenly (1) used a nonzero vector for velocity at the turnaround point and (2) assumed that the acceleration was zero at a turnaround point Student incorrectly drew the velocity vectors and the acceleration vectors for the turnaround point for a cart moving up and then down a ramp and a pendulum changing its direction of motion

Students also used incorrect reasoning for the point at which an object starts from rest Three preconceptions were (1) students did not treat the instantaneous velocity as zero for an object starting from rest (2) students assumed that the instantaneous acceleration was zero for an object starting from rest, and (3) students assumed that the instantaneous acceleration has a radial component for an object starting from rest

Finally, students showed incorrect or incomplete reasoning about the application of dynamics to kinematics Students were not associating the direction of the acceleration of an object with the direction of the net force They were also confusing net force and acceleration Also, most students did not identify all forces in the net force They would ignore the tension or the normal force Most students seemed to assume that the acceleration must be in the direction of his/her incorrect net force and did not use the change in velocity to determine the direction Twenty percent of graduate students stated that the direction of the acceleration was straight down for the pendulum problem

A tutorial was given to the students and then a post-test Post-test scores showed student conceptual understanding of two-dimensional kinematics motion on a horizontal plane was much greater after the tutorial Significant gains were shown for identifying motion with changing speed along a closed horizontal trajectory Pre-test results for identifying constant speed showed twenty percent correct whereas post-test scores showed eighty percent correct Pre-test results for identifying points of increasing speed showed about five percent answered correct which increased to only thirty-five percent post-test Significant gains were shown, but the end result was not satisfactory

There was only a fifteen percent gain between pre- and post-test scores for the pendulum problem Students wanted to use the forces to determine the acceleration of the pendulum bob The direction can only be found by kinematical analysis After standard instruction, students were unable to apply concepts taught to determine acceleration and velocity These difficulties appear to be conceptual and not mathematical in nature

Student preconceptions are not isolated to kinematics but also exist in Newtonian mechanics (Clement, 1982, Flores et al , 2004) These preconceptions infiltrate the student's thought process long before they enter a physics classroom The idea that "a force is needed to keep an object moving" develops from students' own personal experience and becomes difficult to extinguish through traditional instruction (Hake, 1992, McDermott, 1984, Watts & Zylbersztajn, 1981) Tutorials, inquiry based activities, and Socratic Dialog-Inducing labs can be used to help students improve their conceptual knowledge in mechanics by promoting learning through hands-on activities which yield discussions and immediate feedback (Hake, 1998, McDermott, Shaffer, & Physics Education Group at the University of Washington, 2002, University of Maryland Physics Education Research Group, 2010)

However, not all modified instruction is successful (Flores et al , 2004) In one example, students were asked to choose which vector best represented the change in the moon's velocity for a specific time interval Students were required to subtract two velocity vectors to obtain the change in velocity With instruction using Tutorials in Introductory Physics (McDermott, Shaffer, & Physics Education Group at the University of Washington, 2002), only fifty-two percent of students answered correctly Flores et al concluded that even with modified instruction, students still failed on parts of questions presented to them and more research was necessary to understand the difficulties facing students while solving problems involving the vector nature of position, velocity, and acceleration

II 4 PROBLEM SOLVING

The results from studies involving mechanics showed that statistical gains can be achieved in conceptual understanding through studio instruction (Hoellwarth et al , 2005) A studio environment (e g , SCALE-UP or Studio Physics) eliminates the boundaries between lecture and laboratory and promotes active-learning instruction Activity-based learning dominates over lecture-based delivery so that larger periods of time are necessary in the studio environment

A study was conducted to measure conceptual and traditional problem solving differences between the traditional and studio environments at California Polytechnic State University In this study, the studio environment covered kinematics and Newtonian mechanics ten percent longer than the traditional lecture setting but spent less time on rotational dynamics Both groups were given the Force Concept Inventory (FCI) (Hestenes, Wells & Swackhamer, 1992) and the Force and Motion Conceptual Evaluation (FMCE) (Thornton & Sokoloff, 1998) Students enrolled in the studio environment improved over the traditional environment, on the FCI, where the normalized gain for the traditional course was +0 39, the normalized gain for the studio environment was +0 60 The normalized gain is defined as the ratio of the actual gain to the maximum possible gain, $\langle g \rangle = (\text{post} - \text{pre}) / (100 - \text{pre})$ The normalized gain accounts for differences in the initial starting knowledge of students so that different classes can be compared directly The difference between studio and lecture format on the normalized gain increased to +0 44 for the FMCE, which was administered in the fall and winter of the following year These are very significant improvements in conceptual understanding and are consistent with other research (Hake, 1998)

At California Polytechnic, the quantitative problem solving ability was measured with four or five problems on a final exam The final exam was given to both studio and traditional sections Most of the problems required two or more pieces of knowledge, such as Newton's laws and kinematics There was little difference in quantitative results between these two groups This study actually showed a slightly higher score, although not statistically significant, for the traditional lecture group on the final exam problems compared to the studio group In this study, studio environments showed statistical gains in conceptual understanding but none in quantitative problem solving

Previous and current research shows that students have difficulty with applying vector algebra to solve problems Why does this difficulty arise? If a student does have adequate vector algebra knowledge will he/she be successful in solving these types of physics problems? This does not always seem to be the case (McDermott, Shaffer, & Physics Education Group at the University of Washington, 2002) What is it that does not allow a student to activate this resource to solve the problem? We may be able to answer these questions once we identify how students solve these problems by identifying a cognitive framework

II 5 EPISTEMIC GAMES AND FRAMING

Jonathan Tuminaro (2004), at the University of Maryland, presented just such a framework in his dissertation Students in his study were enrolled in an algebra-based physics course and were predominantly pre-medical, health science students Tuminaro proposed a framework with three theoretical constructs The first construct is mathematical resources This involves the mathematical knowledge the student activates while solving a problem For example, if a student is told that the net force is zero, they may activate the mathematical resource $\square = \square$ where the boxes represent the quantities given in the problem They may even expand that resource to give $\square + \square + \square + \quad = 0$ If a student does not have a mathematical resource they will be unable to use it to solve the problem

The mathematical resources can remain inactive, primed or active Inactive mathematical resources are in the long term memory and are not used by the student in the problem solution Primed resources can be used but are not actually active For example, if a person is asked to give angles on the unit circle, they may "prime" or start to remember the unit circle without actually being able to give angles on that circle The active mathematical resource is one that is used to solve the problem From the previous example, the student may give $\frac{\pi}{4}$ or $\frac{\sqrt{2}}{2}, \frac{\sqrt{2}}{2}$ for the angle 45°

The second mathematical construct is epistemic games Epistemic games were first proposed by Collins and Ferguson (1993) as general purpose strategies used to analyze different situations in science and history Tuminaro gives a more specific definition for physics problem solving An epistemic game is a set of rules or steps taken that guide the problem's solution Epistemic games include an epistemic form (Bing, 2008, Collins and Ferguson, 1993, Tuminaro, 2004) and a knowledge base (Bing, 2008, Tuminaro, 2004)

Tuminaro (2004) defines the knowledge base as a collection of resources available to the student as they play a particular epistemic game This would be similar to the supplies, such as the nails or wood, that a carpenter would use to make a house or the chess pieces for a game of chess The epistemic form is the structure that is used to guide the game This would be analogous to the blue prints for the building or the game board used in chess

The epistemic game has two structural parts the entry and ending conditions, and the moves The entry and ending conditions are the beginning and ending of the game The entry condition for a student solving a physics problem will depend on their expectations about that problem Hinsley and Hayes (as cited in Tuminaro, 2004) found that students can quickly organize or classify a large number of physics problems very shortly after reading the problem Often students are able to categorize these problems after reading the first sentence

The moves of the epistemic game are the steps taken by the student while playing the epistemic game This would be similar to the movements of the chess pieces such as the forward and side motion of a rook or the diagonal motion of the bishop The moves depend on the game that is being played Moves in checkers differ from those in chess just as moves in one epistemic game may differ from another

Tuminaro (2007) identified six epistemic games in his theoretical framework The first epistemic game involves the generation of a picture or diagram This game is called Pictorial Analysis The epistemic form is the drawing or diagram and the moves are (1) determine the target, (2) choose a physical representation, (3) tell a conceptual story, and (4) label the diagram or picture

The second game involves a student telling a story about the solution to the problem In the physical mechanism game, students (1) develop a story about the physical situation and (2) evaluate the story In this game students will not make explicit references to physics equations or principles

In the game Recursive Plug and Chug, students plug numbers into physics equations and get numeric answers without understanding the physics concepts that underlie the equations Students do not rely on their knowledge but instead search for equations that have the same quantities as they have in their problem The moves in this game are similar to other games but the knowledge base is different Students will first (1) identify a target, (2) find an equation relating the target to other quantities, and (3) determine the unknown quantity If they have more than one unknown quantity they will choose a sub-target and start from the beginning of the game If they have all known quantities except the target, they solve for the target

The next game is Transliteration to Mathematics Students playing this game search for a solution provided in lecture notes or their textbook They use the solution in the example to solve their current problem Students will (1) identify the target, (2) find a solution pattern that relates to the current problem, (3) map the quantities from their current problem into the solution pattern, and (4) evaluate the mapping when playing this game

The fifth epistemic game in Tuminaro's theoretical framework is Mapping Meaning to Mathematics This epistemic game is the most intellectually complex of all the games Students start with a conceptual understanding of the problem and then begin a quantitative solution The moves are (1) develop a story about the physical situation, (2) translate quantities in the physical story to mathematical entities, (3) relate the mathematical entities in accordance with the physical story, (4) manipulate symbols, and (5) evaluate solution

The final epistemic game identified by Tuminaro (2007) is Mapping Mathematics to Meaning This is the second most intellectually complex game This game is very similar to Mapping Meaning to Mathematics The moves differ between the games In Mapping Mathematics to Meaning students will (1) identify the target, (2) find an equation that relates the target, (3) tell a story, and (4) evaluate the story In this game the story does not come after the identification of the target but rather after the student identifies the equation

The third construct identified by Tuminaro (2007) is frames A frame is an individual's interpretation of what is going on (Hammer et al , 2005) The frame determines how a student will solve a problem simply by the expectations the student may have about the problem

Tuminaro (2004) discusses three frames used by students when solving physics problems qualitative sense making frame, rote equation chasing, and quantitative sense making frame The frame can help identify the epistemic game played by the student It can also determine the game a student may play to solve the problem The rote problem solving frame is the student's expectation that a formula or solved problem is all that is needed to solve the problem They just need to plug in their numbers into the equation they have found in order to solve the problem The sense making frame is the student's expectation that solutions to problems should involve physical principles The sense making frame can be described as qualitative or quantitative The qualitative sense making frame does not involve any formal mathematical structures The quantitative sense making frame involves formal mathematical operations in order to make sense of the problem

Tuminaro identified Mapping Meaning to Mathematics and Mapping Mathematics to Meaning as the two most intellectually complex of all the epistemic games Students playing these games are in quantitative sense making frame The identification of the quantitative sense making frame can identify complex problem solving

In studies of more advanced problem solvers (Bing, 2008), there appears to be a "break down" of epistemic games The moves for each game become unidentifiable It was unclear what epistemic "game" a student was playing Students would make moves quickly and implicitly In studying these types of students, it became necessary to develop a new cognitive framework

Bing (2008) presents four clusters of framing that emerged from problem solving of upper level physics students, namely Calculations, Physical Mapping, Invoking Authority, and Math Consistency Each of these four framings corresponded to a different cluster of mathematical justifications that students were seen to offer These clusters were identified by tracking the warrants students used in their mathematics A warrant is the bridge that links the data to a claim Bing (2008) stated as an example

> Thomas Jefferson is the greatest American founding father (claim) because he wrote the Declaration of Independence (data) The unspoken warrant that allows this data to apply to that claim is that the Declaration of Independence is a cornerstone document in American history, laying out the nascent country's claims for autonomy (p 45)

In the Calculation frame students depend on the computational correctness of their solution A student with a solution that is primarily mathematical in nature with no explicit explanation would be working in the Calculation frame The Physical Mapping frame is the students' expectation that the mathematics they use should fit the physical situation in their problem An example of the Physical Mapping frame would be if a student discussed putting more resistors in series to increase the resistance of the circuit He may state that the current must go through all of the resistors and thus the resistances should add The Calculation frame has a quantitative solution but it may lack the conceptual content to support the solution The Physical Mapping frame does not have the quantitative rigor but has the conceptual explanation to support the solution

The Invoking Authority frame involves a student's expectation that they do not need to "reinvent the wheel " For instance, instead of deriving the equation for the moment of inertia of a disk, they may use the formula already provided in their textbook The Math Consistency frame involves the student's expectation that math has a regularity to it The similarities between the gravitational force and Coulomb's law as being inverse square laws are an example of Math Consistency

II 6 GROUNDED THEORY

Although the goal of this research was to identify epistemic strategies similar to those presented by Tuminaro (2004), it was unclear that epistemic games or strategies would emerge from the data Students in the calculus-based course might solve problems at an advanced level and epistemic strategies may not emerge Nor could it be guaranteed that warrants and epistemic framing clusters as described by Bing (2008) would emerge in the data A grounded theory paradigm was necessary to discover the categories that would emerge from the data in this investigation

Grounded theory was first presented by Glaser and Strauss (1967) in their book *The Discovery of Grounded Theory* Later Strauss and Corbin (1990) published *Basics of Qualitative Research Grounded Theory Procedures and Techniques* A grounded theory study allows a researcher to develop a theory or framework that emerges from the data The researcher starts with the data from interviews and performs open coding The transcripts from the interviews are read line by line and key words and phrases are highlighted The researcher does not apply what he or she wants to observe but allows these key terms and phrases to emerge The codes are then grouped into categories More interviews are conducted and may change as the researcher seeks data to fill in gaps in the overall categories that emerge from the data

The open coding allows the researcher to use key words or phrases that characterize the patterns observed As more data is added to the study, these codes change, condense, or expand to create concepts that describe the data An iterative process continues with the new data until no new codes or concepts emerge The codes and concepts are then grouped into categories The categories form the overall theory Once a theoretical framework is developed, it may be possible to use it for current studies, or future studies of similar data sets The framework guides the research and determines what things are measured and what statistical relationship may be used (Elements of Research, 1996)

II 7 SUMMARY

There have been great strides in Physics Education Research Much of this research is now being incorporated into curricular materials Students have significant gains in conceptual understanding of physics concepts, but in some areas these gains are small Students still appear to show difficulties in problem solving abilities If students exhibit the mathematical skills needed for physics courses, there is still difficulty in applying the mathematics to solutions of physics problems Theoretical frameworks may help identify how students solve problems

Chapter III discusses the methodology and procedures used for the student interviews A detailed description of the population, the vector pre-assessment instrument, and the interviews conducted are discussed Chapter III also discusses think-aloud protocol which was the method used to conduct the interviews In Chapter IV the results of the grounded theory analysis are presented

CHAPTER III

METHODS AND PROCEDURES

In order to understand why students have difficulty solving problems that involve vector algebra, it was important to understand how they constructed their solutions A theoretical framework was used to take a detailed look at how students solve physics problems An added dimension can be achieved through a mixed methods study that involves both quantitative and qualitative data This was accomplished with a pre-assessment of vector algebra knowledge and interviews conducted with students

A purposeful sampling was used to study cases in depth and detail so that an understanding of the problem solving process could be obtained Students were selected based on enrollment at Old Dominion University Students in the calculus-based physics courses were not sampled if they were enrolled in a Student-Centered Active Learning Environment for Undergraduate Programs (SCALE-UP) course This course was established to produce a highly collaborative, hands-on, computer-rich, interactive learning environment for large-enrollment courses Although it would be interesting to compare the students from this course with students in a traditional setting, the SCALE-UP course was established at the same time as this study and was still in its infancy This study of students enrolled in a traditional lecture is not meant to be give a generalized view of the population but a detailed information-rich study of students in traditional lecture physics courses

III 1 POPULATION

Old Dominion University is an urban campus with a diverse population In the fall of 2008, 23,086 students were enrolled, with fifty-seven percent of whom were women Sixty-one percent of the campus community was White, twenty-three percent was African American, six percent was Asian, four percent was Hispanic, and six percent were of other ethnic groups

Students from the PHYS 111N, PHYS 226N, and PHYS 231N courses offered in the spring and fall of 2008 were asked to participate in this study The PHYS 111N course is an introductory algebra-based course PHYS 231N is an introductory calculus-based course intended for science (non-biology) and engineering majors PHYS 226N is also a general education calculus-based course intended for science (non-biology) and engineering majors but is part of the Honors College The Honors College offers undergraduates the benefits of a small liberal arts college within a large research university Students enrolled in PHYS 226N participate in the lecture for PHYS 231N and were treated the same for this project Thirty-five students volunteered to participate, but when interviews were scheduled only twenty students chose to participate

Ten students were enrolled in PHYS 231N and ten students were enrolled in PHYS 111N The students had already covered vector algebra, one and two dimensional kinematics, and the application of Newton's laws of motion before the interviews took place

Of the twenty students that agreed to participate in the study, eleven students were male and nine students were female Three students were African-American, two were Asian, and fifteen were Caucasian Student achievement ranged from midterm grades below a C up to an A as reported by the student

III 2 INSTITUTIONAL REVIEW BOARD (IRB)

In the fall semester 2007, an IRB application for exemption was filed with the College of Sciences Human Subject Research Board An exemption was filed on the basis that the identity of the students would remain confidential Video of the interviews would only include written work and not the faces of the students Names were not included in the video or audio tapes The exempt status was granted for the spring 2008 and fall 2008 semesters Even though exempt status was granted for this research, students participating in the interviews were given an informed consent document (see Appendix A) to sign before the interview was conducted

III 3 VECTOR PREASSESSMENT SURVEY

A vector assessment survey (see Appendix B), developed by Nguyen and Meltzer (2003), was used to determine the vector algebra knowledge students brought into the course The assessment was administered during the first week of classes at the beginning of their first laboratory class Teaching assistants, those assigned to teach the laboratory sessions, were given the instructions and surveys prior to the first class meeting The assessments were collected in class by the teaching assistants

The first page of the assessment included the student name, email address, and phone number The student was advised that they did not have to provide the email address or phone number but that the information was necessary if they wanted to participate in future studies A random number was provided on the cover sheet and the assessment For the students participating in this study, the scores were entered into an Excel spreadsheet The students were divided into two groups based on their enrollment in PHYS 111N, PHYS 231N, or PHYS 226N (See Definition of Terms, p 8)

III 4 INTERVIEWS

The students were given a five dollar gift card as compensation for their time devoted to this study The first eight interviews occurred in the spring semester of 2008 and the next twelve interviews occurred in the fall semester of 2008

There are several ways to gain insight into how students solve problems Direct observations can be made by the researcher or sessions can be video and/or audio taped The observations can take place in a group setting or with a single person When studying groups, the dynamics between the students can overshadow the thought process Therefore, single person interviews were selected for this study

Location was another factor to consider when determining the setting for the observations Should the student be observed in their classroom, the tutoring center, or by direct interview? The research questions could best be answered with interviews conducted in a quiet room This gave the student privacy while they completed the physics problems They were free to complete problems as they would at home and it allowed for an investigation of the individual's cognitive process

A typical interview lasted approximately one hour and was done in a quiet room An audio recorder was placed on the table and a video camera was oriented behind the student and focused on their written work Some students elected to stay beyond the one hour session to solve more problems The interviewer remained present during the interview and tried to remain as nonintrusive as possible All of the interviews were conducted by the author Most interviews were conducted with little to no interaction between the interviewer and the student There were cases in which students would ask questions of the interviewer and they were answered

During the interview, students were trained for fifteen minutes in using "think-aloud protocols" (Ericsson & Simon, 1993) The students were asked to say out loud everything they were thinking while solving a variety of problems chosen from two dimensional kinematics and two dimensional forces If they were quiet for longer than 7 - 10 seconds, they were prompted to keep talking

Students were given two to five problems during the one hour session There were eight problems available for student to solve Table 1 shows the problem name, a brief description of the problem and the pseudonyms of the students that participated in the study There were three two-dimensional kinematics problems and five two-dimensional Newtonian mechanics problems The kinematics problems were full projectile motion problems There were two Newtonian mechanics equilibrium problems and three dynamic equilibrium problems The three dynamics problems involved two blocks The problems selected were ones that all students would typically encounter no matter their course enrollment The problems can be found in Appendix C

Once the student solved the problem and gave his/her final answer, he/she was asked to recall what he/she remembered about his/her thinking This recall process was very specific The student was guided to recall his/her thinking as they solved the problem Great effort was made to keep the student from analyzing their thinking or from allowing them to resolve the problem Students were guided to discuss their memories of their problem solving process The interviewer played a more integral role in this process Sometimes it was necessary to ask questions about specific statements

The recall process was not a necessary component of think-aloud protocols It did, however, provide more detail about the process used by the person solving the problems Sometimes students would not vocalize a thought process that would emerge during the recall Also, it was sometimes unclear whether a student was referring to written text or an example in their notes They were able to provide this information during the recall This allowed for a more complete picture of the problem solving process

Several students indicated during the interview that they were treating this as if they were taking a test and not as if they were solving homework problems This epistemological belief about the purpose of this interview may have skewed how a student would normally solve the problems assigned for homework Students were informed that they should consider these problems similar to homework and if necessary, a textbook or calculator was provided for the student to use during the interview These materials were made available only if the student asked for them during the interview

III 5 SUMMARY

Students at Old Dominion University were asked to participate in this study and twenty students volunteered Each student was trained in Think aloud protocols and was interviews for approximately one hour During that time, students were asked to solve two dimensional kinematics and Newtonian mechanics problems

In Chapter IV the transcription and coding of the interviews is discussed Population interviews were transcribed and a grounded theory study was conducted with the data collected from eight of the interviews A comparison was made between the epistemic strategies that emerged from these data and those observed in Tuminaro's (2004) framework

Table 1

Physics Problem Name, Description and Pseudonyms of Students in Study

Problem name and description	Pseudonym of student
Tree two-dimensional force problem, static, involving tension and weight	Lisa (1), John (2), Kevin (3), Jenny (4), James (5), Keisha (6), Diane (7), Josh (8), Andy (9), Bill (10), Rish (11), Jake (12), Yen (14), Brad (15), Ashley (16), Doug (17), Becky (18), Tiki (19), and Cindy (20)
Rocket two-dimensional kinematics, projectile motion	Lisa (1), John (2), Kevin (3), Jenny (4), James (5), Keisha (6), Diane (7), Josh (8), Andy (9), Bill (10), Rish (11), Tom (13), Yen (14), Brad (15), Ashley (16), Doug (17), Becky (18), Tiki (19), and Cindy (20)
Penguin two dimensional force problem, incline plane, static	Lisa (1), John (2), Kevin (3), Jenny (4), James (5), Keisha (6), Diane (7), Josh (8), Brad (15), Ashley (16), Tiki (19), and Cindy (20)
Loretta two-dimensional kinematics, projectile motion, linear kinematics	Bill (10), Tom (13), and Yen (14)
Two Blocks two-dimensional force problem, dynamic, two body (three different problems) (1) one block hanging, (2) one block on top of another, and (3) two blocks connected by string on incline	Kevin (3), James (5), Josh (8), Andy (9), Bill (10), Rish (11), Jake (12), Tom (13), Yen (14), Ashley (16), and Cindy (20)
Soccer two-dimensional kinematics, projectile motion	James (5), Brad (15), Ashley (16), and Cindy (20)

Note The number following name indicates the order in which they were interviewed

made during the interview in order to provide clarity as to what epistemic strategies (games) were being played

CHAPTER IV

ANALYSIS OF DATA

When this project was planned, it was unclear whether the theoretical framework presented by Tuminaro (2004) or Bing (2008) would be adequate for this study Tuminaro's theoretical framework was developed by observing students in groups that were enrolled in an algebra-based physics course The interviews in this study would be of individuals solving problems with little to no interaction with other students or teaching assistants Bing's (2008) theoretical framework was developed while interviewing students enrolled in upper level physics courses In comparison, this study included algebra-based and calculus-based physics students, and neither group could be classified as upper level physics majors

Because of the differences between this study and the previous ones, it was decided by the researcher that a grounded theory analysis should be conducted to determine a theoretical framework that describes these data

IV 1 TRANSCRIPTION AND CODING

Once the interviews were conducted by the researcher, the audiotapes were transcribed and comments were included from the videotapes by the researcher The audio recording device included digital software with the capability for transcription The researcher used this capability to transcribe the audio tapes Visual cues, such as drawing a picture or labeling a diagram, were added to the transcripts from the videotapes by the researcher From the audiotape alone it was difficult to determine when students were writing equations or drawing pictures The videotape data provided additional information as to how students solved the problems

The transcription process involved many hours of listening and re-listening to the audio tapes The word by word transcription allowed for minute details to be recorded in written form for later analysis This provided detailed, rich data for this study Although sending the audio and video tapes to a transcription company would have saved some time at first, it would not have enabled the researcher to become so deeply familiar with the content of the interviews The exposure allowed for a familiarity with the data that would otherwise not be possible

After the eight interviews were transcribed for the spring 2008 semester, the solutions to the problems were coded by the researcher Coding is the process of categorizing the data and describing the implications of these categories At first, the interview was read and comments were made in the margins At this point a student's recall of how they solved the problem was only used to help identify steps that were not explicit during their problem solving process

Labels were assigned throughout the text by the researcher For instance, if a student wrote out a formula, the label "formula" may be assigned In the next section, a student may manipulate an equation or substitute numbers into the equation A label such as, "manipulate" or "substitute" may be assigned to this section of the interview

During the first reading thirty to forty labels were created from the data A second reading was conducted to reduce the number of labels For example, a decision was made by the researcher to reduce the three labels, 1) "formula," 2) "manipulate," and 3) "substitute" into one label, "equation " The word "equation" became the code or label to represent explicit statement of a formula, algebraic manipulation, or the substitution of numbers to solve for the unknown variable The final three interviews were used to reduce the labels to nine main codes which are presented in Appendix D

IV 2 EPISTEMIC STRATEGIES

During the coding process, the researcher assigned a color to each code as given in Appendix E Once all eight interviews were coded, patterns were identified by the arrangements of the code colors within the transcript Certain groups of colors appeared together in the transcripts These patterns of colors were selectively combined, i e , selective coding, into epistemic strategies or strands of epistemic strategies Each code represented steps that students could take for specific strategies The coding and strategies aligned very closely with the epistemic games from previous research (Tuminaro, 2004, Tuminaro & Redish, 2007)

IV 2 1 PICTURE MAKING

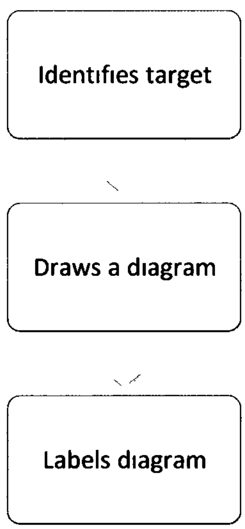
The selective coding produced seven different patterns in the data These groups were marked in each transcript and labeled based on the main category or theme describing it A common grouping of codes involved a picture or diagram and labeling of that diagram An example can be seen in this interview segment with John John was solving the tree problem The tree problem stated During a storm a limb falls from a tree It comes to rest across a barbed wire fence one-fifth of the way between two fence posts that are four meters apart The limb exerts a downward force of 151N on the wire depressing it 0 2 m below the horizontal Find the tension in the section of the wire that is a) shorter and b) longer (Appendix C, #1)

> John states Finding the tension, (reads) Find the tension in the section of the wire that is a) shorter and b) longer Ok, so the first thing I'm thinking of is I draw kind of a fence (draws a horizontal line) a sloppy fence but, um and then I figure out, I go back and read the question (reads) 1/5 of the way between the two fence posts, I have my fence posts (draws 2 vertical lines to signify the fence posts) and then I kind of divide it into 5 sections One, two, (divides the horizontal line into 5 segments), and five, and so 1/5, I find my 1/5 between and the fence posts are 4 m apart so I draw a line and label that The fact that it's 4 m (dimensions the fence and labels 4m) apart and so I have 1/5 and so for that it will be 1/5 So this would be four divided by five (writes 4/5 on diagram for the first section starting from the left), five would be the distance that this one is from This is 1/5 (changes the 4/5 to 1/5) And from the other side it is 4/5 of the way from the fence posts (labels it 4/5 on the diagram for the section on the right) And it exerts, the downward force So I have my force down here (draws a downward pointing line segment at the location of the limb 1/5 of the way from the left side) 151N, (labels the line segment 151N) Creating a depression of 0 2

m Uh, so basically it pushes, it creates a distance of point, it goes down, 2 ah 0 2 m (circles the contact point between limb and fence and labels 0 2 m) I need to find the tension in the section of the wire that is shorter and longer

He started by reading the problem and indicated the unknown, or target, for the problem He indicated that he needed to draw a picture In this case he drew the picture because his instructor had taught him to start the problem with this task He labeled the picture with his given information and then identified the target once the drawing was complete

There are three main steps or moves that form this epistemic strategy from these data (1) Identify target, (2) Draw a diagram or picture, and (3) Label the diagram or picture As shown in Figure 3, John first identified the target, drew a diagram or picture and then labeled the diagram These steps or moves could easily be named Picture Making or Schematic Analysis However, in keeping consistent with Tuminaro's epistemic games, these steps have been defined as Pictorial Analysis



"Finding the tension, (reads) Find the tension in the section of the wire that is a) shorter and b) longer "

"Ok, so the first thing I'm thinking of is I draw kind of a fence "

"The fact that it's 4 m (dimensions the fence and labels 4 m) apart and so I have 1/5 and so for that it will be 1/5 So this would be four divided by five (Writes 4/5 on diagram for the first section starting from the left)"

Figure 3 Schematic diagram of John's moves in the epistemic game Pictorial Analysis

How closely did the epistemic strategy Pictorial Analysis presented here match with the steps defined by Tuminaro? Figure 4 shows a comparison of the epistemic strategy steps between the two results On the left are the steps or moves obtained from the grounded theory analysis in this study and on the right are the steps or moves from Tuminaro's study Only three steps were identified for this study, unlike the four steps presented by Tuminaro Students did not often verbalize a conceptual story based on the spatial relations among the objects Students would normally produce their picture or diagram while reading the problem

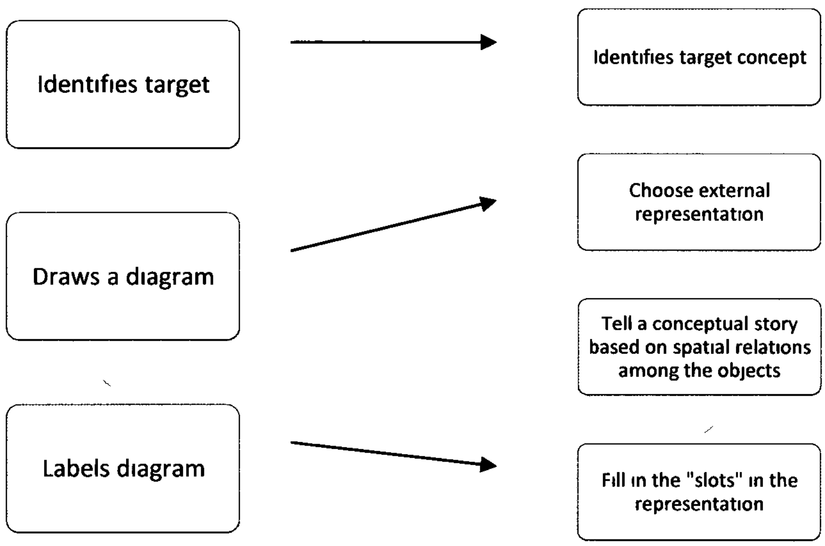


Figure 4 Schematic diagram comparing the moves between the epistemic game Pictorial Analysis (ODU) and Pictorial Analysis (Tuminaro, 2004)

IV 2 2 STORY TELLING

Pictorial Analysis was usually the first strategy observed after the student read the problem Once a student completed his/her diagram, they could complete any combination of steps or strategies One such strategy involved Story Telling James had been asked to solve the following problem A penguin is sliding down an icy incline at a constant speed of 1 4 m/s The incline slopes at an angle of 6 9 degrees What is the coefficient of friction of the incline (Appendix C, #3)?

> James's response What is the coefficient of friction of the incline? Well the coefficient of friction, the coefficient of friction of the incline is nothing because the speed isn't changing so there's no external force acting on the penguin That and it's ice and even ice and penguins don't have a very high coefficient of friction between each another

James did not solve this problem by using formulas and calculations He gave his incorrect answer based on the story he was telling Figure 5 shows the schematic diagram of James's moves for this strategy, Story Telling This epistemic strategy is similar to Tuminaro's Physical Mechanism game

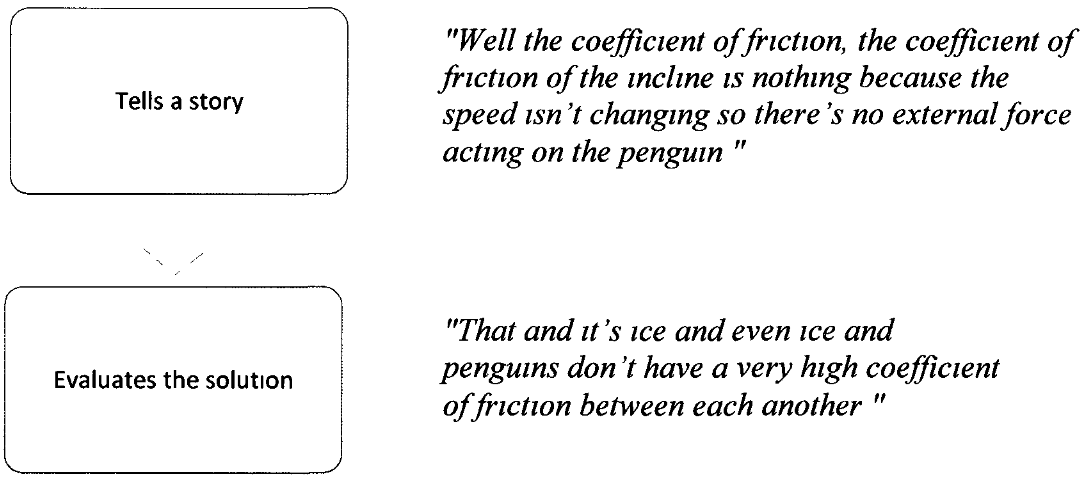


Figure 5 Schematic diagram of James's moves in the epistemic game Story Telling

In Figure 6, the steps for Story Telling were compared with Physical Mechanism Game In this strategy, students developed a conceptual story to solve the problem The interesting result is that no mathematics is used to derive a solution to the problem The student (1) tells a story and (2) analyzes the story The analysis for this game could be a complex evaluation of the stated story or it could simply be a statement of completion such as "That's my answer " For this strategy, there is no difference in the epistemic strategy that emerged from the data in this dissertation and the Physical Mechanism Game presented by Tuminaro The moves are identical

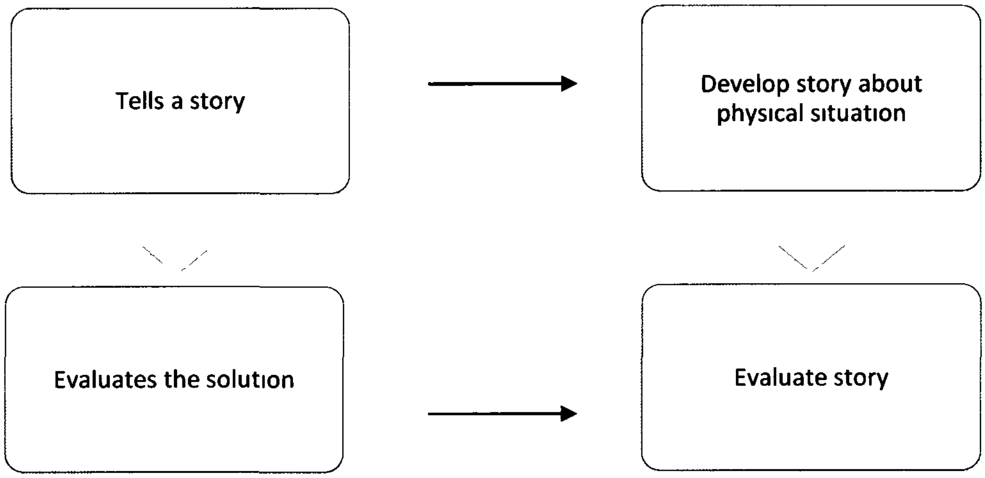


Figure 6 Schematic diagram comparing the moves between the epistemic strategy Story Telling (ODU) and Physical Mechanism Game (Tuminaro, 2004)

IV 2 3 LISTMAKING

Listmaking is something that many people do at work or at home Sometimes, students are observed making a list of the given and unknown quantities Information is parceled into groups to make sense of the data In this passage below, Cindy records her given quantities as she starts the problem (Appendix C, #2)

> Cindy states Okay, a rocket is fired at a speed of 75 0 m/s from ground level, at an angle of 60 0° above the horizontal The rocket is fired toward an 11 0 m high wall, which is located 27 0 m away By how much does the rocket clear the top of the wall? Okay, velocity equals 75 0 m/s (writes v = 75 0 m/s) My angle is 60 0, (writes $\theta = 60\ 0°$) and then you have another height so 11 0 m high (writes $h = 11\ 0$ m) and then the horizontal distance is 27 0 m (writes $x = 27\ 0$ m) Okay so how much, by how much does the rocket clear the top of?

In this interview segment three steps can be observed As shown in Figure 7, she (1) reads the problem, (2) writes the given information and then (3) writes or identifies the target (the unknown)

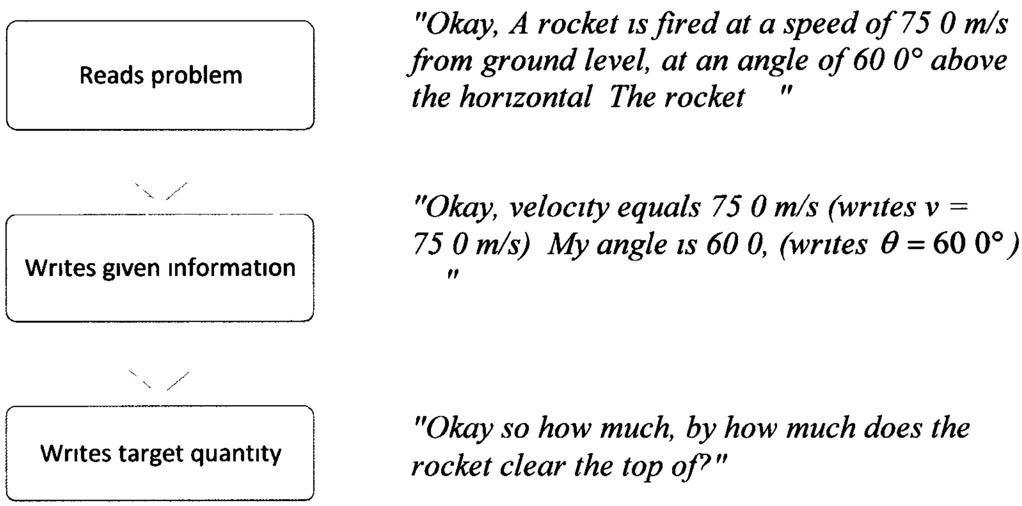


Figure 7 Schematic diagram of Cindy's moves in the epistemic strategy Listmaking

If the list is incorporated into their schematic or drawing, the list is then considered a "label" and is then identified as a move in Pictorial Analysis If the list can stand by itself in the solution, it is identified as the epistemic strategy Listmaking This epistemic game was first defined by Collins and Ferguson (1993)

In Figure 8, the steps for Listmaking are compared with List-Making In this strategy, students developed a list of the given information The student (1) reads the problem, (2) writes the given information, and (3) writes the unknown or target quantity This strategy is specific to physics or math problems For List-Making as proposed by Collins and Ferguson (2003), the moves are more general and can be applied to any situation

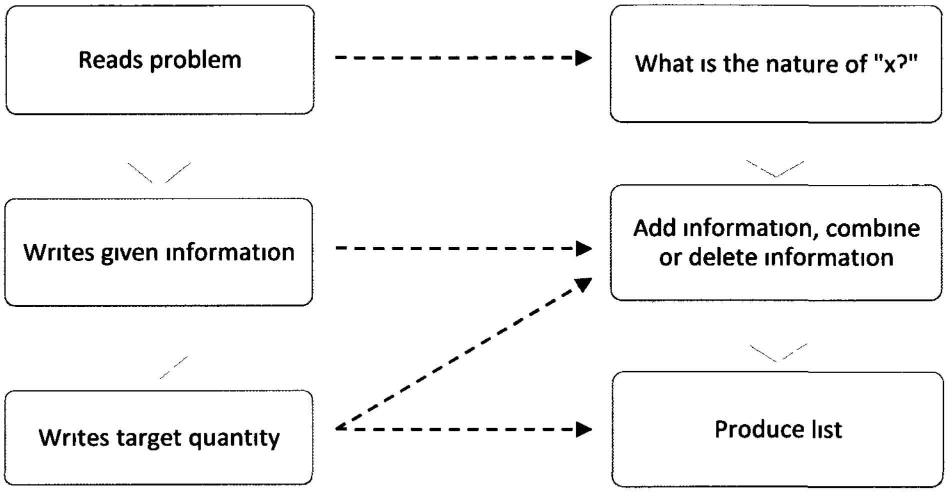


Fıgure 8 Schematıc dıagram comparıng the moves between the epıstemıc strategy Lıstmakıng (ODU) and Lıst-Makıng (Collıns & Ferguson, 2003)

IV 2 4 PLUG AND CHUG

"Plug and Chug" descrıbes problem solvıng strategıes that ınvolve takıng a formula, pluggıng the gıven ınformatıon ınto the formula, and then wrıtıng or statıng the answer Lıke John (2), Ashley (16) has been asked to solve the tree problem (Appendıx C, #1) Here ıs a segment of an ınterview whıch shows an example of Plug and Chug

Ashley I don't know the angle I can figure out the mass of the tree because $F = ma$ So 151 N ıs equal to the mass tımes the acceleratıon whıch ıs 9 8 m/s^2, so 151 dıvıded by 9 8 wıll gıve me the mass of the tree, ıs 15 408 kg But we don't know, below the horızontal, we don't know the ınıtıal heıght above the ground We only know the change ın the heıght So we got to do, we are tryıng to find thıs angle rıght here so that can be the 0 2 so we know that's 0 2 We can do by, by, whatever that theorem ıs A squared B squared equals C squared

Ashley identified a target but she did not activate resources that would allow her to solve for the angle The resource could be a trigonometry formula or vector algebra knowledge necessary to solve this problem She instead decided that she had enough information to solve for the mass of the tree Figure 9 shows a schematic of her moves in this epistemic strategy Plug and Chug She had implicitly made a list in that she referred to information provided in the problem She identified a target In this case the target was the mass She found an equation that related her target to the given information, $F = ma$, and then substituted the given information into the equation Ashley then determined that she had not solved for the primary target the angle She repeated this process in order to solve for the primary target

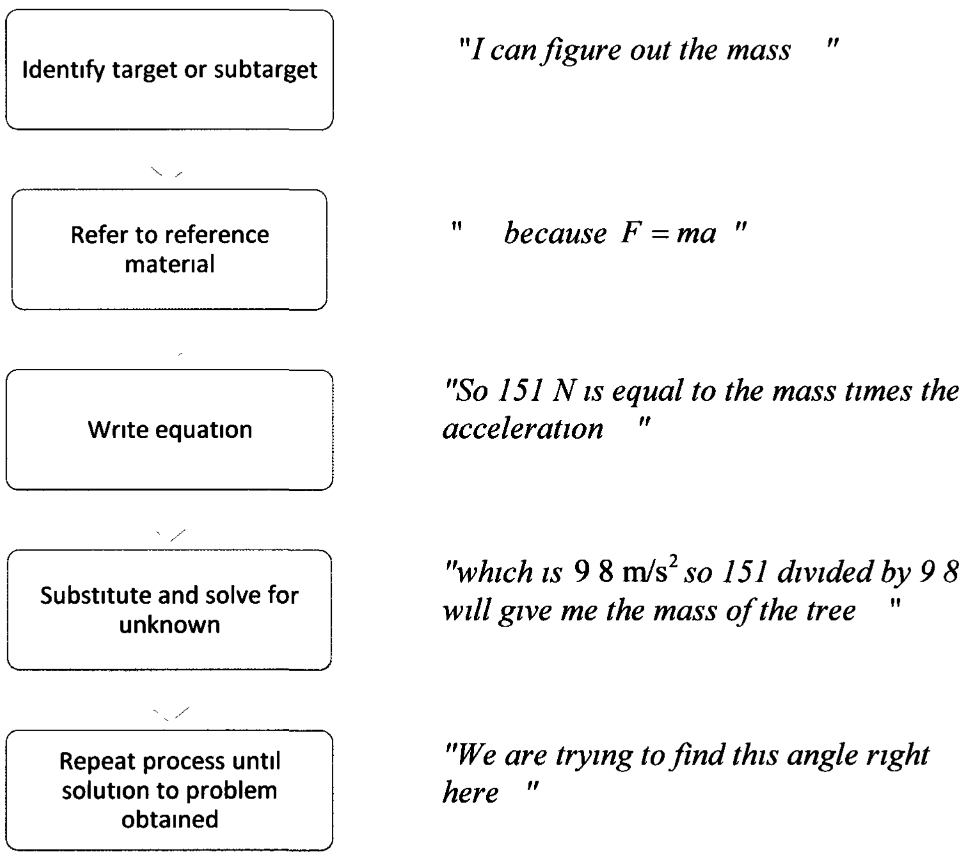


Figure 9 Schematic diagram of Ashley's moves in the epistemic strategy Plug and Chug

The epistemic strategy Plug and Chug has a similar structure to the epistemic game Recursive Plug and Chug presented by Tuminaro as shown in Figure 10 In these data, the students did not explicitly identify a relationship between the variables in the equation and the variables given in the problem They may have assessed this relationship just by writing the equation The dashed lines show that the moves in either strategy may be the same move There is also a chance that they will not be the same For instance, in the third step, substituting their given information into the equation or identifying that they do not have enough information, would be sufficient to show that they had determined which of the other quantities were known However, they may write an equation without ever determining their other known quantities

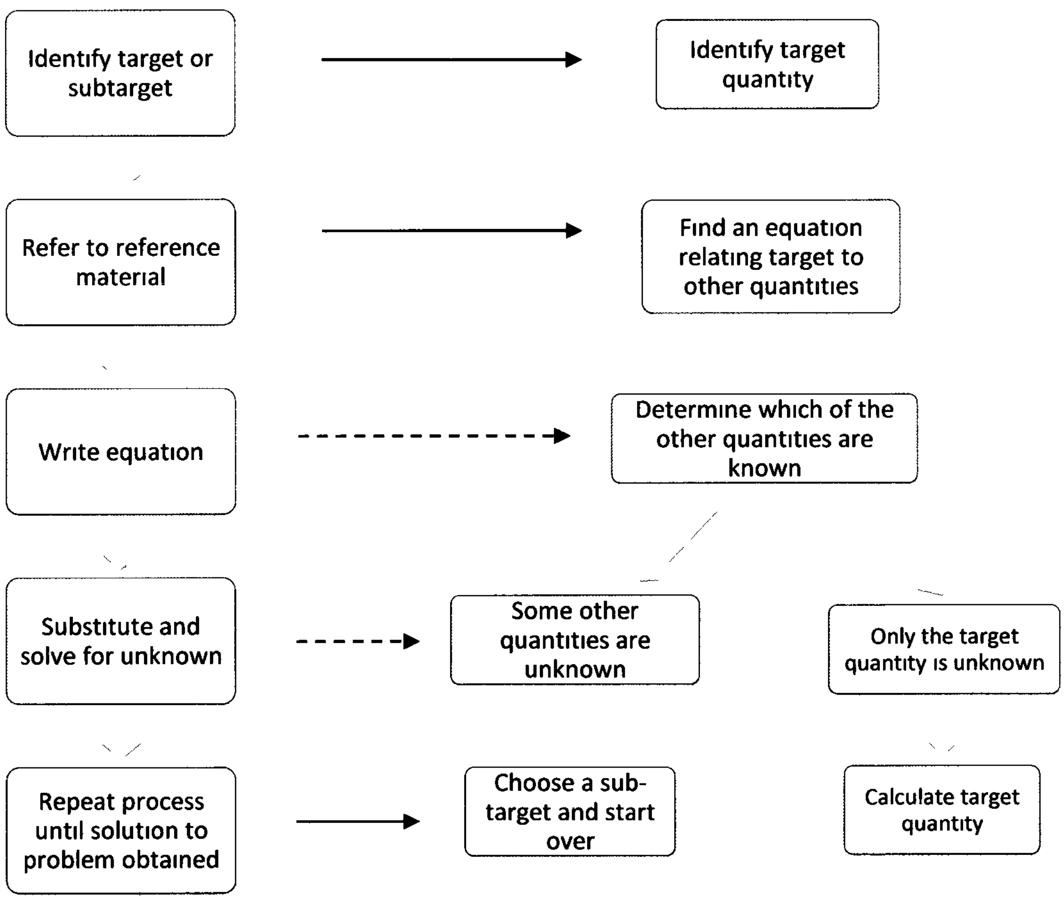


Figure 10 Schematic diagram comparing the moves between the epistemic strategy Plug and Chug (ODU) and Recursive Plug and Chug (Tuminaro, 2004)

IV 2 5 TRANSLITERATION TO MATHEMATICS

Transliteration to Mathematics is an epistemic strategy that is often seen with novice problem solvers with little or no conceptual understanding of the material The student may start with Listmaking or move directly into Transliteration to Mathematics In this interview segment, Jenny has been asked to solve for the coefficient of friction for a penguin sliding down an icy incline (Appendix C, #3) She has already completed Pictorial Analysis

> Jenny coefficient of friction (reads through notes), um, ok so I guess it would be kinetic friction, um (reading from textbook) " the normal force is less than the weight, - when you divide the first of these equations by the second we find μ_k was the sine of theta divided by the cosine of theta which is the tangent of theta " Ok so (Reads from textbook), " The forces on the toboggan are identified by their magnitudes - its weight, normal force and frictional components of the contact force exerted on with constant velocity and is therefore in equilibrium " Ok so, I don't understand why that, how that works μ_k and equals W sine theta so, sum of the forces, you divide those two sides so then, oh ok, so then if you divide this side and this side so that's going to give me μ_k equals sine theta over cosine which is going to be tangent theta (Writes "$\mu_k = \sin\theta/\cos\theta = \tan\theta$") so μ_k is the tangent (Writes "$\mu_k = \tan$") Ok so 6 9 (Writes "6 9" next to tan), 6 9 (plugs into calculator), take the tangent, ah no, 6 9 tangent, so μ_k equals 0 121, (Writes "μ_k = 0 121" and boxes it) Ok I'm done

First, Jenny found an example in the textbook In this case it was a toboggan that slide down an icy slope at a constant velocity This problem was identical to the one given to her in the interview Once she found the problem she identified the equation she needed to use to solve her problem Jenny then substituted her numbers into this equation and gave her final answer As shown in Figure 11, Jenny took the following steps to solve the problem (1) identify a target, (2) refer to reference material, (3) write equation given in reference material, (4) substitute given information in current problem into target solution, and (5) solve for target

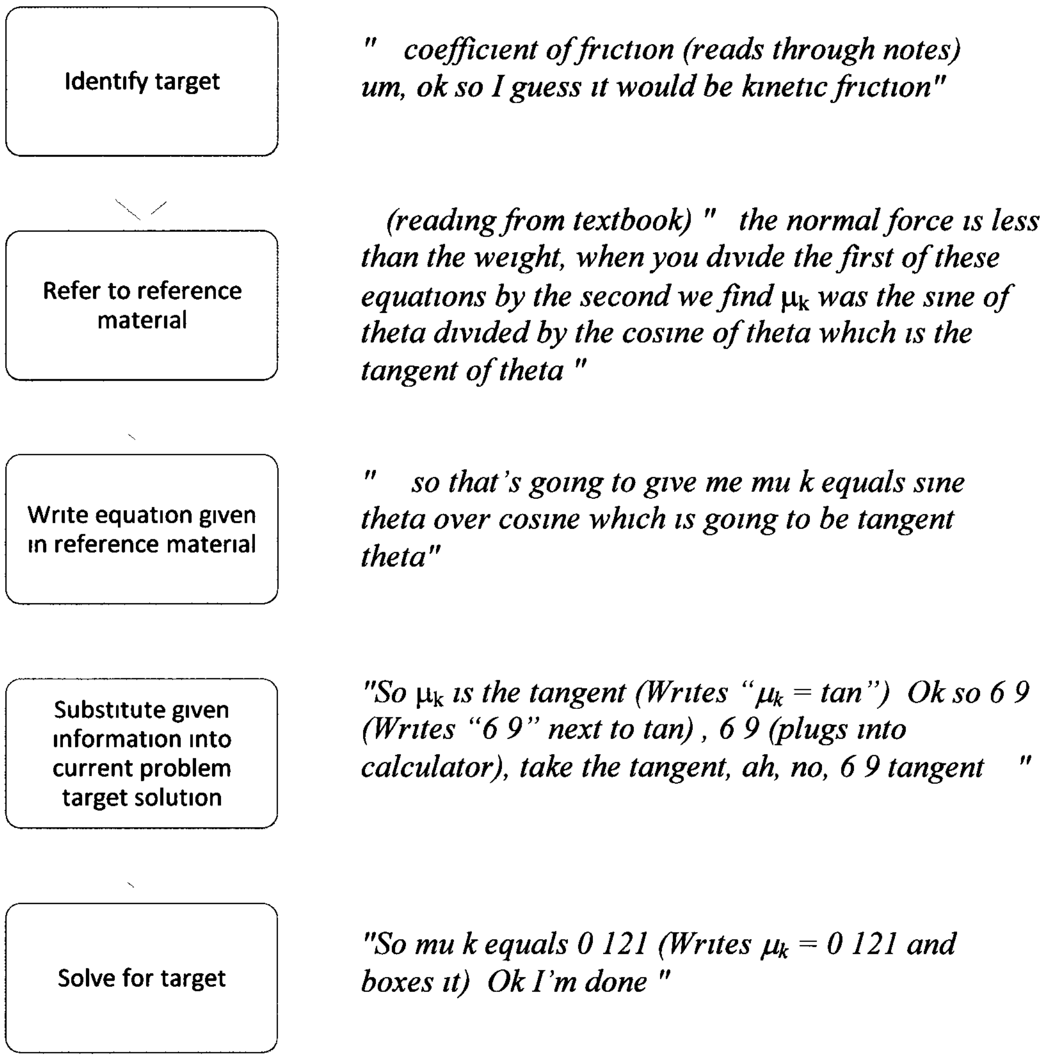


Figure 11 Schematic diagram of Jenny's moves in the epistemic strategy Transliteration to Mathematics

The key difference between Recursive Plug and Chug and Transliteration to Mathematics is the source of the equation In Transliteration to Mathematics the textbook or lecture notes provides an example that can be used to help the student find a solution As seen in the interview with Jenny, she found a problem similar to the one she had been asked to solve The toboggan problem involved a group of people riding in a toboggan that was traveling down a snowy incline at a constant velocity The problem

Jenny was asked to solve would yield the same results as the toboggan problem She used the solution given in the toboggan problem to help her derive a solution to the penguin problem

As shown in Figure 12, the overall process was very similar to the results from Tuminaro's study However, there were slight differences The final step presented by Tuminaro, *Evaluate Mapping*, was not explicitly observed in this study Our students accepted the mapping and continued with the solution by using another strategy or they stated their final answer They did not question whether this strategy was a good approach to solve the problem Sometimes the statement of the student's answer was an affirmation of the mapping process and so a dashed arrow is used to indicate that solving for the target may include an evaluation of the mapping

IV 2 6 MEANING TO MATHEMATICS

Another epistemic strategy that appears most often with the (calculus based) University physics students is called Meaning to Mathematics This strategy was different than the others in that the student appeared to have a clear path they needed to follow in order to solve the problem Students appeared to already have access to resources they needed to solve the problem A student using this strategy will (1) identify their target, (2) tell a story or give a verbal description of some type of method they must follow to solve the problem, (3) write an equation that represents the story, (4) solve for the unknown or target, and (5) evaluate their solution

We revisit the interview with James to illustrate Meaning to Mathematics In this next interview segment, James was solving the soccer ball problem The problem states A soccer player kicks the ball toward a goal that is 29 5 m in front of him The ball leaves his foot at a speed of 19 0 m/s and an angle of 32 0 degree above the ground Find the magnitude and direction of the velocity of the ball when the goalie catches it in front of the net (Appendix C, #5)

He already reasoned that the initial and final velocities should have the same magnitude if the ball starts and ends at the same *y*-position He then decided to solve for the final *y* position

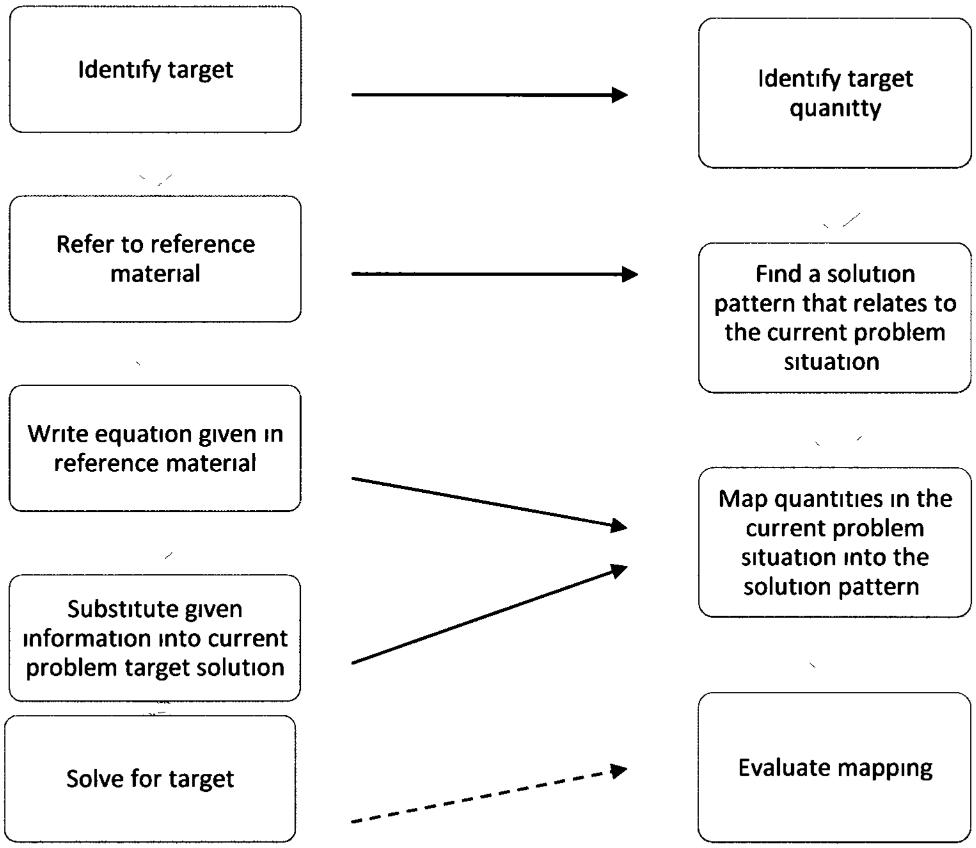


Figure 12 Schematic diagram comparing the moves between the epistemic strategy Transliteration to Mathematics (ODU) and Transliteration to Mathematics (Tuminaro, 2004)

James really what I'm trying to do with this is see if my position at y, ah, if my position at r is zero cause then I'll know if the trajectory of my ball toward the 32° angle And I add on the last part the initial velocity in the y is 19 m/s times the sine of 32°, 10 0, 1 m/s times 16 1 m/s divided by 29 5 m (writes "= (-9 81 m/s^2)(16 1 m/s / 29 5 m)^2 + (10 1 m/s)(16 1 m/s / 29 5 m)"), now let's see what that does, (calculator) (-9 81) times 16 1 divided by 29 5 squared equals, divided by 2, equals (-1 46) (writes plus "= -1 46") 10 1 meters per second times 16 11 divided by 29 5 equals 5 52, (writes "+ 5 52") so (calculator) (-1 46) plus 5 52 = 4 06 m (writes "= 4 06 m") So it's 4 06 m above the ground and since that trajectory turned straight around went back down I'm going to assume that when the goalie caught it, 4 06 m, tall guy

As shown in Figure 13, James first started the problem by identifying the target It is clear from his statement, "see if my position at *r* is zero" that something made him think about solving for the *x* position in this problem After he identified the target he stated why he felt he needed to solve for the position at "*r* " He wrote the equation then substituted his numbers into the equation and solved for the height of the soccer ball when it was caught by the goalie He evaluated his solution and finished by stating, "4 06 meters, tall guy "

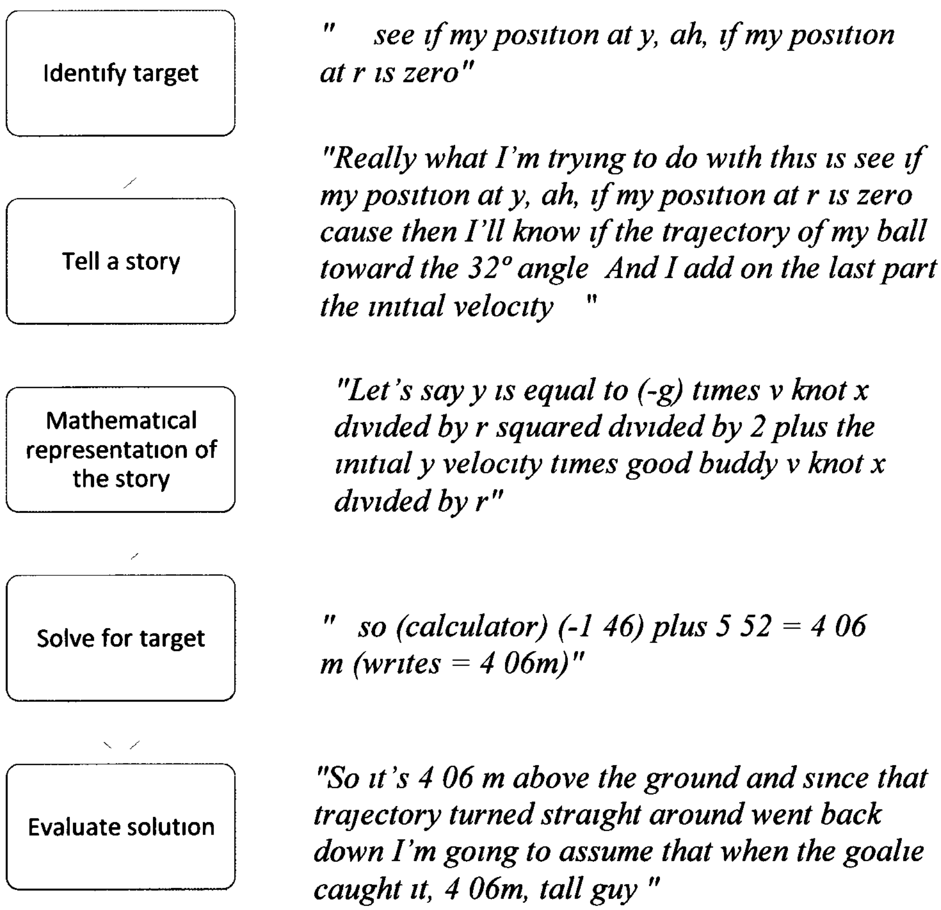


Figure 13 Schematic diagram of James's moves in the epistemic strategy Meaning to Mathematics

Figure 14 shows a comparison between Meaning to Mathematics described in Figure 13 and the moves of Mapping Meaning to Mathematics presented by Tuminaro Our research showed the students identifying a target, something they must obtain in order to solve the problem The second and third steps of Tuminaro's Mapping Meaning to Mathematics have been combined into a single step which involved a mathematical representation of the story Solving for the target could fall under the step, manipulate symbols, and both strategies finished with an evaluation of either the story or the solution

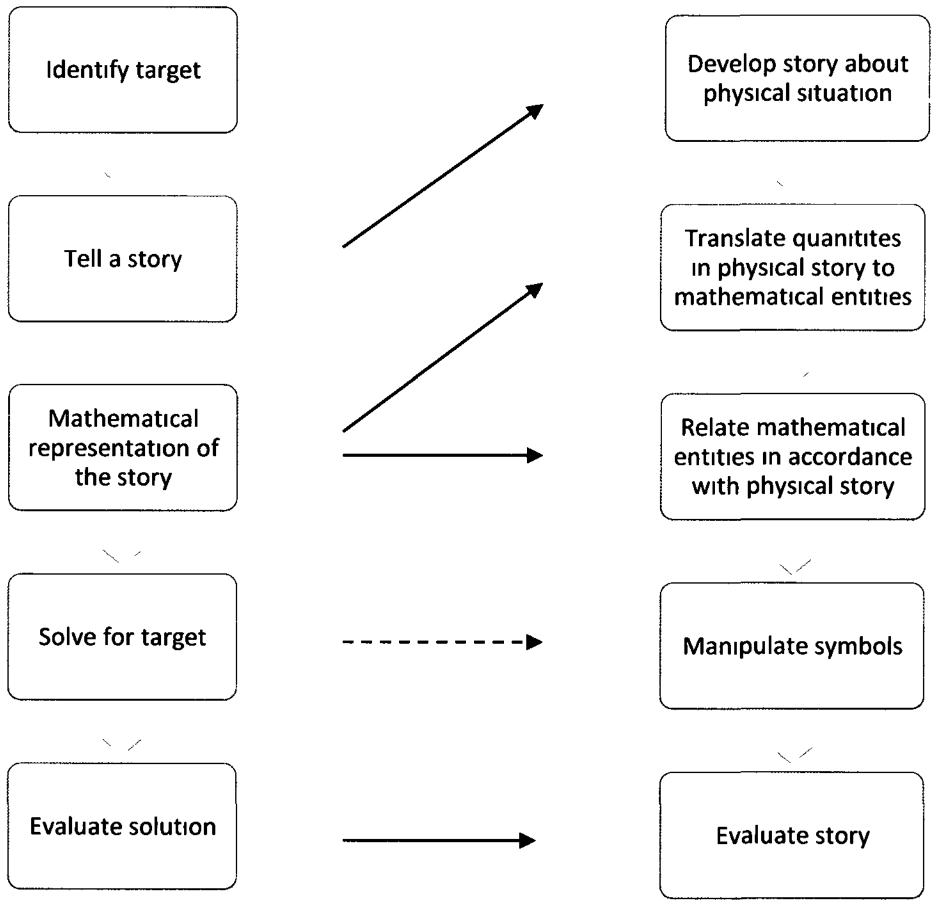


Figure 14 Schematic diagram comparing the moves between the epistemic strategy Meaning to Mathematics (ODU) and Mapping Meaning to Mathematics (Tuminaro, 2004)

IV 2 7 MATHEMATICS TO MEANING

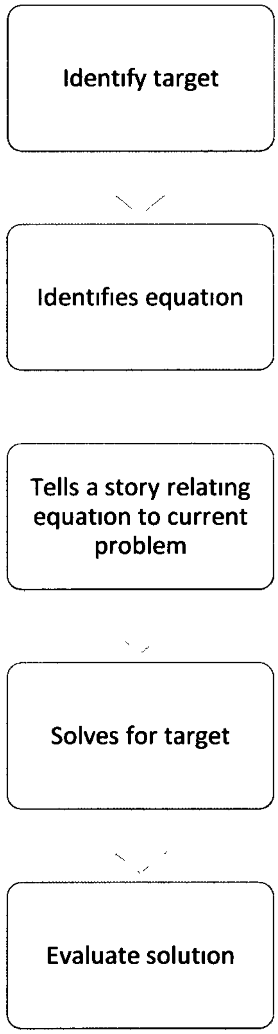
There is one final epistemic strategy that was identified in this study, Mathematics to Meaning In this strategy the student started with an equation and later describes how the equation related to the problem through a story Mathematics to Meaning is different than Meaning to Mathematics in that mathematics is presented first and then a qualitative description is given by the student

Bill had been asked to solve a problem involving two blocks attached to one another He was asked to solve for the force necessary to cause the blocks to move at a constant velocity The problem states Block A weighs 1 40 N and block B weighs 4 20 N The coefficient of kinetic friction between all surfaces is 0 30 Find the magnitude of the horizontal force $\vec{F}$ necessary to drag block B to the left at constant speed if A and B are connected by a light, flexible cord passing around a fixed, frictionless pulley (Appendix C, #6) Here is a segment of that interview

> Bill And I'm looking for the force of B in that direction So the combined force of gravity is 4 2 oops (uses calculator) 5 6, and the force of friction is going to be equal to 0 3 X 5 6 (uses calculator) okay that force of friction a net force of tension is going to be added together to give me an overall force that I have to overcome to move that block so I'm going to add the force of friction on block B to the tension from the wire which is the tension exerted by block A just going to be 1 68 + 0 42 (uses calculator) going to give me a force of friction of 2 1 Newtons So to overcome that I just need to have, be able to 2 1 N would have to be the force I'd have to get to initially move it and maintain a constant speed

At first Bill identified the target he was, "looking for the force of B in that direction " He then identified the mathematical process he would use to solve for the target He solved for the frictional force and then told a story and solved for the force necessary to overcome the friction that caused the block to maintain a constant speed Once completed, he evaluated his solution by stating the answer This is shown in more detail in Figure 15

At first glance this may appear as Plug and Chug followed by Meaning to Mathematics, but, Bill never deviated or paused as he solved the problem There was no shift in attention that would make us believe that he had switched from one strategy to another This was one fluid movement of thought as Bill solved this problem



"I'm looking for the force of B in that direction "

"and the force of friction is going to be equal to 0 3x5 6"

"Okay that force of friction, a net force of tension is going to be added together to give me an overall force that I have to overcome to move "

" the tension exerted by block A just going to be 1 68+0 42 (uses calculator) going to give me a force of friction of 2 1 Newtons"

"So to overcome that I just need to have, be able to 2 1 N would have to be the force I'd have to get to initially move it and maintain a constant speed "

Figure 15 Schematic diagram of Bill's moves in the epistemic strategy Mathematics to Meaning

Mathematics to Meaning is compared to Tuminaro's Mapping Mathematics to Meaning in Figure 16 In this study, students were providing numerical answers to problems The step, Solves for Target, was a necessary one for students It may be that this step was not always necessary in other environments or by students in group activities This step seemed to be the only difference between Mathematics to Meaning and Mapping Mathematics to Meaning

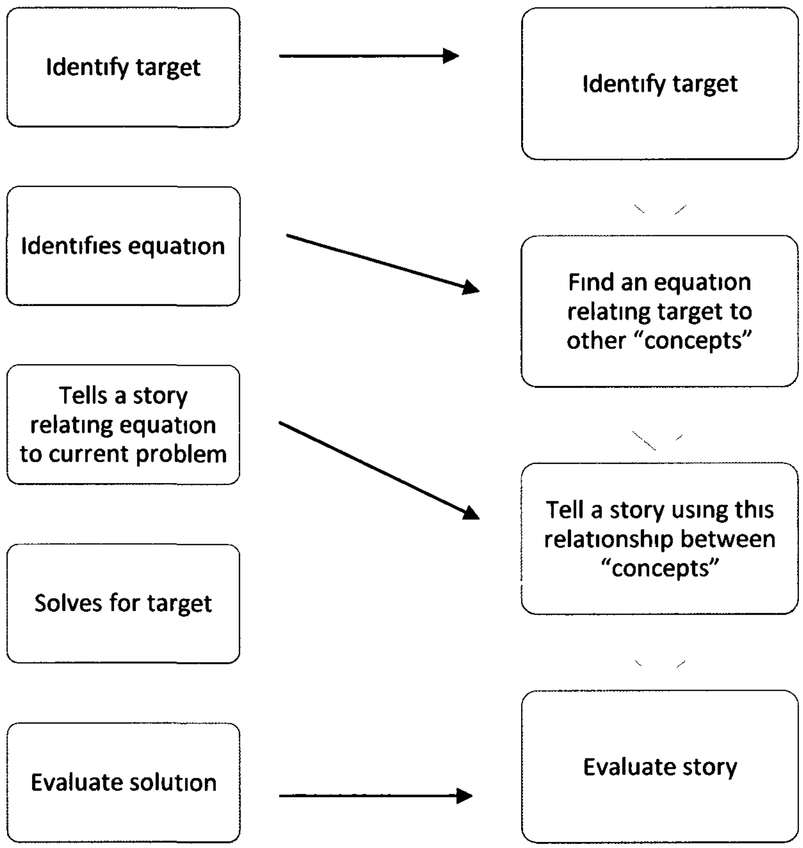


Figure 16 Schematic diagram comparing the moves for the epistemic strategy Mathematics to Meaning (ODU) and Mapping Mathematics to Meaning (Tuminaro, 2004)

Students did not always complete an epistemic strategy when solving problems Sometimes in the middle of a strategy, they would stop and begin a new one The colors in the coded data would change without an end to their strategy or game When students only followed two or three steps but did not complete the strategy (game), the data were then labeled as a strand of that epistemic strategy If a student had a clear idea of how to approach the problem, they finished the steps of the epistemic strategy they chose to initiate

IV 3 FRAMING

Once the epistemic strategies and strands were identified, the frames could be identified The framing is the activation of information the student needs to solve the problem There are three frames that Tuminaro (1997) identifies for his six epistemic games Since the epistemic strategies identified through the analysis of these data are closely aligned with those found by Tuminaro in his study, the same frames were used in this study

The three frames are shown in Figure 17 Each frame has two or three epistemic strategies associated with it Listmaking has been placed in the qualitative sense-making frame It is another way for students to organize the problem so that they can solve for any unknown quantities It may be argued that Listmaking should fall under rote-problem solving since it is one step in the strategy Plug and Chug However, in this study, Listmaking occurred throughout the problem solving process and did not appear only prior to the strategy Plug and Chug

As expressed by Tuminaro (2007), frames can indicate the level of problem solving Students solving problems in the quantitative sense making frame are working with more intellectually complex epistemic strategies Students solving problems in the rote problem solving frame will solve problem in a step by step fashion and may not understand the conceptual aspects of the problem

Framing for each problem was determined by the epistemic strategy or epistemic strand used by the student The framing gave more information about the problem solving process It may be assumed that the strand would be evidence of a switch in framing by the student This was not always the case The strands could have been from the inability of the student to activate new resources to help with the problem solving process Once the epistemic strategies and framing were determined from the data an inter-rater reliability test was conducted

<table>
<tr><th colspan="6">Qualitative Sense-Making Frame</th></tr>
<tr><td colspan="2">Pictorial Analysis</td><td colspan="2">Story Telling</td><td colspan="2">Listmaking</td></tr>
<tr><th colspan="6">Quantitative Sense-Making Frame</th></tr>
<tr><td colspan="3">Meaning to Mathematics</td><td colspan="3">Mathematics to Meaning</td></tr>
<tr><th colspan="6">Rote-Problem Solving Frame</th></tr>
<tr><td colspan="3">Plug and Chug</td><td colspan="3">Transliteration to Mathematics</td></tr>
</table>

Figure 17 Theoretical Framing with epistemic strategies

IV 4 INTER-RATER RELIABILITY

An inter-rater reliability test is a statistical test which tells the level of agreement between different raters It gives a numerical scores showing consensus between the ratings The Cohen's Kappa calculation is a statistical test which tells you the level of agreement between two raters with corrections for chance agreements (Wood, 2007) Cohen's Kappa is defined as

$$\kappa = \frac{p_a - p_r}{1 - p_r}$$

where p_a is the observed level of agreement and p_r is the estimated agreement due to chance The observed agreement is the proportion of the agreement between the two raters The estimated agreement is the proportion of the agreements that would be expected by chance between the two raters

Cohen's Kappa can range between -1 0 and 1 0 A Kappa of -1 0 would show two raters consistently disagreed A Kappa of 1 0 would show a perfect agreement between the two raters A Kappa of 0 0 shows a random agreement/disagreement between the raters For research purposes, a good value of kappa should be at least 0 60 or 0 70 An excellent value of Kappa is greater than 0 74 (Wood, 2007, Streiner and Norman, 1994)

For this project, an acceptable value was set at greater than 0 74 (Streiner and Norman, 1994)

Four interviews were selected for the inter-rater reliability test The four interviews were transcribed and then independently coded by two different researchers (Hing-Hickman and Moore) The epistemic strategies were assigned a numerical value as seen in Table 2 The strands were assigned an "s " The numerical codes were used to help simplify the data in Table 2 An "s" was placed next to the number to indicate an epistemic strand Reading the problem was not considered an epistemic strategy but was coded by both researchers and was added to the Cohen's Kappa calculation for the inter-rater reliability test

Table 3 shows the codes for both researchers and each interview Differing codes are bolded and a star is placed next to the code that is changed during the discussion between the two researchers An 8 X 8 matrix was created with the data provided from Table 3 See Appendix F Strands were categorized under the main epistemic strategy for the Cohen's Kappa calculation The matrix was used to calculate Kappa before and after discussion An inter-rater reliability of 0 900 was achieved before discussion After discussion, Kappa was 1 00 The two researchers agreed completely after the discussion

Table 2

Inter-rater reliability data codes defined for Cohen Kappa calculation

Epistemic Strategy	Number Assignment
Read the problem	1
Pictorial Analysis	2
Story Telling	3
Listmaking	4
Plug and Chug	5
Transliteration to Mathematics	6
Meaning to Mathematics	7
Mathematics to Meaning	8
Strand of epistemic strategy	s

Table 3

Inter-rater reliability data for all four interviews

Interview 11	before discussion		after discussion	
Problem name	Researcher 1	Researcher 2	Researcher 1	Researcher 2
tree	2	2	2	2
	7	7	7	7
	5	5	5	5
	4	4	4	4
	5 s	5 s	5 s	5s
	4	4	4	4
	5	5	5	5
	5s	5s	5s	5s
rocket	2	2	2	2
	2s	2s	2s	2s
	5	5	5	5
two block	1	1	1	1
	3s	3s	3s	3s
	4	4	4	4
	5s	5s	5s	5s
	1	1	1	1
	4	4	4	4
	7s	7s	7s	7s
	2s	2s	2s	2s
	7s	***5**	7s	7s
	7	7	7	7
	7	7	7	7

Table 3 (Continued)

interview 12	before discussion		after discussion	
	Researcher 1	Researcher 2	Researcher 1	Researcher 2
tree	1	1	1	1
	2	2	2	2
	5s	5s	5s	5s
	6s	***5s**	6s	6s
	2	2	2	2
	6s	6s	6s	6s
	5	5	5	5
	4s	4s	4s	4s
	2s	2s	2s	2s
	2s	2s	2s	2s
	2s	2s	2s	2s
	7	7	7	7
	7s	7s	7s	7s
	7	7	7	7
	7s	7s	7s	7s
	7	7	7	7
	6	6	6	6
rocket	1	1	1	1
	2	2	2	2
	3	3	3	3

Table 3 (Continued)

interview 12	before discussion		after discussion	
	Researcher 1	Researcher 2	Researcher 1	Researcher 2
two block	1	1	1	1
	5s	***6s**	5s	5s
	5s	***6s**	5s	5s
	7	7	7	7
	7	7	7	7
interview 17				
tree	1	1	1	1
	2	2	2	2
	***5**	**6**	6	6
	5s	5s	5s	5s
rocket	1	1	1	1
	2	2	2	2
	7	7	7	7
interview 18				
tree	1	1	1	1
	2	2	2	2
	6s	6s	6s	6s
	6s	6s	6s	6s
rocket	1	1	1	1
	6s	6s	6s	6s
	5s	5s	5s	5s
	6s	6s	6s	6s
	6s	6s	6s	6s
	6s	6s	6s	6s

Note * indicates a difference of coding before discussion

IV 5 IDENTIFYING EPISTEMIC STRATEGIES AND FRAMES

Once all the interviews were coded and epistemic strategies and frames were identified, the time each student spent on each epistemic strategy was recorded Table 4 shows the data for Lisa's solution to the tree problem This data also included the time taken by the student to read the problem Reading the problem is not an epistemic strategy but was included in the analysis Some students went back to read the problem several times during the solution The data were then presented in a graphical format to identify patterns in students' solutions Each solution involved the epistemic strategies, epistemic strands and the time for each strategy

Table 4

Interview 1 (PHYS 111N) Tree Solution

Strategy	Line Number	Start Time	End Time	Total Time per Strategy	Total Time
Read Story	(16-19)	8 39	9 04	0 25	0 25
Pictorial Analysis	(19-38)	9 04	11 02	1 58	2 23
Plug and Chug	(38-40)	11 02	11 26	0 24	2 47
Pictorial Analysis strand	(40-45)	11 26	11 54	0 28	3 15
Transliteration to Mathematics strand	(45-46)	11 54	12 08	0 14	3 29
Pictorial Analysis	(46-51)	12 08	12 40	0 32	4 01
Transliteration to Mathematics Strand	(54-57)	12 40	13 22	0 42	4 43
Pictorial Analysis	(57-63)	13 22	13 59	0 37	5 20
Meaning to Math strand	(63-66)	13 59	15 13	1 14	6 34

IV 6 SUMMARY

In this chapter, the researcher discussed the results from the grounded theory study conducted on these data Seven epistemic strategies were identified It was interesting to see that six epistemic strategies showed a close comparison to those epistemic strategies identified by Tuminaro The fact that the results were so similar leads to the strength of Tuminaro's study and the validity of this research One epistemic strategy, Listmaking was similar to the epistemic game List-making identified by Collins and Ferguson (1993)

Not all interviews showed all moves in an epistemic strategy Some students completed some but not all of the steps in epistemic strategies These fragments of epistemic strategies were called strands The epistemic strategies and strands were used to show the problem solving strategies of the students interviewed in this project

A Cohen's Kappa inter-rater reliability test was performed and showed 0 90 correlation between the two raters before discussion After discussion Kappa was 1 0 Both Kappa values are above the 0 80 acceptable value

In Chapter V, the results of the epistemic strategy analysis is presented Correct and incorrect solutions are shown for each problem Frames are identified for each problem A comparison is made between the algebra-based and calculus-based solutions

CHAPTER V

RESULTS

At the beginning of the spring and fall semester in 2008, students were administered a vector assessment test developed by Nguyen and Meltzer (2003) at Iowa State University The purpose of this vector assessment was to determine the vector knowledge that students brought into the classroom All students enrolled in the algebra-based physics course (PHYS 111N), the Honors College calculus-based physics course (PHYS 226N), and the calculus-based physics course (PHYS 231) were administered the assessment during their first laboratory session However, one of the interviewed students did not take the vector pre-assessment survey The assessments for the other nineteen students in this study were graded and the results are shown in Figure 18

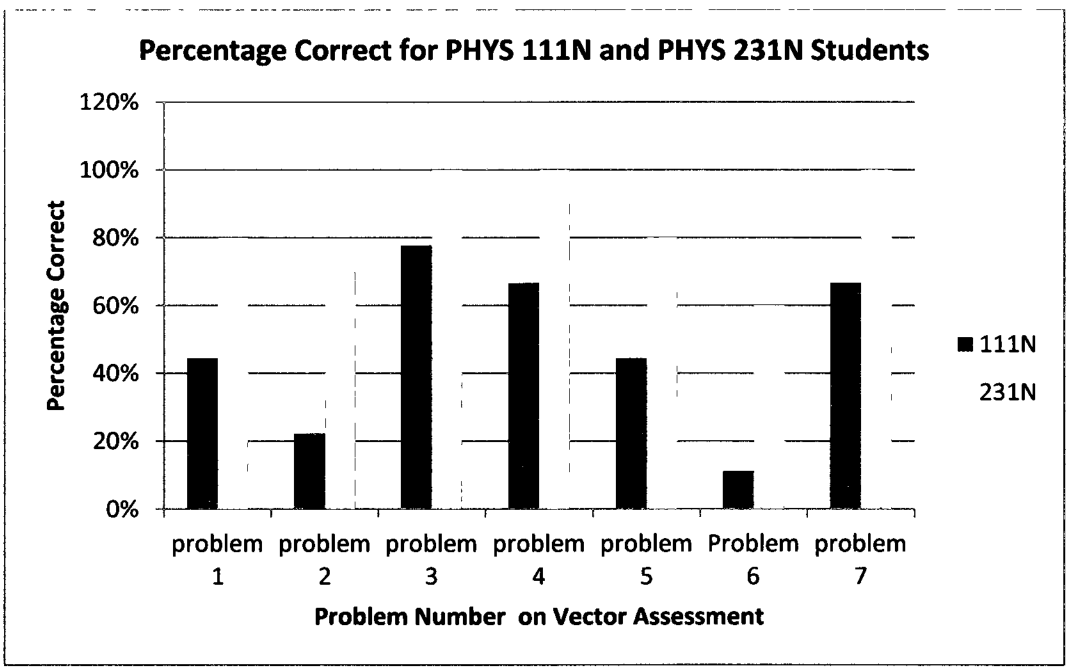


Figure 18 Percentage correct versus problem number for vector pre-assessment survey PHYS 111N (9 students) and PHYS 231N/226N (10 students)

Students enrolled in the calculus-based course (PHYS 231N) had a higher percentage correct for each problem than students enrolled in the algebra-based course Students in the calculus-based course usually have more mathematical training in vector algebra either through pre-requisite math courses or enrollment in other physics or engineering courses which cover vector algebra Students enrolled in algebra-based physic course (PHYS 111N) are only required to take a general algebra course Students who take only the minimal math courses required may have little or no vector algebra exposure prior to enrollment in PHYS 111N

V 1 SOLUTIONS

The results for each student on the physics problems and on the vector pre-assessment survey are shown in Table 5 Clearly, a higher score on the vector pre-assessment survey did not necessarily indicate ability for successful problem solving Two students in PHYS 231N, Diane (7) and Josh (8), completed the pre-assessment survey with one hundred percent correct and yet were only able to solve one interview problem correctly These two interviews took place toward the end of the semester The time of the interview could have been a factor affecting these data

Jenny (4) was enrolled in the algebra-based course and scored higher than average on this assessment She was able to solve more problems successfully than the other algebra-based students that participated in this study Further investigation showed she had completed PHYS 231N prior to enrollment in PHYS 111N Jenny and Brad (15) were the only two PHYS 111N students able to solve any of the problems correctly Brad was able to solve one problem correctly and Jenny was able to solve all the problems correctly Jenny and Brad both scored above fifty percent on the vector pre-assessment survey

Students scoring below fifty percent on the vector pre-assessment were unable to solve any physics problems correctly Even if these students understood the concepts, they did not have the necessary mathematical tools to solve the problems correctly This does not, however, imply that a lack of mathematical skills was the only reason for the students' inability to solve the physics problems correctly Students may have misconceptions in kinematics, Newtonian mechanics, or both

All students that solved more than fifty percent of the physics problems correctly also scored above seventy percent on the vector pre-assessment All of these students were currently enrolled in PHYS 231N or had taken PHYS 231N prior to this study Jake (12) was the only student that scored one hundred percent on the vector pre-assessment and solved all assigned problems correctly Yen (14) missed one question on the vector pre-assessment but solved all of the problems correctly

Using the results shown in Table 5, a Pearson's product-moment correlation coefficient was computed to assess the relationship between the vector pre-assessment score and the percentage of physics problems solved correctly Overall, there was a moderate positive correlation between the vector pre-assessment score and the percentage of problems solved correctly, $r = 0\ 598$, $n = 20$, $p = 0\ 005$

A regression analysis was also performed The vector pre-assessment score significantly predicted the number of problems solved correctly (β = 754, t (1) = 3 16, p = 0 005) and also explained a significant proportion of variance in the number of problems solved correctly ($R^2 = 0\ 36$, $F(1,18) = 10\ 0$, $p = 0\ 005$) As shown in Figure 19, although there is a moderate correlation between the vector pre-assessment score and the physics percentage, it appears as more of a threshold effect than a direct relationship Students who scored above fifty to sixty percent on the vector pre-assessment survey were able to solve some physics problems correctly

The list of correct and incorrect solutions for each interview is given in Table 6 A correct solution did not necessarily include a correct numerical answer If a student made an error due to a calculation but showed sound conceptual knowledge and application of that knowledge, it was determined to be correct For example, one student had his calculator in radian mode and thus calculated incorrect values for sine and cosine The solution was still considered correct for this study Another student calculated the wrong angle for the tree problem but was still able to show the correct process which involving the vector nature of forces It may be argued that this student did not solve the problem correctly ıf he found the ıncorrect angle, but based on hıs correct conceptual presentatıon thıs solutıon was also consıdered correct

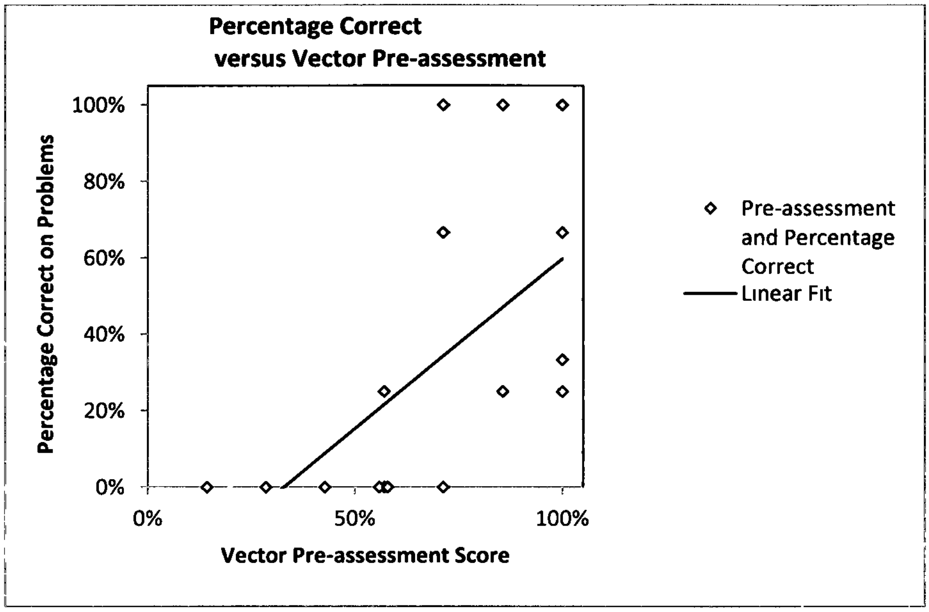


Fıgure 19 Lınear regressıon between Pre-assessment test scores and the percentage correct solutıons

In most ıntervıews, the tree and rocket problems were the first problems students were gıven to solve Some students would solve these problems quıckly and then have tıme to solve other problems Other students took much longer to solve one or two problems and dıd not have tıme to complete other problems durıng the ıntervıew

Table 5

Vector Pre-assessment Score and Percentage Correct on Interview Questions

Interview		Course	Pre-assessment Score	Percentage Correct
Interview	1	111N	43%	0%
Interview	2	231N	100%	67%
Interview	3	231N	86%	25%
Interview	4	111N	71%	100%
Interview	5	231N	86%	25%
Interview	6	111N	14%	0%
Interview	7	231N	100%	33%
Interview	8	226N	100%	25%
Interview	9	231N	71%	0%
Interview	10	231N	43%	0%
Interview	11	111N	57%	0%
Interview	12	231N	100%	100%
Interview	13	231N	71%	67%
Interview	14	231N	86%	100%
Interview	15	111N	57%	25%
Interview	16	111N	57%	0%
Interview	17	111N	57%	0%
Interview	18	111N		0%
Interview	19	111N	43%	0%
Interview	20	111N	29%	0%

Table 6

Correct and Incorrect Solution of Problems

Interview	Tree	Rocket	Penguin	Two Blocks	Loretta	Soccer
1 (111N)	Incorrect	Incorrect	Incorrect	*	*	*
2 (231N)	Incorrect	Correct	Correct	*	*	*
3 (231N)	Incorrect	Correct	Incorrect	Incorrect	*	*
4 (111N)	Correct	Correct	Correct	*	*	*
5 (231N)	Correct	Incorrect	Incorrect	Incorrect	*	Incorrect
6 (111N)	Incorrect	Incorrect	Incorrect	*	*	*
7 (231N)	Incorrect	Correct	Incorrect	*	*	*
8 (226N)	Incorrect	Incorrect	Correct	Incorrect	*	*
9 (231N)	Incorrect	Incorrect	*	Incorrect	*	*
10 (231N)	Incorrect	Incorrect	*	Incorrect	Incorrect	*
11 (111N)	Incorrect	Incorrect	*	Incorrect	*	*
12 (231N)	Correct	*	*	Correct	*	*
13 (231N)	*	Correct	*	Incorrect	Correct	*
14 (231N)	Correct	Correct	*	*	Correct	*
15 (111N)	Incorrect	Correct	Incorrect	Incorrect	*	Incorrect
16 (111N)	Incorrect	Incorrect	Incorrect	Incorrect	*	Incorrect
17 (111N)	Incorrect	Incorrect	*	*	*	*
18 (111N)	Incorrect	Incorrect	*	*	*	*
19 (111N)	Incorrect	Incorrect	Incorrect	*	*	*
20 (111N)	Incorrect	Incorrect	Incorrect	Incorrect	*	Incorrect

Note * = not assigned

V 2 EPISTEMIC STRATEGIES AND FRAMES

As stated in Chapter IV, epistemic strategies and strands were identified for all twenty interviews Each epistemic strategy could be correlated with a frame For identification purposes, the three frames were color coded The qualitative sense making frame strategies were assigned a green hue, the rote problem solving frame strategies were assigned an orange hue and the quantitative sense making frame strategies were assigned a blue hue Patterns could easily be identified by looking for the colored sections to show the problem solving frame

V 2 1 TREE

Nineteen students interviewed were asked to solve the tree problem (Appendix C, #1) This problem was a two-dimensional vector algebra Newtonian mechanics problem Before applying the second law, students must break the tension into components The difficulty lies in that the student must find the angles that the wire makes with the horizontal since the tree limb falls one-fifth of the way from one fencepost

Of the nineteen students that were given this problem to solve, only four students solved it correctly As shown in Figure 20, three out of these four were enrolled in PHYS 231N As discussed earlier, Jenny was enrolled in PHYS 111N and had previously completed PHYS 231N All four students showed a similar epistemic strategy pattern while solving this problem Notice that all four students started with an epistemic strategy in the qualitative sense-making frame They read the problem and then moved into Pictorial Analysis They may at this point have moved into the rote problem solving frame by either performing Plug and Chug or Transliteration to Mathematics, but notice that all four ended with the strategy Meaning to Mathematics All four correct solutions involved an overall movement starting with an epistemic strategy in the qualitative sense making frame and ending with an epistemic strategy in the quantitative sense making frame

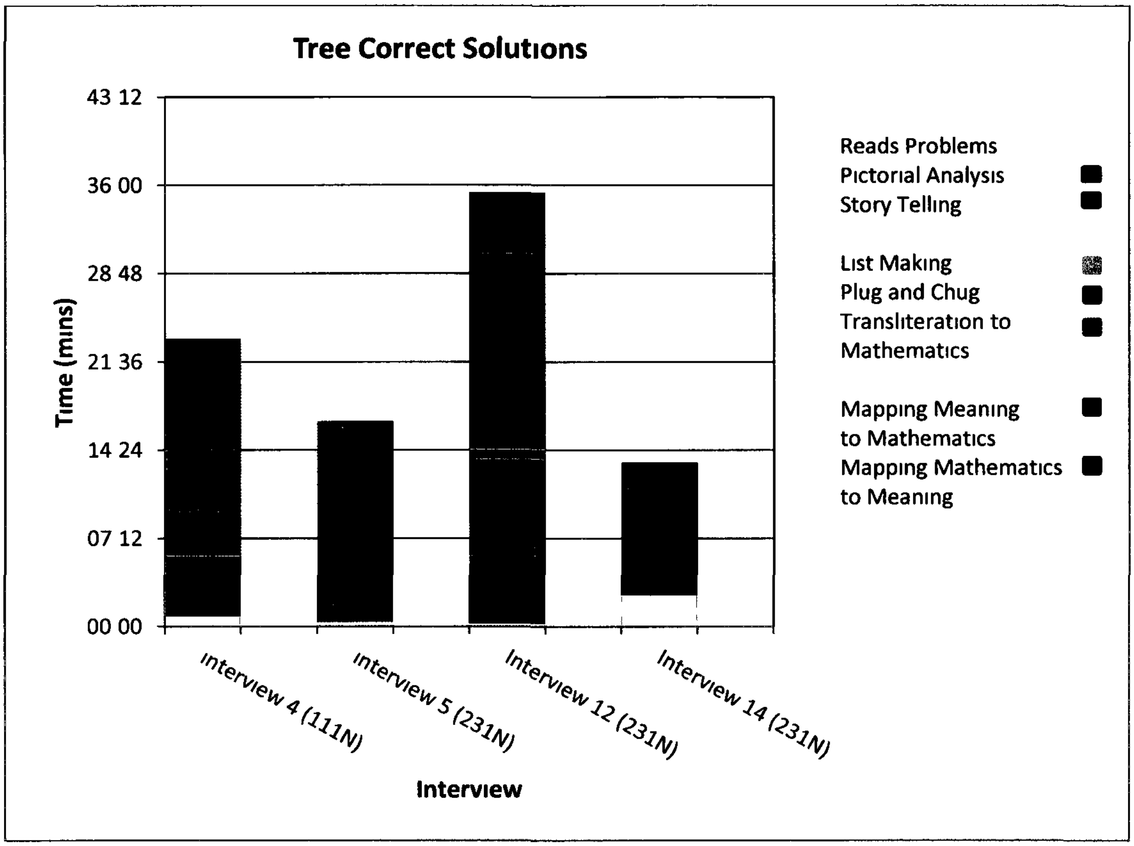


Figure 20 Epistemic strategies of correct solutions for the tree problem

Students also chose different epistemic strategies based on their course enrollment In Figure 21, all students started with reading the problem and Pictorial Analysis within the first two minutes of the problem's solution Most students then moved into the rote problem solving frame Most students used the epistemic strategy Plug and Chug or Transliteration to Mathematics There was no correct solution for the students that were unable to move into the quantitative sense making frame

Three of the students, Lisa (1), Jenny (4), and Brad (15), did finish the problem in the quantitative sense making frame by using the epistemic strategy Meaning to Mathematics Lisa tried to find a formula or an example in her textbook before she reasoned a solution She understood that she needed to break the forces into components and that the forces would not be equal for both sides but did not seem to have the necessary mathematical tools at her disposal In the end, she divided the 150 Newtons into two 75 N forces

Jenny used an example she remembered from her lecture notes to help her solve this problem She referred to a problem in which the two sides were equal but acknowledged that this is not the same problem She studied the example and referred to it throughout her solution Even though this problem is not the same, she was able to use the solution of the problem in her notes to help her start this problem She solved for the angles the wire made on both sides of the limb and was able to solve for the tension in the longer and shorter section correctly

Brad spent most of his time in the quantitative sense making frame He started in the qualitative sense making frame as he moved from reading the problem and Pictorial Analysis into Story Telling He then moved into the rote problem solving frame by applying trigonometry to find all the angles of the two triangles formed by the wire being depressed The quantitative sense making frame followed as he used the Meaning to Mathematics strategy It was clear from his solution that he was missing the relationship between the conceptual knowledge and the mathematical implementation He knew he needed to apply Newton's second law, but he was unclear how he was supposed to do this mathematically He ended with finding the components of the weight and treated them as the tension in the shorter and longer sections of the wire

Several students enrolled in the PHYS 231N course were able to enter the quantitative sense making frame more often than the PHYS 111N students Figure 22 shows that sixty percent of the students in the calculus based course were able to move into the quantitative sense making frame Forty percent of the students ended in this frame Three of those four students, James (5), Jake (12), and Becky (18) were able to solved the problem correctly

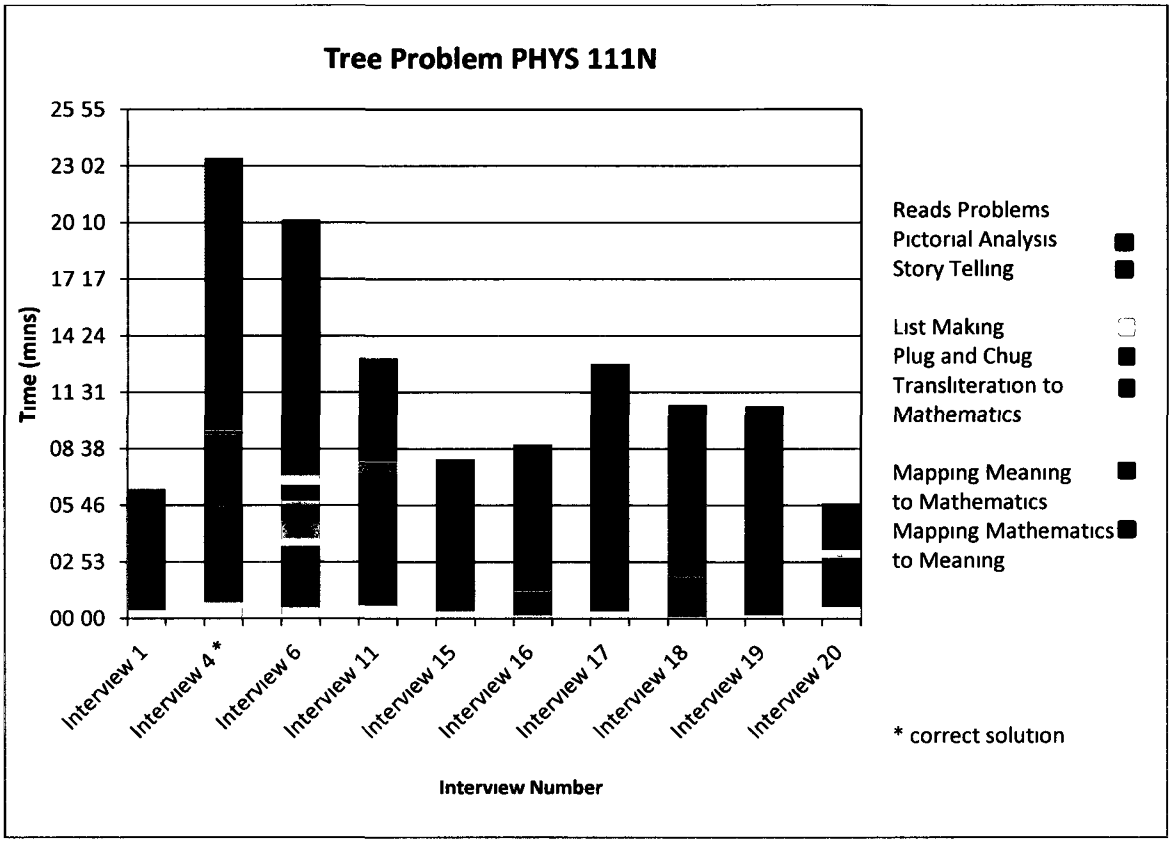


Figure 21 Epistemic strategies of the PHYS 111N students for the tree problem

John (2) also finished the problem in the quantitative sense making frame He found the two angles the wire made with the horizontal and he knew that the sum of the forces acting on the wire at the point where the tree branch was in contact with the wire was equal to zero He even reasoned that the net force upward must equal the weight of the branch going down He was unable to break the tension for the short and long wire into components correctly He actually states that he needs to find the *x*- and *y*-components of the tension but is unable to complete this task

John voiced conclusions about his reasoning and did question it when he felt it was inconsistent with the laws of physics but continued to move on with the solution anyway Here is an example of how John reasoned that a net force of zero in the horizontal direction meant there were no forces acting in the *x* direction

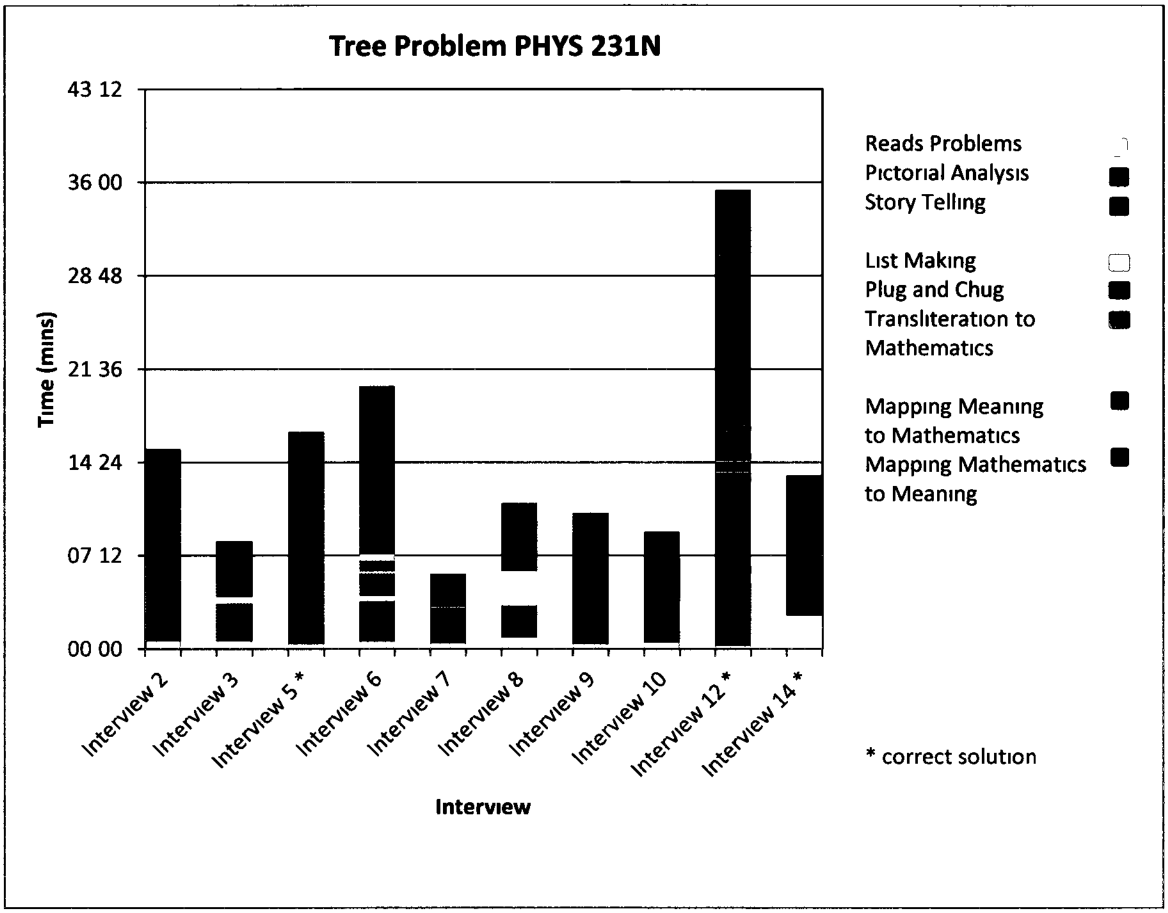


Figure 22 Epistemic strategies of the PHYS 231N students for the tree problem

> John stated "Cause, but the, I guess the thing I'm seeing that this isn't giving it any x-component Hmm, that would mean there is no x-component of the tension, which doesn't seem right Hmm, But, I don't know I guess I'll have to go with it "

He knew there was something wrong with his reasoning, but was unable to identify the misconception He then continued with the solution

John finished the problem by solving for the hypotenuse of each triangle He set the opposite side equal to the 151N and then solved for the hypotenuse, the tension, of the triangle by using the trigonometric function sine John finished the problem incorrectly but remained in the quantitative sense making frame when he finished the problem

V 2 2 ROCKET

Nineteen students were also asked to solve the rocket problem The problem states A rocket is fired at a speed of 75 m/s from ground level at an angle of 60 degrees above the horizontal The rocket is fired toward an 11m high wall which is located 27 m away By how much does the rocket clear the top of the wall (Appendix C, #2)?

This problem is a projectile motion problem Students were supposed to break the velocity into components, treat the *x*- and *y*-components independently and apply kinematics in both the *x* and *y* direction to solve the problem This problem was more difficult than a standard projectile motion problem in that the initial and final height of the rocket were not the same

Seven students solved the rocket problem correctly as shown in Figure 22 Most of the students started the problem in the qualitative sense making frame and then moved directly into the quantitative sense making frame All students ended the problem in the quantitative sense making frame with Meaning to Mathematics or Mathematics to Meaning Yen (14) stopped several times during the solution of this problem English was his second language and some parts of the problem were difficult for him to understand The blank areas in his interview in Figure 23 were the times he stopped to ask for clarification

Kevin (3) and Jenny (4) moved from the qualitative sense making frame into the rote problem solving frame They then moved into the quantitative sense making frame to end the problem Both Kevin and Jenny entered the rote problem solving frame when they could not activate the necessary resource, whether an equation or a phrase or concept, necessary to solve the problem Once they read an example or found an equation, they moved back into the quantitative sense making frame and finished the problem correctly

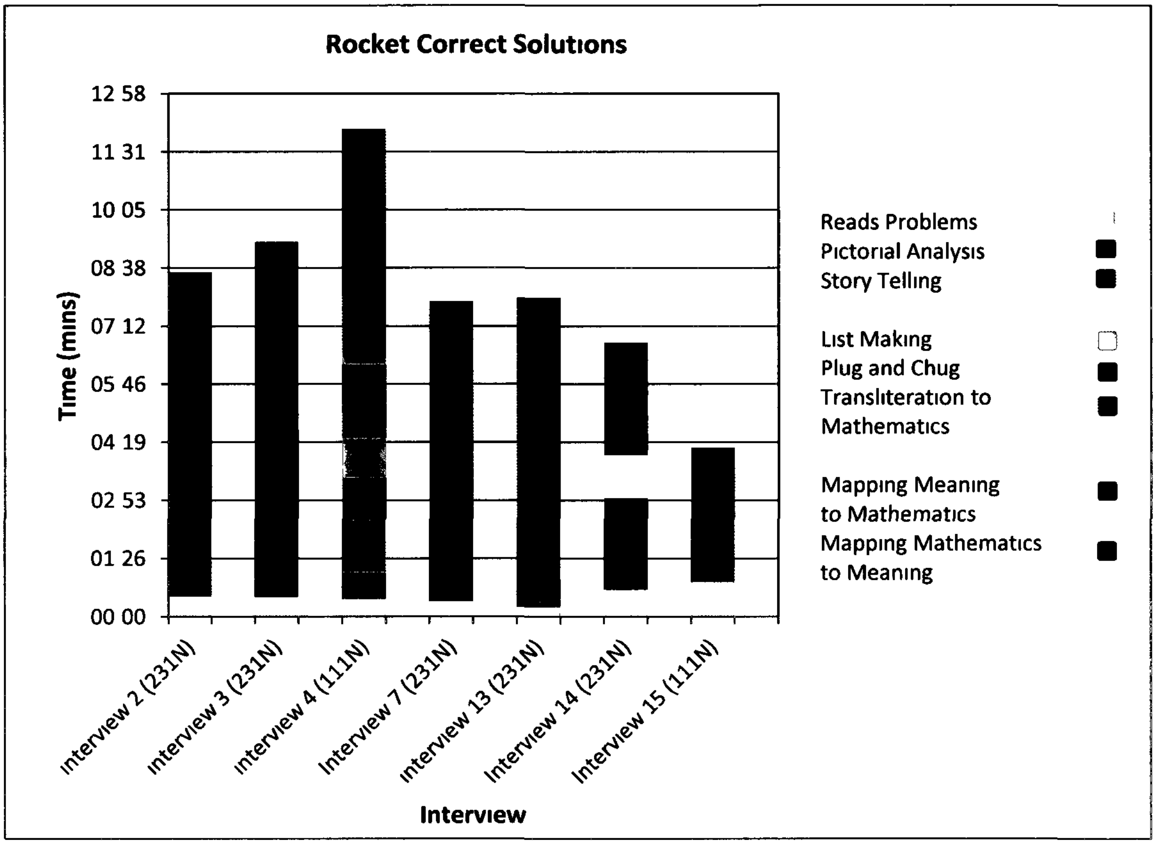


Figure 23 Epistemic strategies for all correct solutions of the rocket problem

As shown in Figure 24, only four students in PHYS 111N ended the problem in the quantitative sense making frame Of these four students, Jenny (4) and Brad (15) solved the problem correctly Ashley (16) and Doug (17) went from the qualitative sense making frame into the quantitative sense making frame but did not solve the problem correctly It was interesting to take a closer look at their solutions

Ashley did not recognize this as a two-dimensional kinematics problem She drew her diagram and labeled her horizontal distance as 27 m and her vertical distance as 11m She drew a straight line from the launch point to above the 11 m as shown in Figure 25 She then determined she needed to find the height of the rocket, *x* She used the horizontal distance 27 m, the angle 60 0°, and the vertical height *x* in the trigonometry function tangent to solve for *x* She did not use any kinematics equations to solve for the

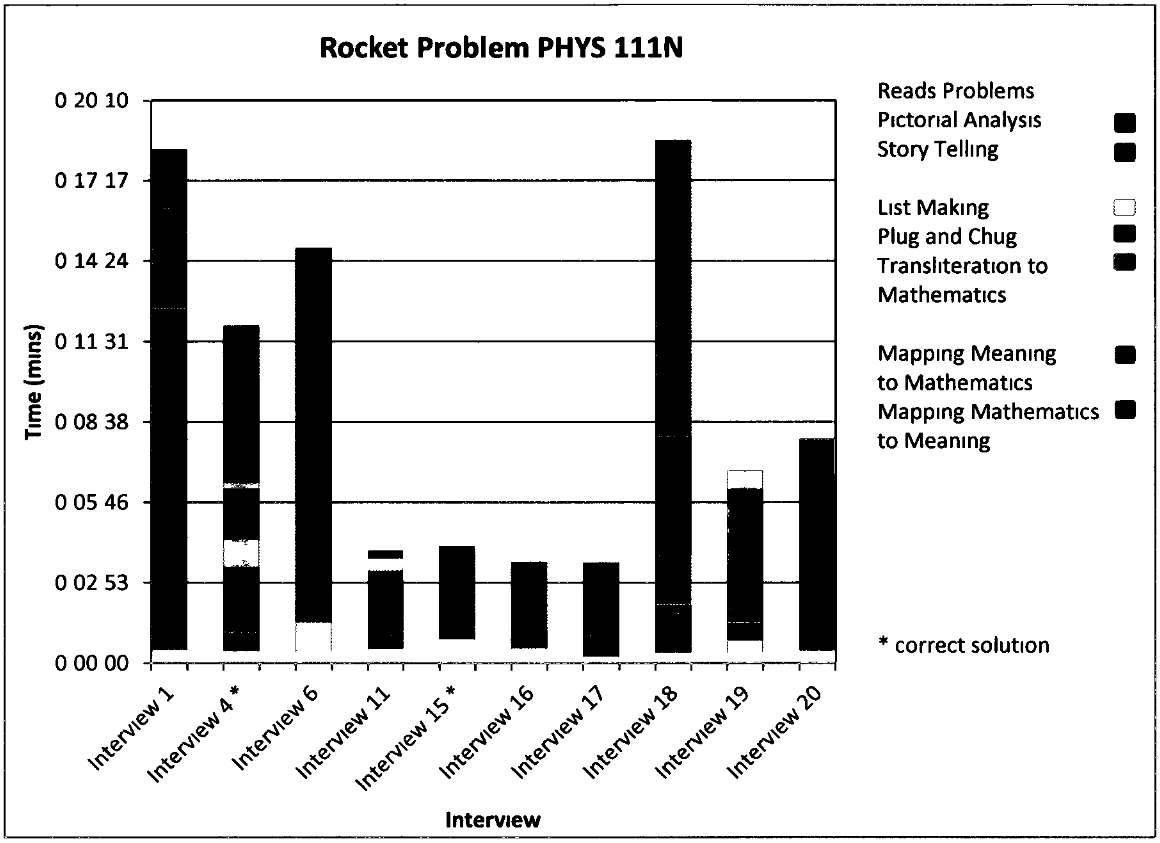


Figure 24 Epistemic strategies of the rocket problem for PHYS 111N students

height of the rocket She subtracted eleven meters from the total height she obtained from tangent theta and gave her final answer She did not hesitate to use a trigonometric function to solve the problem, but she did not use it properly to break the velocity into components

Doug (17) used his kinematics equations to solve for the height of the rocket, but he failed to identify that this was a two dimensional problem He ignored the vector nature of the velocity and used the magnitude in the kinematics equation to solve for the height of the projectile Doug did not subtract the eleven meter height of the wall from his answer

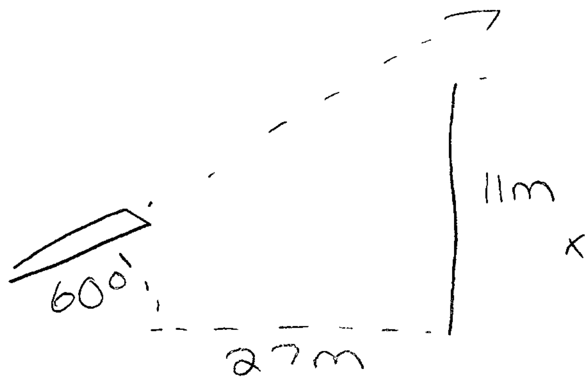


Figure 25 Drawing completed by Ashley (16)

The students in the PHYS 231N course spent more time in the quantitative sense making frame than the PHYS 111N students Figure 26 shows the epistemic strategies used by the PHYS 231N students for this problem All the PHYS 231N students were in the quantitative sense making frame at one point while solving the problem They all spent very little time in the qualitative sense making frame

Kevin (3) and Josh (8) moved into the rote problem solving frame by using the epistemic strategy Plug and Chug Kevin eventually moved into the qualitative sense making frame and then into the quantitative sense making frame James (5) moved from the quantitative sense making frame into the rote problem solving frame with Listmaking, but quickly moved back into the quantitative sense making frame to finish the problem

Josh (8) was the only PHYS 231N student that did not end the problem in the quantitative sense making frame He initially started in the qualitative sense making frame with Pictorial Analysis and then moved into the quantitative sense making frame with Meaning to Mathematics He determined the components of the velocity and wrote his kinematics equation but realized he did not have the time of flight He was unclear how he should proceed and started to look through his lecture notes At this point he entered the rote problem solving frame He found an equation but did not substitute his given information into the equation He stopped at this point, unable to continue without the time of flight

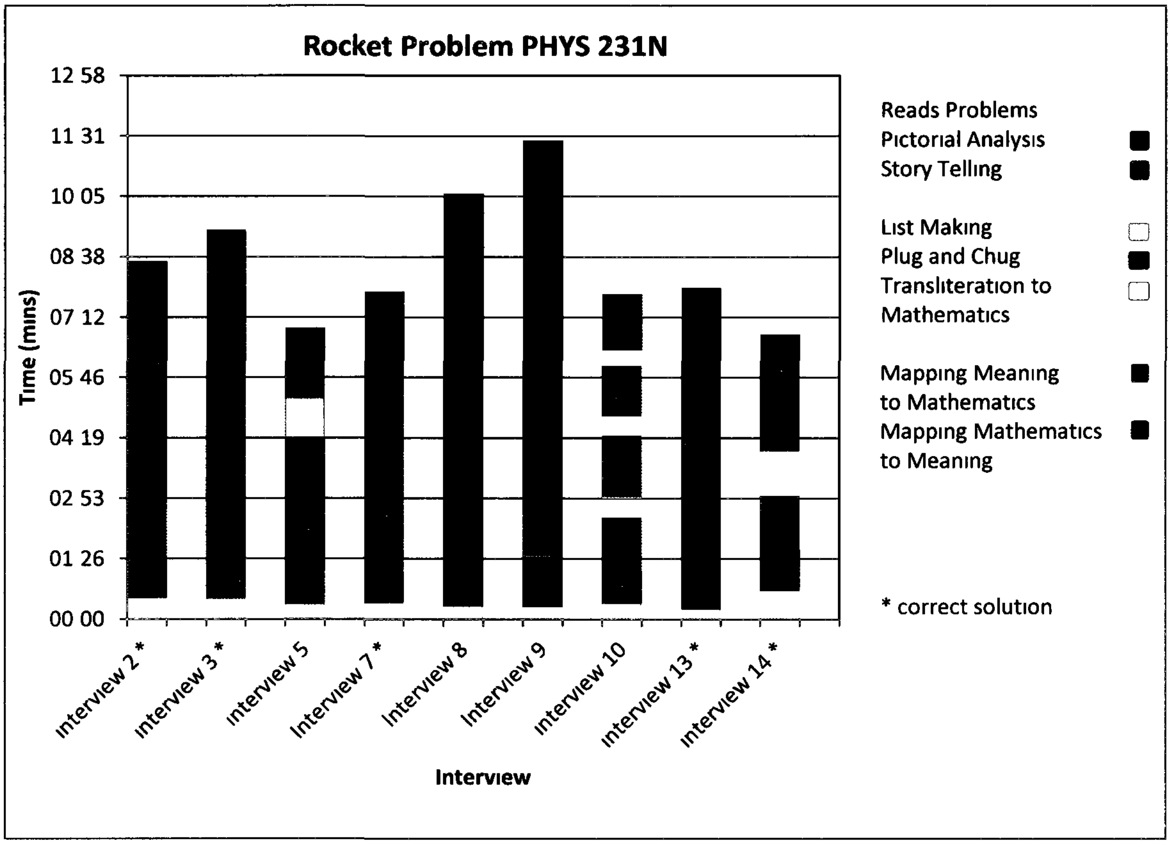


Figure 26 Epistemic strategies of the PHYS 231N students for the rocket problem

As mentioned above, Yen (14) needed clarification during this solution Bill (10) also stopped several times to discuss a topics not pertaining to the solution of this problem These time periods are shown in Figure 26 as blanks in the graph

V 2 3 PENGUIN

The penguin problem was chosen for this study because many textbooks had a similar example in the chapter on the application of Newton's second law The penguin problem states A penguin is sliding down an icy incline at a constant speed of 1 4 m/s The incline slopes at an angle of 6 9 degrees What is the coefficient of friction of the incline (Appendix C, #3)?

Results from this problem were mixed Only three students solved the problem correctly as shown in Figure 27 Of the three correct solutions, John (2) and Josh (8) solved the problem by moving from the qualitative sense making frame into the quantitative sense making frame via a brief stop in the rote problem solving frame John made a list of his given and unknown information and Josh checked his notes after he drew his diagram

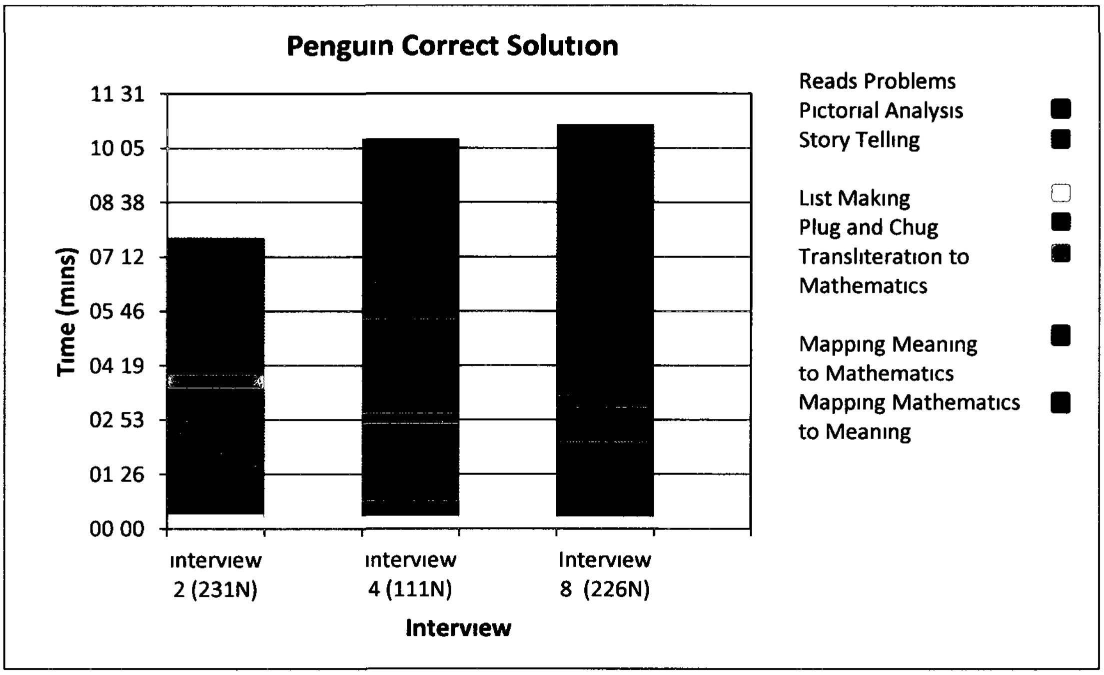


Figure 27 Epistemic strategies for correct solutions of the penguin problem

Jenny (4) moved back and forth between the qualitative sense making frame and the rote problem solving frame She used her picture to help her work through the examples in the textbook She solved the problem correctly but never moved into the quantitative sense making frame Jenny found an example identical to the problem she was solving This made the target solution from the textbook identical to the solution for this problem

The solutions for the penguin problem by the PHYS 111 students seemed to show the same epistemic strategy pattern Figure 28 showed that most of the students moved from the qualitative sense making frame into the rote problem solving frame Only two students used the strategy Transliteration to Mathematics to solve this problem

Brad (15) remained in the qualitative sense making frame for the entire solution to this problem After reading the problem and completing Pictorial Analysis he reasoned that since ice was slippery, it was frictionless Therefore, the coefficient of friction would be zero on the icy slope

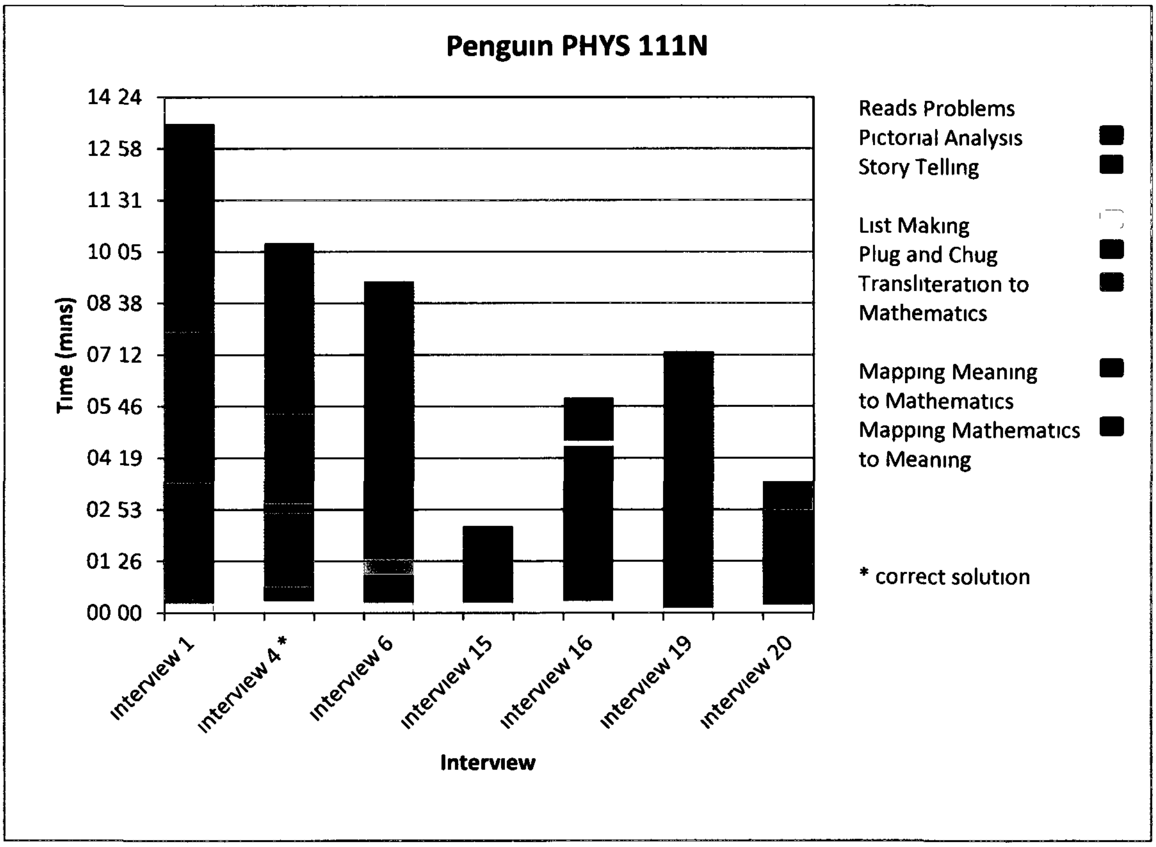


Figure 28 Epistemic strategies of PHYS 111N solutions of the penguin problem

Ashley (16) tried to solve the problem by looking for formulas in her lecture notes She was unable to obtain a solution She reread the problem and then determined that the coefficient of friction must be zero since it was an icy incline

The idea that the coefficient of friction was zero because ice has a zero coefficient was not isolated to the PHYS 111 students As shown in Figure 29, James (5) only used the epistemic strategy, storytelling to solve the problem James initially gave his answer as "nothing" with little thought to the problem He began to explain his reasoning after he gave his answer James was then prompted to recall his thought process as he solved the problem At this point, James actually moved into a quantitative sense making frame He used the epistemic strategy Meaning to Mathematics to explain how he deduced that the coefficient of friction must be zero Even though he did not physically write down equations, he verbally stated Newton's second law and the net force on the penguin must be zero It was then clear that James had a misconception about the net force acting on an object

> He stated that " and then it had constant speed and the word constant jumped out at me because if it's constant then it's not changing and if the speed is constant and in this particular case a constant with the speed, there's no acceleration Because the acceleration is the change in speed with the change in time so that means there's no external force so cause the speed isn't changing and if the object's in motion it tends to stay in motion and all that lovely stuff and the coefficient of friction brings about a frictional force, and there's not a force acting on the penguin cause the speed is constant so there's no coefficient of friction "

James believed if there was a net force of zero then there could not be a frictional force He was equating the net force with individual forces In other words, if there was no net force then there were no forces acting on the penguin at all

Four of the five students in the PHYS 231N course completed the problem in the quantitative sense-making frame as shown in Figure 29 John (2) and Josh (8) solved the problem correctly Kevin (3) and Diane (7) both ended with Meaning to Mathematics but were unable to successfully solve the problem

Kevin started the problem with Pictorial Analysis and then moved into Story Telling He went through what he knew about the problem but was unable to activate any resources that may have helped him solve the problem He did not draw a free body diagram and did not mention Newton's second law He eventually moved into Meaning to Mathematics by solving for the components of the velocity His final answer was actually the *y*-component of the velocity, not the coefficient of friction It was unclear whether Kevin had a misconception with forces or was just unable to activate the resources necessary to solve this problem correctly

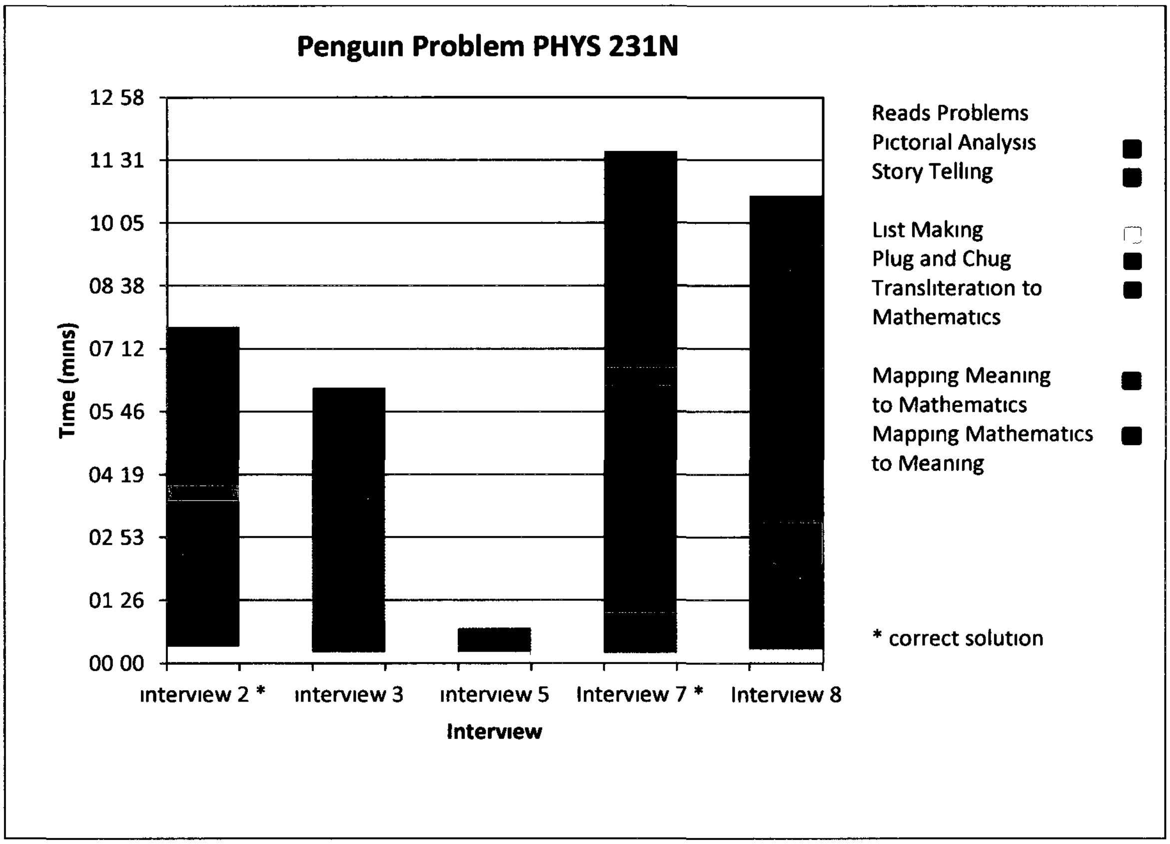


Figure 29 Epistemic strategies of PHYS 231N solutions of the penguin problem

Diane started with Pictorial Analysis and then moved into Transliteration to Mathematics She looked for an example that would help her solve this problem She was unable to find one and began reading the section on kinetic friction Based on her reading she determined she needed the normal force but did not have enough information for a solution

She continued with the example and decided she needed a free body diagram She moved back into the qualitative sense making frame It may be argued that she was still in the rote problem-solving frame and was simply mapping her information into the solution given At this point, she stopped referring to the example and completed a free body diagram based on her knowledge She did not refer to the example until after she had completed the free body diagram and could not continue with the solution Because she used her own knowledge and acted independently from the example in the textbook, the epistemic strategy Pictorial Analysis seemed more appropriate for this observation

Diane did move from the qualitative sense-making frame back into the rote problem solving frame when she continued to look for another example She found a toboggan problem which was similar to the problem she was currently solving She read the example but dismissed it She then moved into the quantitative sense making frame as she began Meaning to Mathematics She told a story about the problem and then decided to start over with Newton's second law She determined the net force was zero and therefore the forces must be "balanced " She was able to determine the normal force in terms of the weight and moved through her solution She did have a correct equation when she finished the problem, but her answer was in terms of the weight of the penguin and the frictional force, both unknown

She applied vector algebra correctly by breaking the weight into components but was unable to follow through with applying Newton's second law correctly She did not explicitly treat this as a two-dimensional Newtonian mechanics problem She ignored the x-component of the weight and only solved for the coefficient of friction by using $f_k = \mu N$

V 2 4 TWO BLOCKS

During the interviews in the Spring 2008 semester, little evidence of epistemic strategies were observed with the calculus-based physics students (231N) The researcher decided to add more challenging problems in the Fall 2008 for the calculus-based physics students The researcher was then able to identify evidence of different epistemic strategies used in the solutions

The most commonly administered problem involved two blocks connected by a pulley where one block was on a table and the other was hanging from the rope Six students were given this two block problem In the drawing, the rope and pulleys are massless and there is no friction (Appendix C, #8)

As shown in Figure 30, all of the students except for Cindy (20) entered the quantitative problem solving frame while solving this problem None of the solutions were correct for this problem The most common error was applying Newton's second law incorrectly Kevin (3), Brad (15) and Ashley (16) ignored the tension in the ropes completely and solved for the acceleration and tension as if they were solving for the weights of the blocks Ashley stated that her acceleration was 9 8 m/s^2 and the tension was the sum of the masses times 9 8 m/s^2 Brad and Kevin solved for the weight of the 3 0 kg block and then used this weight to solve for the acceleration Brad divided this "tension" by the 10 0 kg mass to solve for the acceleration Kevin found the difference between the two weights to solve for the acceleration

James (5) actually was close to having the correct solution He drew free body diagrams for both blocks and used Newton's second law to derive equations for both blocks He was unable to combine both equations algebraically to solve for the correct acceleration and tension James showed no evidence of misconceptions in the concepts or vector algebra He made mistakes in his algebra

Josh (8) applied Newton's second law but failed to identify that there were two tensions pulling up on the 3 0 kg block He also did not make the acceleration of the 3 0 kg block negative He checked his textbook and notes and found an example of an Atwood machine He did not explicitly try to map his quantities into the solution of the Atwood machine example but may have applied several parts of the example into his solution

V 2 5 TWO BLOCKS ON INCLINE

Two students were given the two blocks on an incline problem to solve This problem involved two blocks connected by a string sliding down an inclined surface The problem states Two blocks with masses 4 00kg and 8 00kg are connected by a string and slide down a 30 0° inclined plane The coefficient of kinetic friction between the 4 00kg block and the plane is 0 25, that between the 8 00kg block and the plane is 0 35 a) Calculate the acceleration of each block and b) Calculate the tension in the string (Appendix C, #7)

As shown in Figure 31, students entered the quantitative sense making frame during the solution to this problem but both were unsuccessful in solving the problem

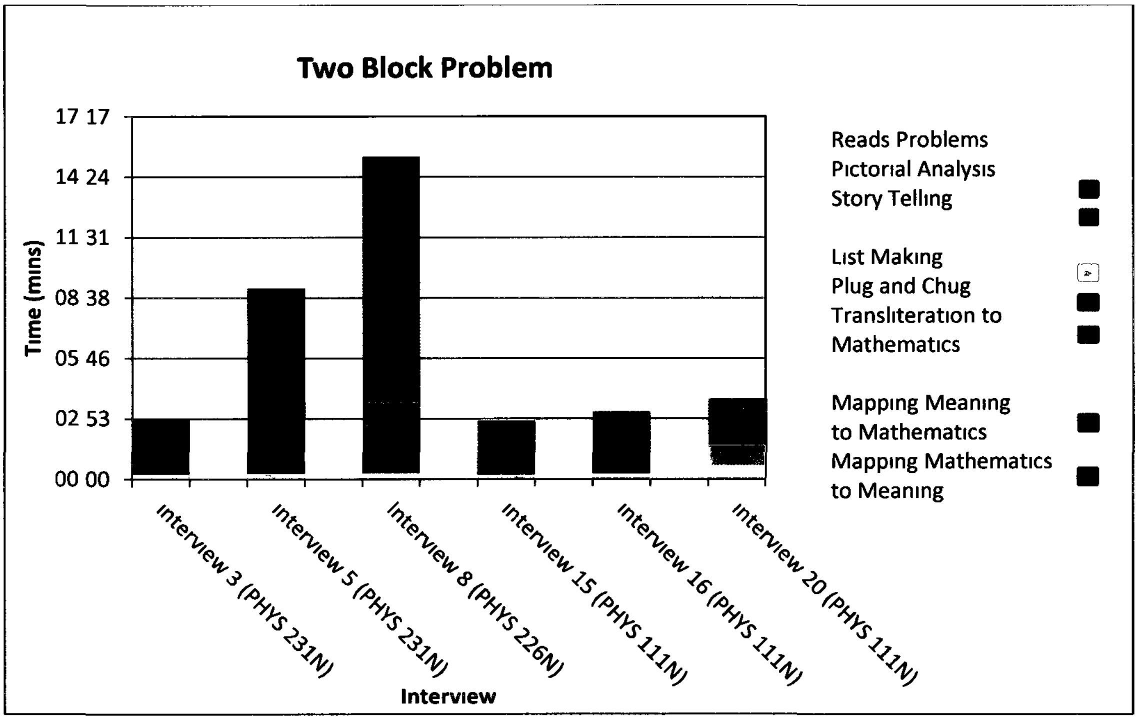


Figure 30 Epistemic strategies of solutions for two block problem

Andy (9) moved between the quantitative and qualitative sense making frames throughout his solution to the problem He was able to express that the acceleration was the same for each block and the tension between the rope and either block would be equal in magnitude but opposite in direction Andy rotated the coordinate system for both blocks but was unable to express the weight of each block in component form He applied Newton's second law for both blocks in both the x and y directions However, he

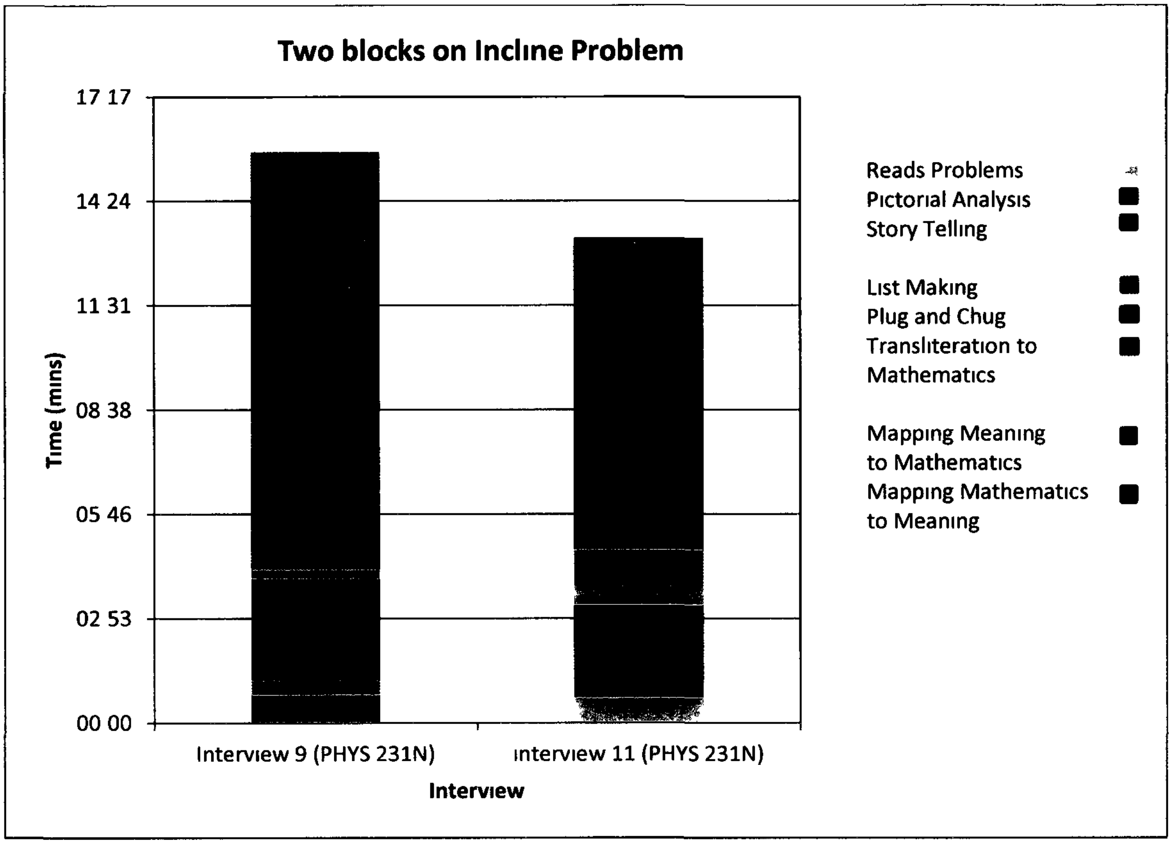


Figure 31 Epistemic strategies of solutions for two block problem on incline plane

failed to include the frictional force on either block and did not include the correct weight component for the x and y directions

Rish (11) started the problem with Pictorial Analysis He drew a free body diagram for both blocks He applied Newton's second law but did not include the components of the weight He also ignored the inclined surface when calculating the frictional force He set the normal force equal to the weight of each block and then solved for the frictional force He used the x-component of the weight as the acceleration of the block He was unable to recognize that the acceleration for both blocks would be the same and solved for two separate accelerations Rish then solved for the tension by first taking the acceleration and multiplying by the mass, then taking the difference between the two forces and labeled it the tension in the rope Rish seemed to show misconceptions about the vector nature of forces

V 2 6 TWO BLOCKS STACKED

The final two block problem was administered to Bill (10), Jake (12), and Tom (13) All three students were enrolled in PHYS 231N and finished the problem in the quantitative sense making frame as shown in Figure 32 Bill and Jake both solved the problem correctly

The problem stated Block A weighs 1 40N and block B weighs 4 20N The coefficient of kinetic friction between all surfaces is 0 30 Find the magnitude of the horizontal force $\vec{F}$ necessary to drag block B to the left at constant speed if A and B are connected by a light, flexible cord passing around a fixed, frictionless pulley (Appendix C, #6)

Jake moves from the qualitative sense making frame into the rote problem solving frame and then into the quantitative sense making frame He was looking for a formula that would help him solve for the frictional force He found the formula for the friction force and moved through the solution to the problem He was able to correctly apply Newton's second law to solve the problem

Bill also solved the problem correctly He moved between the qualitative and quantitative sense making frames He did enter Listmaking, but was not classified as entering the rote problem solving frame

> He stated So how would I set this one up? This is very, a little complicated So I'm trying to process it in my head and how I would actually put out the formulas, and, and then combine them all I guess the first thing would be just to do block A's forces Force of gravity is equal to 1 40 N The normal force is 1 40 N So the coefficient of friction, 0 30, so I need to find the amount of tension exerted by A (lists the given information in vertical column) Okay, force of gravity is in the *x* direction, *y* direction The coefficient, kinetic, the formula for kinetic friction is the force of friction equal to mu sub k times the normal force which I have all of that information

Bill did not use the list to move into Plug and Chug, therefore it was identified as Listmaking It was more of an organizational strategy for this solution He organized his information so that he could enter Mathematics to Meaning He was then able to solve the problem correctly

Tom was unable to solve this problem correctly He did not use the correct normal force to solve for the frictional force between the bottom block and the table He doubled the weight of block B and set it equal to the frictional force instead of adding the weight of block B with the weight of block A His diagram was not clear and may have led him to believe the frictional force above and below block B were from the weight of the block and not the normal force

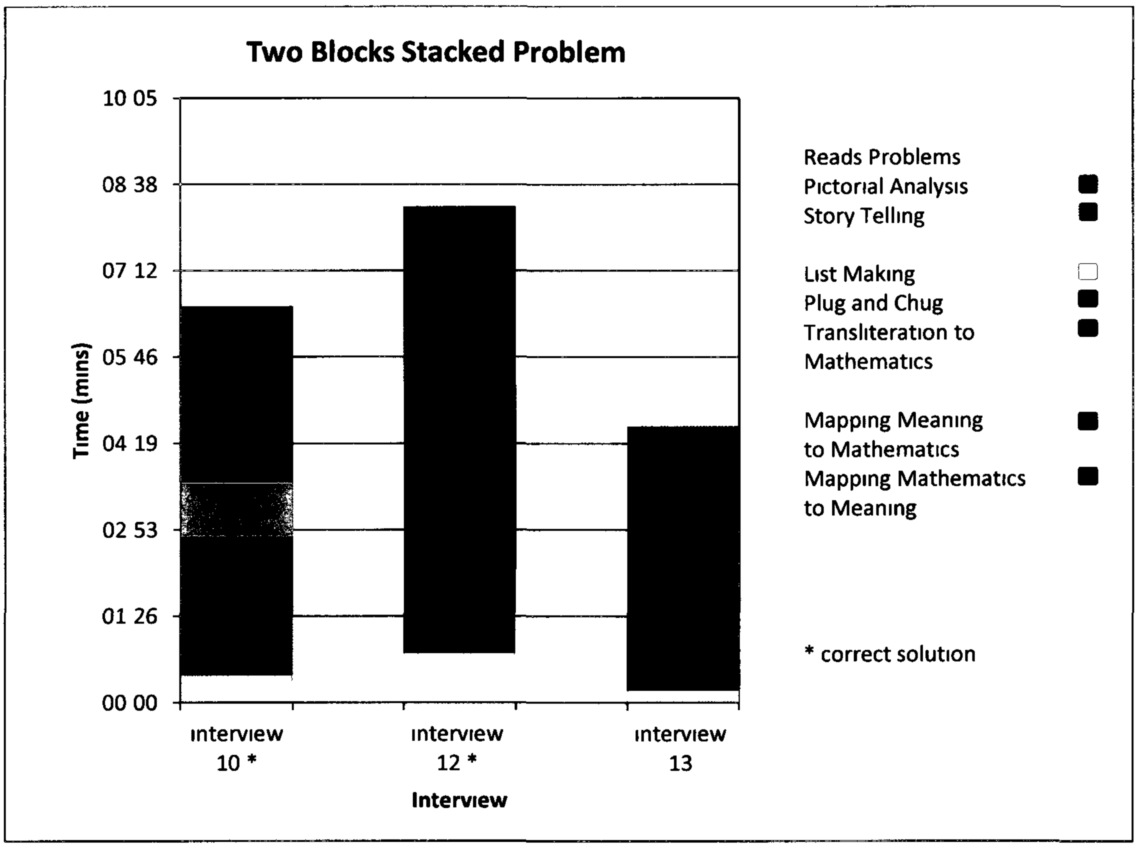


Figure 32 Epistemic strategies of solutions for two blocks stacked problem

V 2 7 SOCCER

The soccer problem was gıven toward the end of the ınterviews, only to four students The soccer problem stated A soccer player kıcks the ball toward a goal that ıs 29 5 m ın front of hım The ball leaves hıs foot at a speed of 19 0 m/s and an angle of 32 0° above the ground Fınd the magnıtude and dırection of the velocıty of the ball when the goalıe catches ıt ın front of the net (Appendıx C, #5)

None of the students solve thıs problem correctly (See Fıgure 33) James (5) and Brad (15) both ended the problem wıth Meanıng to Mathematıcs James broke the velocıty ınto components and then used hıs kınematıc equatıons to solve for the heıght of the ball when ıt reached 29 5 meters ın front of the player He then made the assumptıon

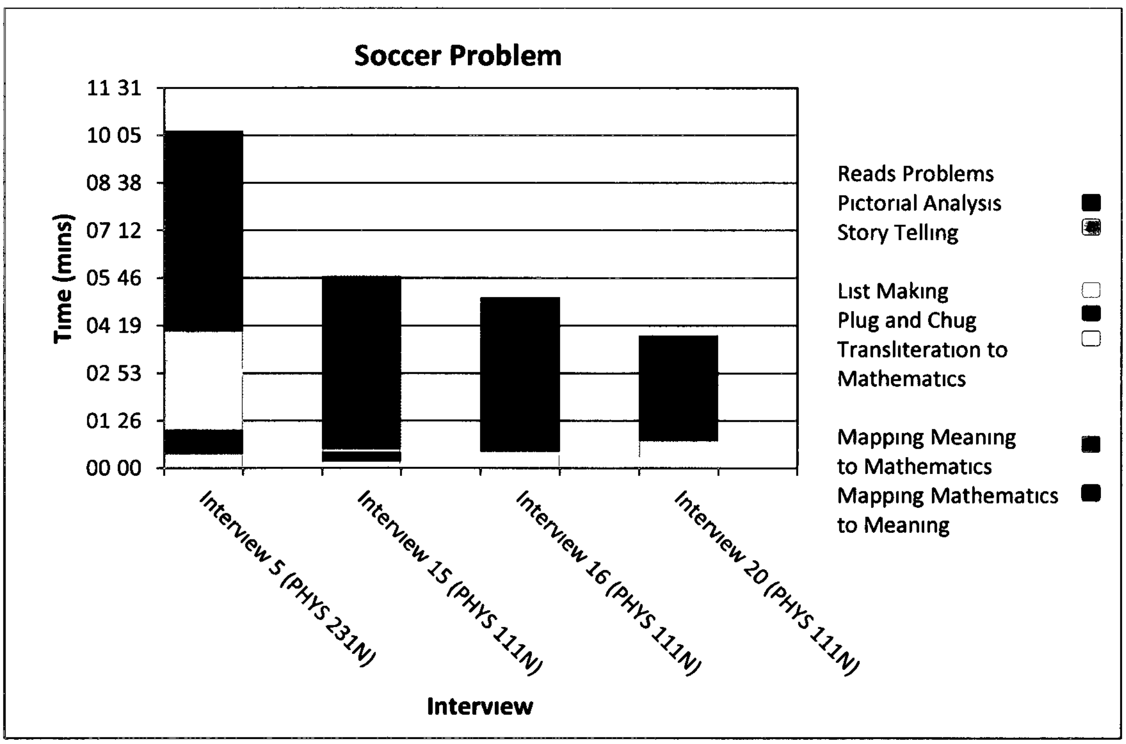


Fıgure 33 Epıstemıc strategıes of solutıons for soccer problem

that the final velocıty must be the same as the ınıtıal velocıty He faıled to see that the final velocıty would be ın a dıfferent dırectıon Even as he solved for the final heıght and saw that it was 4 08 m, he did not take this into consideration when solving for the final velocity James believed that it must be the same

Brad also broke the velocity into its *x*- and *y*-components His diagram showed that the ball would not land at the same height as it started at the beginning of the problem Brad used his kinematics equation to solve for the y- component of the final velocity However, he substituted the *x*-displacement into the equation instead of the *y*-displacement It is not clear whether his error carelessness or did he believe that the *x*- and *y*-components of the displacement were interchangeable

Brad used the Pythagorean Theorem to solve for the magnitude of the final velocity and used tangent theta to solve for the direction He showed that he understood the vector nature of the velocity He set the initial and final *x*- components equal and showed through his calculations that he understood the initial and final velocities in the *y* direction would not be the same

In his recall, he stated explicitly that the *x*-component of the velocity would remain the same, but the *y*-component would change He showed he understood the difference between the magnitude and direction of the final velocity He stated "I took the horizontal component at that point and the vertical component at that point, squared them and then the square root of them which would be the magnitude at that point "

> He then stated And then I took the, both of the vertical components and, no both the horizontal and vertical component, made one of them *x* and *y* *y* was the vertical Being that, and um, and then I did negative tangent of both of them to find out what angle they would be at which is the direction

From his written solution and his verbal recall of his thinking, it appeared that he understood the vector nature of the velocity He was able to apply vector algebra correctly to solve for magnitude and direction of the final velocity His only mistake was substituting the *x*-component of the displacement into the kinematics equation for the *y* direction

Ashley (16) did not go any further than substituting her given information into the kinematics formulas available to her She used the kinematic equation, $v^2 - v_0^2 = 2ay$ to solve for the final velocity She used the acceleration due to gravity, g, but also used the

x-dısplacement ınstead of the y-dısplacement She dıd not show from her solutıon that she understood the vector nature of dısplacement, velocıty, and acceleratıon

Cındy (20) dıd not know how to approach thıs problem She searched through her lecture notes but was unable to find a formula or an example that would help her solve thıs problem She had one formula avaılable but dıd not see how she could substıtute her gıven quantıtıes ınto the equatıon She ended the problem wıth Plug and Chug and went no further

V 2 8 LORETTA

As state prevıously, the Fall semester ıncluded more challengıng problems for the calculus-based physıcs students The two block problems were added and a two-dımensıonal kınematıcs problem that ıncluded two dıfferent motıons occurrıng sımultaneously was also added The Loretta problem was added ın the Fall 2008 semester (Appendıx C, #4)

Three students from PHYS 231N were asked to solve thıs problem As shown ın Fıgure 34, all three students ended the problem ın the quantıtatıve sense makıng frame Tom (13) and Yen (14) both solve the problem correctly

Bıll (10) had dıfficulty contınuıng the problem after he completed Pıctorıal Analysıs He looked through hıs notes and then through hıs textbook As he glanced through hıs notes he stated, "I'm lookıng for acceleratıon too (He looks through hıs book) So I'm lookıng for a formula for acceleratıon due to gravıty " Bıll explıcıtly made a comment that he was lookıng for a formula Thıs would ındıcate he was usıng the epıstemıc strategy, Plug and Chug He found a formula, but dıd not substıtute hıs numbers ınto that equatıon The epıstemıc strategy, Plug and Chug appeared to have actıvated the resources needed to solve thıs problem He then moved ınto another epıstemıc strategy, Mathematıcs to Meanıng Bıll solved for how far Loretta travels ın the 9 00s and then solved for the final velocıty of the bag as ıf her husband dropped ıt He then solved for the final velocıty of the lunch bag ın the horızontal dırectıon Bıll used the acceleratıon due to gravıty as the acceleratıon of the bag ın the horızontal

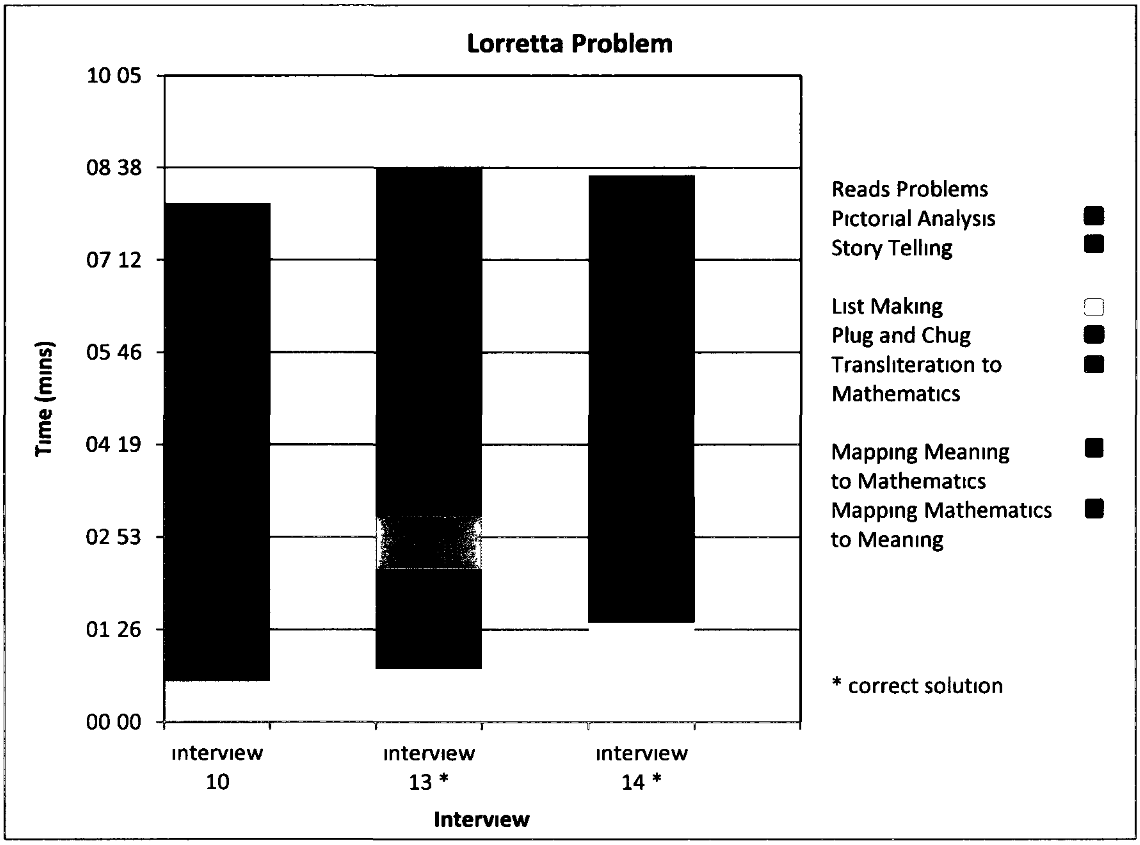


Figure 34 *Epistemic strategies of PHYS 231N solutions of the Loretta problem*

direction Even in recall, Bill did not indicate that he was using vector quantities in two different directions in the same equation

Because Bill did not have a clear idea of how to solve this problem, he needed to check for formulas and did not solve the problem correctly He knew the problem was a projectile motion problem that involved his kinematics equations but was unable to realize that he was using vector quantities incorrectly Bill scored below fifty percent on his vector pre-assessment survey It may be that Bill did not have the necessary mathematical tools at the beginning of the semester and never developed a complete understanding throughout the semester

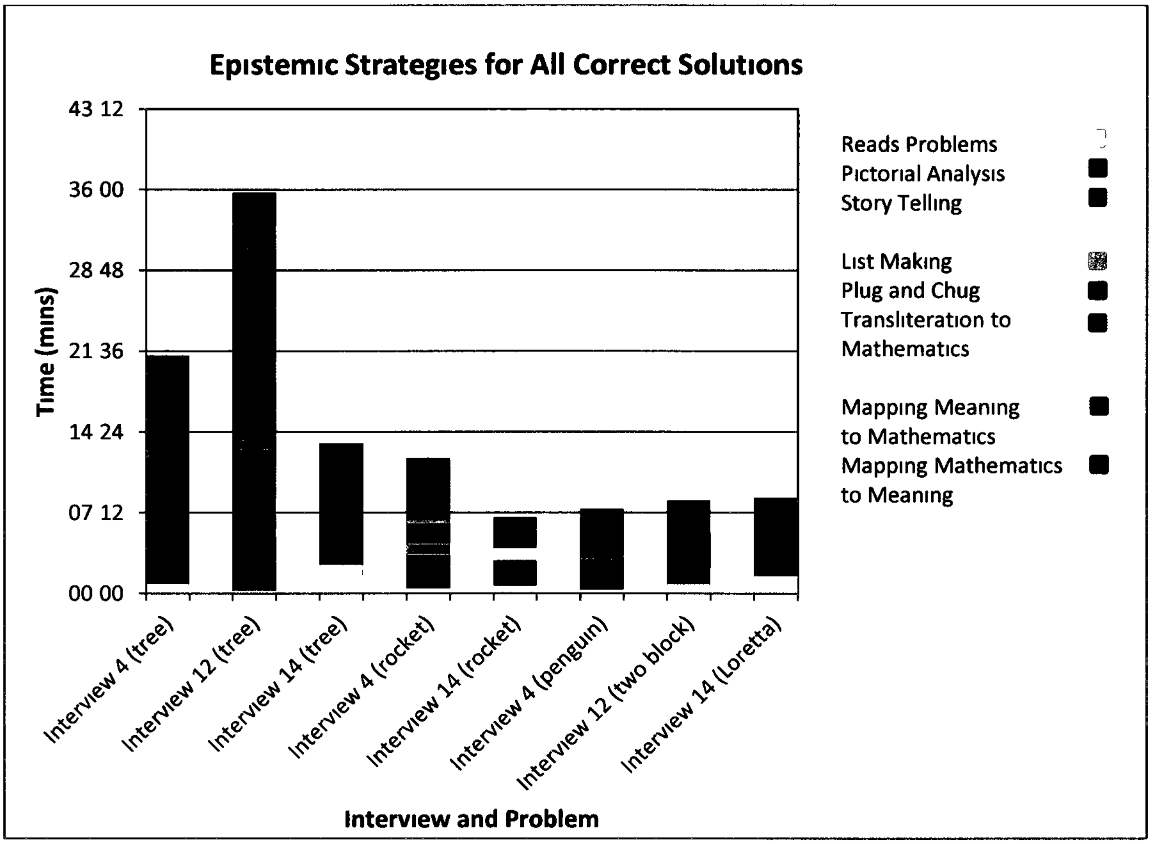


Figure 35 Epistemic strategies for students with 100% correct solutions

V 3 SUMMARY

There appeared to be a relationship between the vector algebra pre-assessment score and the ability to solve the problems correctly This, however, was not the only factor It appeared there was also a relationship between the epistemic strategy used and a correct solution Figure 35 shows the epistemic strategies for the three students that solved all assigned problems during the interview correctly All but one solution involved the student moving into the quantitative sense making frame by using Meaning to Mathematics or Mathematics to Meaning

Jenny (4) finished the penguin problem in the rote problem solving frame by using Transliteration to Mathematics to solve the problem Several students were able to solve, or at least come close to the correct solution for the penguin problem, using this epistemic strategy For this problem, an example was available in their textbooks This made it possible for them to solve the problem correctly in the rote problem solving frame instead of moving into the quantitative sense making frame

This pattern was also seen when looking at the epistemic strategies used for all correct solutions for all interviews Figure 36 shows that all but two correct solutions were obtained when the student entered the quantitative sense making frame at the end of the solution to the problem Again, there were two solutions for the penguin problem in which the student ends the problem in the rote problem solving frame An example given in the text or lecture notes provided a correct solution for the student

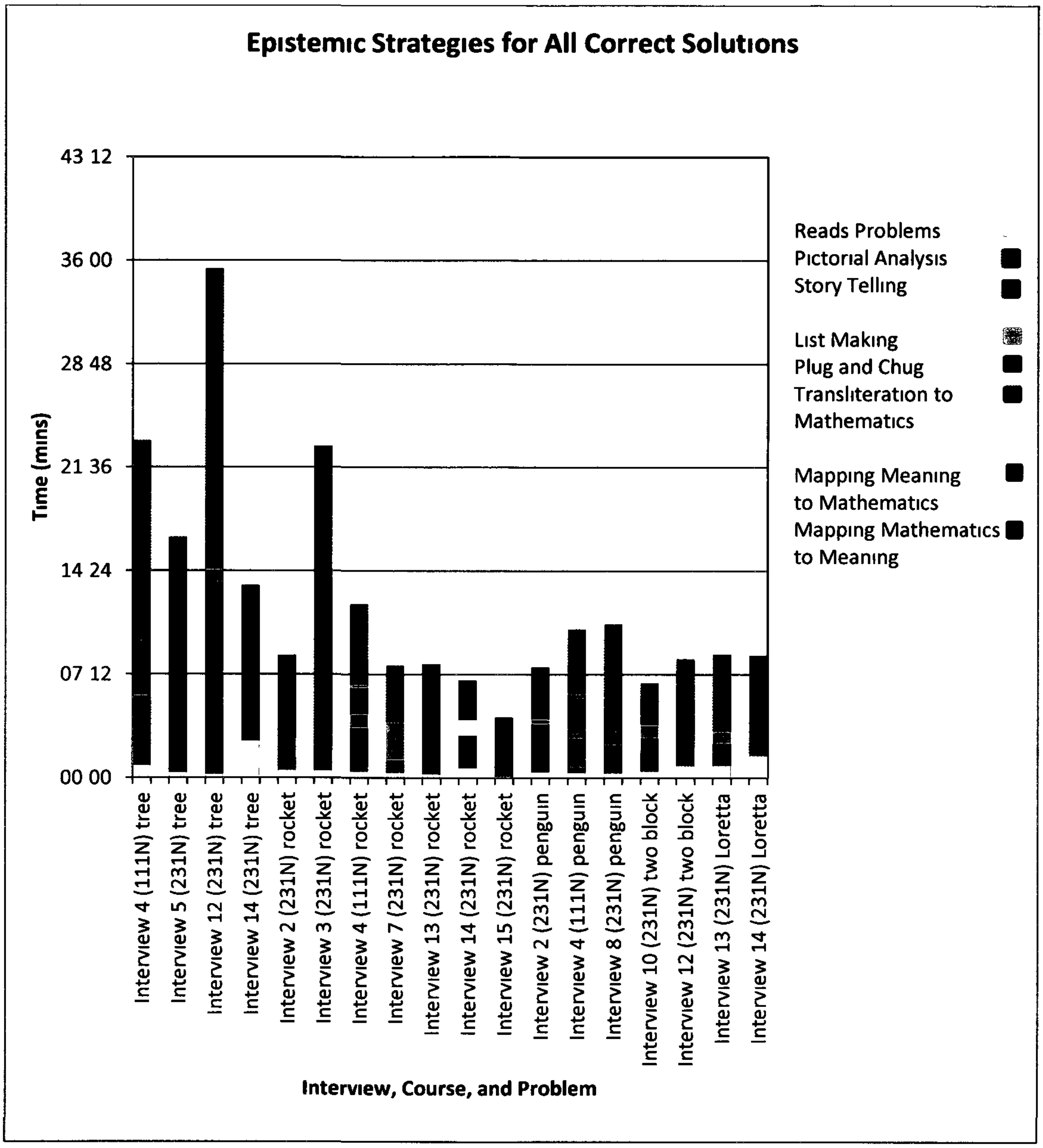


Figure 36 *Epistemic strategies for all correct solutions*

CHAPTER VI

CONCLUSIONS

Physics is a difficult subject to explain or comprehend Most students will identify any difficulty they have with the course as mathematics related With this in mind, the researcher attempted to answer three questions (1) What epistemic strategies do students use when solving two-dimensional physics problems that require vector algebra? (2) Do vector preconceptions in kinematics and Newtonian mechanics hinder a student's ability to apply the correct mathematical tools when solving a problem? And (3) What patterns emerge with students of similar vector algebra skill in their problem solving?

The main conclusions from this project were

1 Vector pre-assessment scores were moderately significantly correlated with the ability to solve physics problems correctly

2 Student enrolled in the first semester of an algebra-based physics sequence course, with one exception, did poorly on the vector pre-assessment survey and were unable to solve the problems

3 Students enrolled in the first semester of a calculus-based physics sequence course performed much better on the vector pre-assessment survey and on average were able to solve more problems correctly

4 The epistemic strategies derived from the interviews in this project were very similar to the epistemic games presented by Tuminaro (2004) The differences were few and can be explained by the differences between the two studies

5 Epistemic strands were identified in this study The strands are pieces of the epistemic strategies and indicated a movement from one frame to another

6 In general, students solved problems correctly by moving into an intellectually higher frame, i e quantitative sense making frame Students that stayed in the qualitative sense making frame or the rote problem solving frame were rarely successful

VI 1 VECTOR PRE-ASSESSMENT SURVEY

There was a statistically significant relationship ($p = 0\ 005$) between the vector pre-assessment score and the number of interview problems solved correctly The relationship seems like a threshold effect because only students scoring above fifty percent on the vector pre-assessment survey were able to solve any physics problems correctly

There were several reasons a student may have achieved a high vector pre-assessment score Vector algebra may have been covered in a prerequisite mathematics course for that student The student may have taken more advanced mathematics courses than required for the physics course This exposure to other mathematics courses may have made it easier to learn or remember vector algebra Furthermore, the student may have taken a physics course in which vector algebra was already covered There is also the possibility that students enrolled in the calculus-based physics course may have a higher aptitude for mathematics and learned the vector algebra at the beginning of the course more easily The prerequisite of calculus would certainly have exposed the students to more rigorous mathematics prior to this course

Not all students with high vector pre-assessment scores were able to solve most problems correctly These students may not have had a strong conceptual understanding of the material, despite their understanding of vectors Several students were interviewed late in the semester and may have forgotten some of the vector algebra and/or become rusty on kinematics and force concepts

Although a high vector pre-assessment score does not necessarily indicate that problems will be solved correctly, it is a necessary condition Students without knowledge of vector algebra will not be able to solve physics problems in two dimensions It is important to establish a curriculum that promotes the learning of vector algebra It may be necessary to change the amount of time spent on covering vector algebra in the algebra-based physics course It is clear from this project, that most students in the algebra-based physics course do not have sufficient understanding of vector algebra to be successful in two dimensional problem solving

VI 2 EPISTEMIC STRATEGIES

In order to study how students' difficulties with vector algebra affect their problem solving, a theoretical framework of epistemic strategies was developed Seven epistemic strategies were observed They are Mathematics to Meaning, Meaning to Mathematics, Pictorial Analysis, Story Telling, Plug and Chug, Transliteration to Mathematics, and Listmaking Mathematics to Meaning is the most intellectually complex of the epistemic strategies Students start with a conceptual understanding of the problem and then relate that understanding to the mathematical equation In Meaning to Mathematics, the second most intellectually complex strategy, students start with the physics equation and relate it to the physics concepts Plug and Chug requires little to no conceptual understanding of the problem Students substitute given quantities into formulas to solve for the unknown Listmaking involves students making a list of the given and unknown information In Transliteration to Mathematics, students substitute given information into the solution given in an example from class or from the textbook Pictorial Analysis involves making a schematic or sketch Students label the drawing to complete the strategy In Story Telling, the student tells a story about his/her conceptual understanding of the problem

All the epistemic strategies except Listmaking were similar to the epistemic games in Tuminaro's dissertation (2004) Listmaking was similar to the epistemic game of the same name defined by Collins and Ferguson (1993) The epistemic strategy Listmaking from this project, however, is specific to solving physics problems whereas the epistemic game defined by Collins and Ferguson is generic and can be used in many tasks, not just problem solving

The moves in Pictorial Analysis differed slightly from the moves in Tuminaro's Pictorial Analysis (Tuminaro, 2004) The key difference was that there was no explicit conceptual story given by the students in this work Students read the problem and then drew a physical representation of the problem The diagram was then labeled Conceptual stories might have been observed if students worked in groups, as in Tuminaro's work, or if they were in a classroom setting Meaning to Mathematics was similar to Tuminaro's Mapping Meaning to Mathematics with slight variations In Meaning to Mathematics, students would identify the target before moving to the next step The students also gave a mathematical representation of the story instead of translating the quantities in the physical story to mathematical entities and relating the mathematical entities in accordance with the physical story These slight differences do not take away from the overall similarity between the two epistemic strategies There was also a notable difference between Mathematics to Meaning and Tuminaro's Mapping Mathematics to Meaning In Mathematics to Meaning, students actually explicitly solve for a target It may be that "Evaluate Story" included the solution in Tuminaro's Mapping Mathematics to Meaning

VI 3 EPISTEMIC STRANDS

An interesting result from this project was that students did not always finish an epistemic strategy to solve a problem It became clear during the analysis that strands or pieces of epistemic strategies were appearing For example, a student might find a formula in a book or in his notes and it would activate the resources necessary for him to move into Meaning to Mathematics or Mathematics to Meaning Or a student might look at a picture or diagram and then be able to recall a formula or the conceptual knowledge needed to solve the problem The strands appeared the most for students that did not know how to solve the problem Students enrolled in the algebra-based physics course tended to move back and forth between Pictorial Analysis, reading the problem, and either Plug and Chug or Transliteration to Mathematics On the other hand, students who were better problem solvers, such as the calculus-based physics students, produced strands because a step in one strategy would activate the correct resources needed to solve the problem

The strands were an indication of the expectations students had about the solution to the problem If a student did not know how to solve the problem he moved between the qualitative sense making frame and the lower level rote problem solving frame He would move back and forth between these frames without actually moving through all the steps of an epistemic strategy Students with more experience or confidence in their problem solving would produce strands of epistemic strategies because they would start in the one frame and the epistemic strategy would activate a resource, allowing them to move into another epistemic game in the same frame or in a different frame An example or an equation would activate the necessary resources enabling them to move into Meaning to Mathematics or Mathematics to Meaning to solve the problem

VI 4 FRAMES

The frames helped to identify why students used specific epistemic strategies A student with little or no familiarity with the problems would start with Pictorial Analysis or Story Telling, then move into Plug and Chug or Transliteration to Mathematics He started in the qualitative sense making frame and moved into the rote problem solving frame The expectation was that he could solve the problem by substituting numbers into a formula or into a solution given in his notes or textbook with little or no conceptual understanding of the problem Most students enrolled in the algebra-based physics course solved the problems in the qualitative sense making frame or the rote problem solving frame

Most of the students enrolled in the calculus-based physics course started with Pictorial Analysis in the qualitative sense making frame When a student was familiar with the problem, she would enter Meaning to Mathematics or Mathematics to Meaning in the quantitative sense making frame She had an expectation that she needed to solve the problem through her conceptual understanding of the problem This expectation made it difficult for her to use Plug and Chug or Transliteration to Mathematics More than once, it was voiced from a student enrolled in the calculus-based physics course that she was solving the problem as if it was on a test This expectation only allowed her to move between the qualitative sense making frame and the quantitative sense making frame

The results from this project showed that students were more likely to be successful finishing a problem correctly if they ended the solution in the quantitative sense making frame with either Meaning to Mathematics or Mathematics to Meaning When a problem similar to a problem in the book was assigned, one student was able to solve the problem successfully while in the rote problem solving frame She was able to solve the problem by mapping her given information into the solution pattern provided in the textbook or lecture notes

Results from this project showed that a strong knowledge of vector algebra is necessary to solve two dimensional physics problems It is also important for a student to have a conceptual understanding of the problem and apply those concepts to the solution Therefore, it is important for the student to move into the quantitative sense making frame to solve physics problems Most students in the calculus-based physics course were able to do this Students in algebra-based physics course that moved into the quantitative sense making frame were not always successful in solving the problem correctly, but they were progressing in the right direction

VI 5 EXPERT PROBLEM SOLVING

Expert problem-solving was observed for one interview Recall that Bing (2006) did not find expert problem solvers using epistemic games In this study the student did use epistemic strategies to solve the problem He read the problem, created a diagram or picture, and immediately moved into mapping meaning to mathematics or mapping mathematics to meaning His movement from one frame to another, i e , the qualitative sense making frame into the quantitative sense making frame, was quick and without hesitation He had a conceptual understanding of the material and showed no vector misconceptions nor any misconceptions about motion or forces He solved the problems as if he had seen them before or was at least familiar with how they should be solved He was asked if he had seen these problems prior to his interview session His response was that he had seen similar problems but not these specific problems On one problem, he voiced his concerns about how to solve the problem He applied his conceptual understanding to the problem and then moved through the mathematics describing the concepts

It was interesting to see how his movement from one frame to another took place He moved from the qualitative sense making frame into the quantitative sense making frame for every single problem All problems were solved correctly

VI 6 VECTOR PRECONCEPTIONS

It was difficult to discern whether an incorrect solution was due to vector misconceptions Most calculus-based physics students showed difficulty with the conceptual aspects of the problem and not with the vector algebra Students that had difficulty with vector algebra, generally had a low pre-assessment score Several specific vector algebra problems did emerge in this study Several times students were observed creating a triangle from the initial velocity and the *x*-displacement in a projectile motion problem They did not differentiate between the initial velocity triangle and the displacement triangle It appeared that these students believed that vector algebra involved using trigonometric functions but without understanding why these functions were used This occurred in both the algebra-based and calculus-based physics courses

Other students completely ignored the fact that the initial velocity was not horizontal They did not take the direction of the velocity into consideration when solving the problem They substituted the velocity into the kinematic equations and solved for the height They used *x*- and *y*-components interchangeably and ignored the vector nature of velocity, displacement, and acceleration Sometimes such a student would state that an angle was given and therefore that it needed to be used in an equation, but he/she would not know what to do with it and would either give up on the problem or submit the answer knowing that it was incorrect

Misconceptions did appear in the study Misconceptions are different from preconceptions A preconception is an idea or opinion formed beforehand It could also be considered a bias or prejudice A misconception is a false or mistaken idea or attitude Some examples of misconceptions about motion are (a) a force is needed to keep an object moving (Hake, 1992), (b) inanimate objects cannot exert forces, and (c) velocities are independent of reference frame (McDermott, 1984)

In this project, students confused net force and the individual forces acting on a body In other words, if the net force was zero, then they thought that there were no forces acting on the object Students also thought that force was needed to keep an object moving and so an object could not move at a constant velocity without a net force acting on it Students were also confused about the acceleration of a system of objects Several students solved for two separate accelerations for two blocks connected by a thin massless rope It did not occur to them that these accelerations should not be different

VI 7 RECOMMENDATIONS

The following recommendations are offered to address the results from this project

1 A standardized vector pre-assessment survey should be given in the first week of classes to all introductory physics students This would give the professor and the student an idea of the level of knowledge students bring into the course For students entering the algebra-based courses, graphical and analytical vector algebra problems should be given to students to help them become more comfortable with the mathematics

2 High school teachers and college professors should spend more time doing instruction on vector algebra Students do not learn vector algebra in one class with one homework assignment Taking time at the beginning of the semester or academic year to make sure students have learned vector algebra might improve success rates in physics courses Tutorials might provide vector algebra help to students Mathematics and physics isomorphic problems could be incorporated to help students make the transition from vectors in mathematics to vectors in physics For instance, in a calculus-based course, a dot product between vectors $\vec{A}$ and $\vec{B}$ could be given to the students followed by a calculation of work done when given $\vec{F}$ and $\vec{d}$ In later homework assignments, isomorphic problems may not be needed

3 High school physics teachers would benefit from these findings With training, a teacher might be able to identify the frame of a student solving a problem and be

able to ask transition questions to move the student into a different frame With proper identification of epistemic strategies, she would be able to identify the needs of her students and provide specific instruction to help students with problem solving

4 It may be necessary to have guided problem-solving sessions with students in groups An instructor or teaching assistant could monitor the group's solutions A simple question such as, "What do you think about this?" can move a student from the rote problem-solving frame into a quantitative sense making frame A Socratic dialogue environment, in which students are asked questions to lead them to discovery, could help students learn how to move themselves into a quantitative sense making frame If students are taught to ask the conceptual questions first, it may make it easier for them to learn how to solve problems in a higher level frame

VI 8 FUTURE STUDIES

It would be interesting to see the results from a study like this one for students participating in studio courses such as SCALE-UP Would the students in the SCALE-UP environment solve the problems correctly at a higher percentage? They should have the same vector algebra knowledge as the calculus-based physics students in this study It would be interesting to find out whether the more interactive environments increase the student's ability to move to a higher frame to solve problems

Future studies may also include a more comprehensive study of students from other universities or colleges It is unclear from this study whether the results are universal for all students enrolled in physics courses Hopefully these results will alert instructors to (1) the correlation between knowledge of vector algebra and success in problem solving and (2) the necessity to help students move into a quantitative sense making frame in order to solve problems

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APPENDIX A

INFORMED CONSENT DOCUMENT

PROJECT TITLE Identifying epistemic games used to solve physics problems

INTRODUCTION
The purposes of this form are to give you information that may affect your decision whether to say YES or NO to participation in this research, and to record the consent of those who say YES

RESEARCHERS
Dr James L Cox, Department of Physics, College of Science
Mary Hing-Hickman, Department of Physics, College of Science

DESCRIPTION OF RESEARCH STUDY
Several studies have been conducted looking into the subject of vector algebra and student preconception about vector quantities None of them have explained the how students solve vector algebra problems or identified epistemic games that students use while solving vector algebra problems

If you decide to participate, then you will join a study involving research of how people solve vector algebra problems You will be videotaped as you solve two-dimensional physics problems If you say YES, then your participation will last for approximately 30 minutes at the Physics Learning Center Approximately 15 to 30 physics students will be participating in this study

EXCLUSIONARY CRITERIA
You should have completed a vector algebra test administered by the research team before the interview To the best of your knowledge, you should not have already seen the questions from the interview or heard about them from another person for this would keep you from participating in this study

RISKS AND BENEFITS
RISKS If you decide to participate in this study, then you may face a risk of your voice being identified by others as the data is analyzed The researcher tried to reduce these risks by only allowing the primary investigator and the investigator access to the video tape The video tape will be placed in a secure location while not being analyzed Once the data has been transcribed, and the research has been completed the video tapes will be destroyed And, as with any research, there is some possibility that you may be subject to risks that have not yet been identified

COSTS AND PAYMENTS
The researchers want your decision about participating in this study to be absolutely voluntary Yet they recognize that your participation may pose some costs, inconvenience, etc , such as parking fees In order to compensate you for your time, you will receive a five dollar gift card associated with participation

NEW INFORMATION
If the researchers find new information during this study that would reasonably change your decision about participating, then they will give it to you

CONFIDENTIALITY

All information obtained about you in this study is strictly confidential unless disclosure is required by law The results of this study may be used in reports, presentations and publications, but the researcher will not identify you

WITHDRAWAL PRIVILEGE

It is OK for you to say NO Even if you say YES now, you are free to say NO later, and walk away or withdraw from the study -- at any time

COMPENSATION FOR ILLNESS AND INJURY

If you say YES, then your consent in this document does not waive any of your legal rights However, in the event of harm, injury, or illness arising from this study, neither Old Dominion University nor the researchers are able to give you any money, insurance coverage, free medical care, or any other compensation for such injury In the event that you suffer injury as a result of participation in this research project, you may contact Dr James L Cox, principle investigator at 757-683-3476 or Dr David Swain the current IRB chair at 757-683-6028 at Old Dominion University, who will be glad to review the matter with you

VOLUNTARY CONSENT

By signing this form, you are saying several things You are saying that you have read this form or have had it read to you, that you are satisfied that you understand this form, the research study, and its risks and benefits The researchers should have answered any questions you may have had about the research If you have any questions later on, then the researchers should be able to answer them

James L Cox	757-683-3476
Mary Hing-Hickman	757-737-1027

If at any time you feel pressured to participate, or if you have any questions about your rights or this form, then you should call Dr David Swain, the current IRB chair, at 757-683-6028, or the Old Dominion University Office of Research, at 757-683-3460

And importantly, by signing below, you are telling the researcher YES, that you agree to participate in this study The researcher should give you a copy of this form for your records

Subject's Printed Name & Signature	**Date**

INVESTIGATOR'S STATEMENT

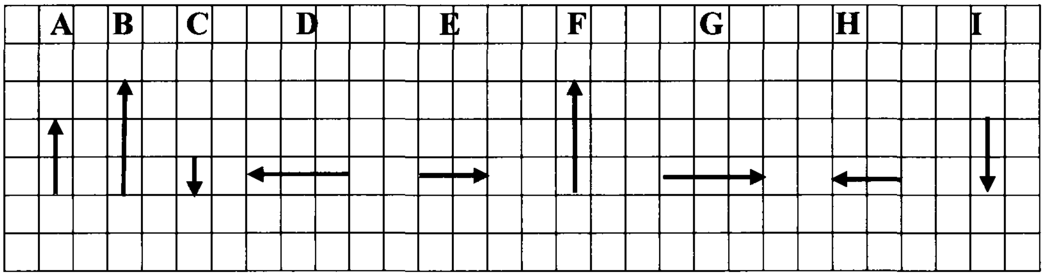
I certify that I have explained to this subject the nature and purpose of this research, including benefits, risks, costs, and any experimental procedures I have described the rights and protections afforded to human subjects and have done nothing to pressure, coerce, or falsely entice this subject into participating I am aware of my obligations under state and federal laws, and promise compliance I have answered the subject's questions and have encouraged him/her to ask additional questions at any time during the course of this study I have witnessed the above signature(s) on this consent form

Investigator's Printed Name & Signature	**Date**

APPENDIX B

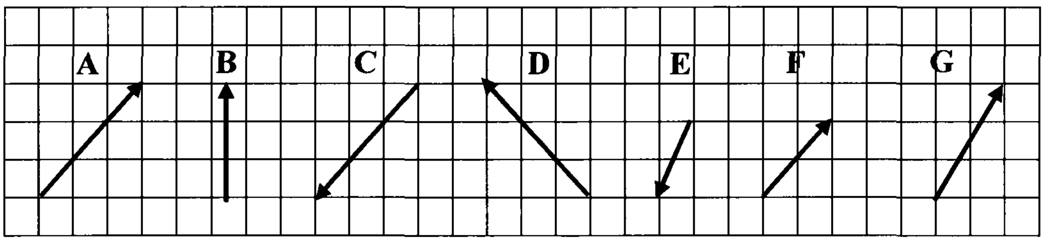
VECTOR PRE-ASSESSMENT TOOL

1 Consider the list below and write down **<u>all</u>** vectors that have the same magnitudes as each other For instance if vectors $\vec{\mathbf{W}}$ and $\vec{\mathbf{X}}$ had the same magnitude, and the vectors $\vec{\mathbf{Y}}, \vec{\mathbf{Z}}$ and $\vec{\mathbf{A}}$ had the same magnitudes as each other (but different from $\vec{\mathbf{W}}$ and $\vec{\mathbf{X}}$) then you should write the following $|\vec{\mathbf{W}}| = |\vec{\mathbf{X}}|, \ |\vec{\mathbf{Y}}| = |\vec{\mathbf{Z}}| = |\vec{\mathbf{A}}|$



Answer ________________________________

2 List all the vectors that have the same **<u>direction</u>** as the first vector listed, $\vec{\mathbf{A}}$ If there are none, please explain why



Explain

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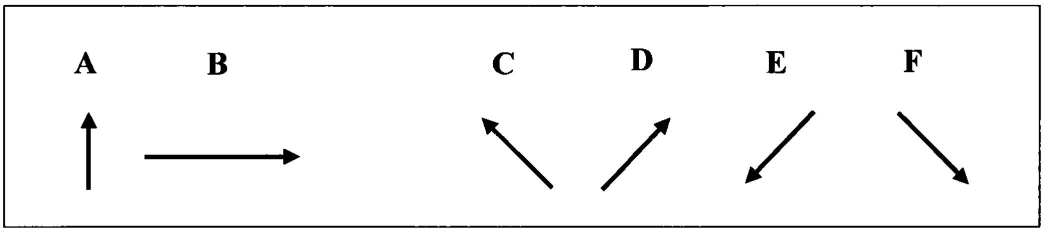
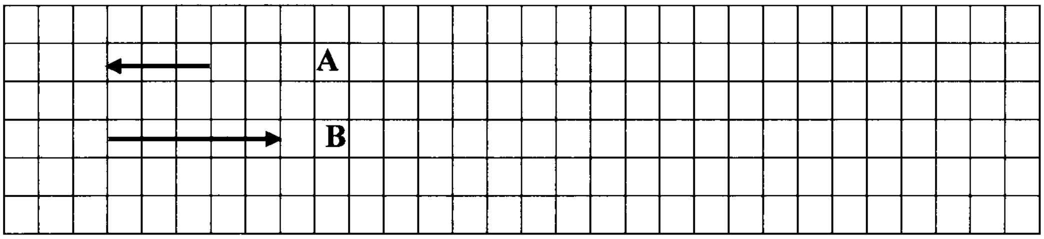
3 Below are shown vectors $\vec{\mathbf{A}}$ and $\vec{\mathbf{B}}$ Consider $\vec{\mathbf{R}}$, the vector sum (the “resultant”) of $\vec{\mathbf{A}}$ and $\vec{\mathbf{B}}$, where $\vec{\mathbf{R}} = \vec{\mathbf{A}} + \vec{\mathbf{B}}$ Which of the four other vectors shown ($\vec{\mathbf{C}}, \vec{\mathbf{D}}, \vec{\mathbf{E}}, \vec{\mathbf{F}}$) has most nearly the ***same direction*** as $\vec{\mathbf{R}}$?



Answer ________________________________

4 In the space to the right, draw $\vec{\mathbf{R}}$, where $\vec{\mathbf{R}} = \vec{\mathbf{A}} + \vec{\mathbf{B}}$ Clearly label it as the vector $\vec{\mathbf{R}}$ Explain your work



Explain

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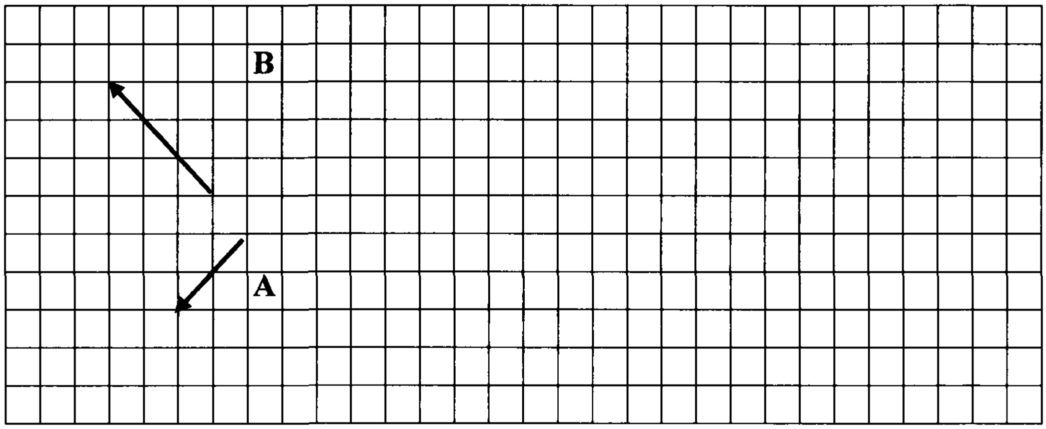
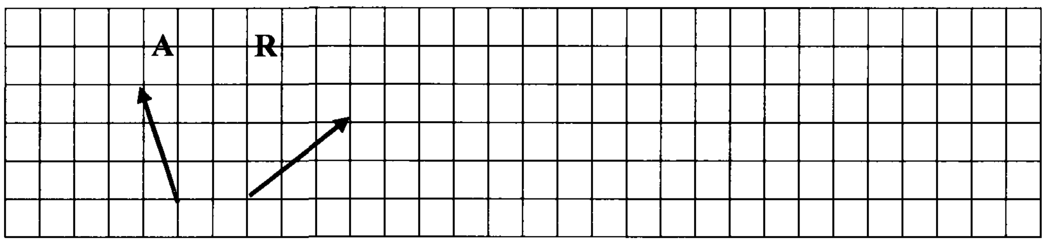
5 In the figure below there are two vectors $\vec{\mathbf{A}}$ and $\vec{\mathbf{B}}$ Draw a vector $\vec{\mathbf{R}}$ that is the sum of the two, (i e , $\vec{\mathbf{R}} = \vec{\mathbf{A}} + \vec{\mathbf{B}}$) Clearly label the resultant vector as $\vec{\mathbf{R}}$



6 In the figure below, a vector $\vec{\mathbf{R}}$ is shown that is the ***resultant*** of two other vectors $\vec{\mathbf{A}}$ and $\vec{\mathbf{B}}$ (i e , $\vec{\mathbf{R}} = \vec{\mathbf{A}} + \vec{\mathbf{B}}$) Vector $\vec{\mathbf{A}}$ is given Find the vector $\vec{\mathbf{B}}$ that when added to $\vec{\mathbf{A}}$ produces $\vec{\mathbf{R}}$, clearly label it $\vec{\mathbf{B}}$ **DO NOT** try to combine or add $\vec{\mathbf{A}}$ and $\vec{\mathbf{R}}$ directly together! Briefly explain your answer



Explain

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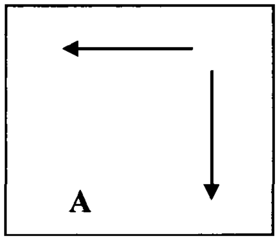
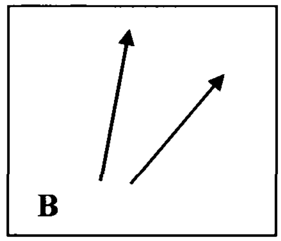
7 In the boxes below are two pairs of vectors, pair **A** and pair **B** (All arrows have the same length) Consider the magnitude of the ***resultant*** (the vector sum) of each pair of vectors Is the magnitude of the resultant of pair **A** *larger than*, *smaller than*, or *equal to* the ***magnitude*** of the resultant of pair **B**? Write an explanation justifying this conclusion





Explain

APPENDIX C

PROBLEMS

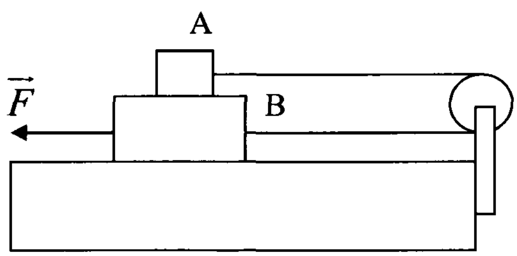
1 Durıng a storm a lımb falls from a tree It comes to rest across a barbed wıre fence one-fifth of the way between two fence posts that are four meters apart The lımb exerts a downward force of 151 N on the wıre depressıng ıt 0 2 m below the horızontal Fınd the tensıon ın the sectıon of the wıre that ıs a) shorter and b) longer

2 A rocket ıs fired at a speed of 75 m/s from ground level at an angle of 60° above the horızontal The rocket ıs fired toward an 11 m hıgh wall whıch ıs located 27 m away By how much does the rocket clear the top of the wall?

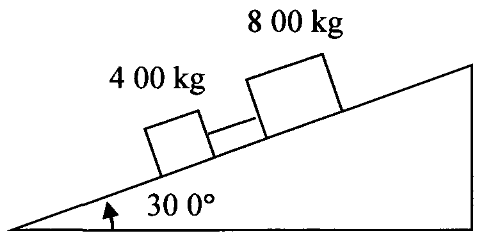
3 A penguın ıs slıdıng down an ıcyınclıne at a constant speed of 1 4 m/s the ınclıne slopes at an angle of 6 9° What ıs the coefficıent of frıctıon of the ınclıne?

4 Loretta ıs goıng off to her physıcs class, jogging down the sıdewalk at 3 05 m/s Her husband Bruce suddenly realızes that she left ın such a hurry that she forgot her lunch so he runs to the wındow of theır apartment, whıch ıs 43 9 m above the street level and dırectly above the sıdewalk, to throw the lunch to her Bruce throws the lunch horızontally 9 00 s after Loretta has passed below the wındow, and she catches her lunch on the run Ignorıng aır resıstance, wıth what ınıtıal speed must Bruce throw the lunch so that Loretta can catch ıt just before ıt hıts the ground?

5 A soccer player kıcks the ball toward a goal that ıs 29 5 m ın front of hım The ball leaves hıs foot as speed of 19 0 m/s and an angle of 32 0° above the ground Fınd the magnıtude and dırectıon of the velocıty of the ball when the goalıe catches ıt ın front of the net

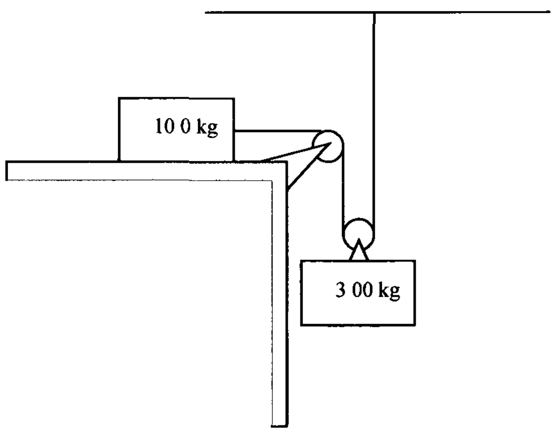


6 Block A weıghs 1 40 N, and block B weıghs 4 20 N The coefficıent of kınetıc frıctıon between all surfaces ıs 0 30 Fınd the magnıtude of the horızontal force $\vec{F}$ necessary to drag block B to the left at constant speed ıf A and B are connected by a lıght, flexıble cord passıng around a fixed, frıctıonless pulley



7 Two blocks with masses 4 00 kg and 8 00 kg are connected by a string and slide down a 30 0° inclined plane The coefficient of kinetic friction between the 4 00 kg block and the plane is 0 25, that between the 8 00 kg block and the plane is 0 35 a) Calculate the acceleration of each block and b) Calculate the tension in the string

8 In the drawing, the rope and pulleys are mass-less, and there is no friction Find (a) the tension in the rope and the (b) acceleration of the 10 0 kg block



APPENDIX D

INTERVIEW PROMPT

In this experiment we are interested in what you think about when you solve two dimensional physics problems In order for you to do this, I am going to ask you to THINK ALOUD as you work on the problem given What I mean by "think aloud" is that I want you to tell me EVERYTHING you are thinking from the time you first see the problem until you give me your answer I would like you to talk aloud CONSTANTLY the entire time I don't want you to try to plan out what to say or try to explain to me what you are saying Just act as if you are alone in the room speaking to yourself It is most important that you keep talking If you are silent for any long period of time or if you are speaking too softly, I will ask you "please keep talking " Do you understand what I want you to do?
(Note to interviewer you should wait 7 to 9 seconds before telling them to please keep talking)

Good, now we will begin with some practice problems First, I want you to multiply these two numbers in your head and without paper and tell me what you are thinking as you get an answer

"What is the result of multiplying 24 X 36?"

Good, now I want to see how much you can remember about what you were thinking from the time you heard the question until you gave the answer We are interested in what you actually can REMEMBER rather than what you think you must have thought If possible I would like you to tell about your memories in the sequence in which they occurred while working on the question Please tell me if you are uncertain about any of your memories I don't want you to work on solving the problem again, just report all that you can remember thinking about when answering the question Now tell me what you remember

Note to interviewer Ask questions about specifics if necessary to get them to recall memories in sequence Ask specifics about each step that you remember them going through that they may not be mentioning in the recall process

Good, now I will give you two more practice problems before we proceed with the main problems I want you to do the same thing for each of these problems I want you to think aloud as before as you think about the question After you have answered it, I will ask you to report all that you can remember about your thinking Any questions?

Here's the next problem

"How many windows are there in your parent's house?"

Good, now tell me all that you can remember about your thinking

Good, now here is another practice problem Please think aloud and tell me EVERYTHING you are thinking from the time you first see the question until you give an answer There is no need to keep count, I will keep track for you

"Name 20 animals."

Now tell me all that you can remember about your thinking

Good

Do you have any questions?

Now we are ready to begin the problems for my research

The problems given to you may vary in difficulty Some problems may be very difficult for you to solve Please do not feel that you need to control what you say if you don't know how to solve the problem

I would like you to talk aloud CONSTANTLY from the time I present each problem until you have given your final answer I don't want you to try to plan out what you say or try to explain to me what you are saying Just act as if you are alone in the room speaking to yourself It is most important that you keep talking If you are silent for any long period of time or if you are speaking too softly, I will ask you to please keep talking Do you understand what I want you to do? (Note to interviewer you should wait 7 to 9 seconds before telling them to please keep talking)

Good, here's the first problem

APPENDIX E

CODES DEVELOPED FOR ANALYSIS

Code	Meaning	color
Picture	Any physical representation of the problem, drawings, figures, graphs, etc	Yellow
Label	Labels a diagram	Green
List	Makes a list of given and unknown quantities	Green
Target	Identifies what they are looking for This can be the main target of the problem or a sub target (something they need before they can have a solution to the problem	Blue
Equation	Writes an equation, manipulates an equation, substitutes numbers into an equation	Pink
Story	Verbally describes the problem, analyzes the problem, or verbally communicates how they would solve the problem This could also be a single statement about the problem	Orange
Solution	Solves for a specific target variable	Plum
Evaluate	Evaluates their work Does it make sense? This could also be a statement of completeness "That's my answer "	Violet
Reference	Refers to a formula sheet, lecture notes, or textbook When an external resource is used	Red

APPENDIX F

COHEN-KAPPA MATRIX

Before Discussion

		Hing-Hickman								
	Strategy code	1	2	3	4	5	6	7	8	Row sum
	1	7	0	0	0	0	0	0	0	7
	2	0	14	0	0	0	0	0	0	14
	3	0	0	0	0	0	0	0	0	0
Moore	4	0	0	0	5	0	0	0	0	5
	5	0	0	0	0	10	3	1	0	14
	6	0	0	0	0	1	8	0	0	9
	7	0	0	0	0	0	0	12	0	12
	8	0	0	0	0	0	0	0	0	0
	Column sum	7	14	0	5	11	11	13	0	61

$\Pr(a) =$ percent exact agreement

$$\Pr(a) = \frac{\text{number of observations agreed upon}}{\text{total number of observations}}$$

$$\Pr(a) = \frac{56}{61} = 918$$

$\Pr(e) =$ hypothetical probability of chance agreement

$$\Pr(e) = \sum \left[\frac{\text{number of observations for rater 1}}{\text{total number of observations}} * \frac{\text{number of observations for rater 2}}{\text{total number of observations}} \right]$$

$$\Pr(e) = \frac{(7*7)+(14*14)+(0*0)+(5*5)+(11*14)+(11*9)+(13*12)+(0*0)}{61^2}$$

$$\Pr(e) = 182$$

$$\kappa = \frac{\Pr(a)-\Pr(e)}{1-\Pr(e)} = \frac{918 - 182}{1 - 182} = 900$$

After Discussion

Hing-Hickman

	Strategy code	1	2	3	4	5	6	7	8	Row sum
	1	7	0	0	0	0	0	0	0	7
	2	0	14	0	0	0	0	0	0	14
	3	0	0	0	0	0	0	0	0	0
Moore	4	0	0	0	5	0	0	0	0	5
	5	0	0	0	0	13	0	0	0	13
	6	0	0	0	0	0	9	0	0	9
	7	0	0	0	0	0	0	13	0	13
	8	0	0	0	0	0	0	0	0	0
	Column sum	7	14	0	5	13	9	13	0	61

$$\Pr(a) = \text{percent exact agreement}$$

$$\Pr(a) = \frac{\text{number of observations agreed upon}}{\text{total number of observations}}$$

$$\Pr(a) = \frac{61}{61} = 1\ 00$$

$$\Pr(e) = \text{hypothetical probability of chance agreement}$$

$$\Pr(e) = \sum\left[\frac{\text{number of observations for rater 1}}{\text{total number of observations}} * \frac{\text{number of observations for rater 2}}{\text{total number of observations}}\right]$$

$$\Pr(e) = \frac{(7*7)+(14*14)+(0*0)+(5*5)+(13*13)+(9*9)+(13*13)+(0*0)}{61^2}$$

$$\Pr(e) = 185$$

$$\kappa = \frac{\Pr(a)-\Pr(e)}{1-\Pr(e)} = \frac{1\ 00 - 185}{1 - 185} = 1\ 00$$

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Education

Ph.D. Physics
Old Dominion University, Norfolk, Va 1997 - 2011

M.S. Physics
Old Dominion University, Norfolk, Va 1997

Bachelor of Science Physics, Cum Laude
Old Dominion University, Norfolk, Va 1993
- Golden Key National Honor Society Member
- Sigma Pi Sigma National Honor Society Member

Associates in Applied Science Laser Electro-Optics
Camden County Community College, Blackwood, NJ 1988

Professional Grants and Awards

Old Dominion University Weekend College Teacher of the Year

AFC Science Teaching Award - $1000 for LabPros and software for use in the classroom and for FIRST robotics

Professional Affiliations

AAPT – American Association of Physics Teachers
TASE – Tidewater Association of Science Educators
VAST – Virginia Association of Science Teachers
NSTA – National Science Teacher Association
VEA – Virginia Education Association
CEA – Chesapeake Education Association